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IEICE Communications Express, Vol.1, 1–6

Improved adaptive STBC-TD in low-to-high mobility environments

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Abstract:

Our recently proposed adaptive space-time block coded transmit diversity (STBC-TD) jointly used with frequency-domain equalization and decision-feedback linear prediction (DFLP) provides a good bit-error rate (BER) performance in a high-mobility environment. However, in a low-mobility environment, the achievable BER performance degrades. In this paper, we propose an improved adaptive STBC-TD, in which the use of DFLP is adaptively decided based on the minimum mean square error (MMSE) criterion of the soft-decision symbol output. Computer simulation results show that the improved adaptive STBC-TD achieves a good BER performance over wide ranges of the transmit symbol energy-to-noise power spectrum density ratio (E_s/N_0) and the normalized maximum Doppler frequency (f_DT).

Keywords: space-time block coded diversity, decision feedback channel estimation prediction, TDD
Classification: Wireless Communication Technologies

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DOI: 10.1587/comex.2019XBL0006
Received January 7, 2019
Accepted February 5, 2019
Publicized February 15, 2019

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1 Introduction

In a severely doubly-selective fading channel, the bit error rate (BER) performance degrades significantly [2]. In [3], we proposed a joint use of space-time block coded transmit diversity (STBC-TD) [4] and frequency-domain equalization (FDE). As for FDE, the minimum mean square error (MMSE)-FDE and the maximal-ratio transmit (MRT)-FDE are employed at the base station (BS) side for single-carrier (SC) uplink reception and the orthogonal frequency division multiplex (OFDM) downlink transmission, respectively. The MMSE-FDE and MRT-FDE weights computed using pilot-aided channel estimation (PACE) at the beginning of each subframe are used during the rest of subframe period. Recently, in [5], we proposed an adaptive STBC-TD to achieve a good BER performance in a high-mobility environment. With the help of the decision-feedback linear prediction (DFLP), the MMSE-FDE weight is updated at the BS side for the SC uplink reception and the skewed equivalent channel is compensated at the user equipment (UE) side for OFDM downlink reception. In a low-mobility environment, however, the BER performance degrades due to the noise enhancement resulting from DFLP. In this paper to remedy this problem, we propose an improved adaptive STBC-TD. Its effectiveness is confirmed by computer simulation.

2 Improved adaptive STBC-TD

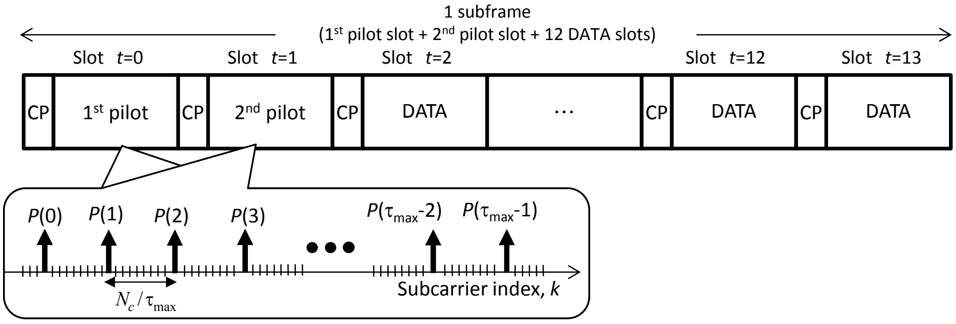


Fig. 1 TDD subframe structure (1st uplink pilot slot + 2nd downlink pilot slot + 12 uplink or downlink user data slots)

The OFDM downlink and SC uplink transmissions with N_c subcarriers jointly used with the well-known 2×2 STBC-TD [4] is considered. The 2×2 STBC coding is a 2-block wise processing and hence, signal transmission is considered over two consecutive slot time periods $t=2q$ and $t=2q+1$ with $q=1\sim6$ in a time-division duplex (TDD) subframe depicted in Fig. 1 [5]. Frequency division multiplexed (FDM) orthogonal pilots are used for PACE of multi-input multi-output (MIMO) channel. Each pilot consists of equally spaced N_p subcarriers mapped over N_c

subcarriers and is constructed by an N_p-length Zadoff-Chu sequence [6]. N_p should be larger than or equal to $\tau_{\max}$ (the MIMO channel maximum delay time normalized by the sampling period of inverse discrete Fourier transform (IDFT) to generate OFDM and SC signals having N_c subcarriers). Assuming that MMSE-FDE and MRT-FDE are employed at BS respectively for SC uplink reception and for OFDM downlink transmission, the number of UE antennas is N_{ue}=2 while the number N_{bs} of BS antennas can be arbitrary [3]. Throughout the paper, the variables $m(=0\sim N_{bs}-1)$ and $n(=0\sim 1)$ represent the BS and UE antenna indices, respectively. By exploiting the channel reciprocity due to TDD, the BS computes the MMSE-FDE weight and the MRT-FDE weight by performing PACE at t=0. BS can continuously use the above MMSE-FDE and MRT-FDE weights during succeeding 12 user data slot periods in a low-mobility environment.

In a high-mobility environment, the channel changes over a subframe period. An adaptive STBC-TD was proposed in [5], in which DFLP was introduced to the BS and UE receivers; the MMSE-FDE weight is updated at BS for SC uplink reception and the skewed equivalent channel (a concatenation of the MRT-FDE weight and the propagation channel) is compensated at UE for OFDM downlink reception. However, it was also found in [5] that the introduction of MMSE-FDE weight updating and the equivalent channel skew compensation degrades the BER performance in a low-mobility environment. In this paper, to remedy this problem, we propose an improved adaptive STBC-TD which introduces new data symbol decision methods based on adaptive selection of MMSE-FDE weight for SC uplink reception at BS and based on adaptive selection of the equivalent channel skew compensation weight for OFDM downlink reception at UE.

Firstly, the SC uplink reception at BS is described. The received signal vector $\tilde{\mathbf{R}}(k;t)=[\tilde{R}_0(k;t),\tilde{R}_1(k;t)]^T$, t=2q, 2q+1, after MMSE-FDE for the k-th subcarrier (k=0~N_c–1) is expressed as

$$\tilde{\mathbf{R}}(k;t)=\mathbf{W}^{\text{MMSE-FDE}}(k;t)\mathbf{R}_{\text{bs}}(k;t)\,, \tag{1}$$

where $\mathbf{R}_{\text{bs}}(k;t)$ is the $N_{bs}\times 1$ received signal vector and $\mathbf{W}^{\text{MMSE-FDE}}(k;t)$ is the MMSE-FDE weight matrix of size 2×N_{bs}. Using $\tilde{\mathbf{R}}(k;t=2q)$ and $\tilde{\mathbf{R}}(k;t=2q+1)$, STBC decoding is done to obtain the soft-decision data symbol vector $\tilde{\mathbf{D}}(k;t=2q)=[\tilde{D}(k;t=2q),\tilde{D}(k;t=2q+1)]^T$ [4]. Then, the data symbol hard-decision based on the best MMSE-FDE weight selection is done to obtain $\hat{\mathbf{D}}(k;t=2q)$ as

$$\begin{aligned}\hat{\mathbf{D}}(k;t=2q)&=\begin{bmatrix}\hat{D}(k;t=2q)\\ \hat{D}(k;t=2q+1)\end{bmatrix}\\ &=\arg\min_{\{\mathbf{W}^{\text{MMSE-FDE}}(k;t=2q)\}}\left(\sum_{k=0}^{N_c-1}\left(\min_{\{D\}}\left|\tilde{D}(k;t=2q)-D\right|^2+\min_{\{D\}}\left|\tilde{D}(k;t=2q+1)-D\right|^2\right)\right)\end{aligned}, \tag{2}$$

where $\{\mathbf{W}^{\text{MMSE-FDE}}(k;t=2q)\}$ represents a set of three different MMSE-FDE weight matrices constructed by PACE only, the 1st-order DFLP (DFLP1), and 2nd-order DFLP (DFLP2), and $\{D\}$ represents a set of candidate data symbol. $\tilde{\mathbf{D}}(k;t=2q)$ is expressed by referring STBC decoding [3] as

$$\tilde{\mathbf{D}}(k;t=2q)=\begin{bmatrix}\tilde{D}(k;t=2q)\\ \tilde{D}(k;t=2q+1)\end{bmatrix}=\begin{bmatrix}\tilde{R}_0(k;t=2q)+\tilde{R}_1^*(k;t=2q+1)\\ \tilde{R}_1(k;t=2q)-\tilde{R}_0^*(k;t=2q+1)\end{bmatrix}. \tag{3}$$

The (n, m)-th element of $\mathbf{W}^{\text{MMSE-FDE}}(k;t)$ is given as

$$W^{\text{MMSE-FDE}}_{n,m}(k;t)=\frac{\tilde{H}^{*}_{m,n}(k;t)}{\sum_{m=0}^{N_{bs}-1}\sum_{n=0}^{1}\left|\tilde{H}_{m,n}(k;t)\right|^{2}+\left(\frac{1}{2}\frac{E_s}{N_0}\right)^{-1}}, \tag{4}$$

where $\tilde{H}_{m,n}(k;t)$ is an estimate of the (m, n)-th element of $N_{bs}\times 2$ MIMO uplink channel matrix and E_s/N_0 is the average transmit symbol energy-to-noise spectrum density ratio. $\tilde{H}_{m,n}(k;t)$ is obtained as [5]

$$\begin{aligned}\tilde{H}_{m,n}(k;t=2q)&=\tilde{H}_{m,n}(k;t=2q+1)\\&=\begin{cases}\hat{H}_{m,n}(k;t=0) & \text{for PACE only}\\ \hat{H}_{m,n}(k;t=2q-2) & \text{for DFLP1}\\ 2\hat{H}_{m,n}(k;t=2q-2)-\hat{H}_{m,n}(k;t=2q-4) & \text{for DFLP2}\end{cases},\end{aligned} \tag{5}$$

where $\hat{H}_{m,n}(k;t=2q-2)$ and $\hat{H}_{m,n}(k;t=2q-4)$ represent the channel gain estimates obtained from the received signals using $\hat{\mathbf{D}}(k;t=2q-2)$ and $\hat{\mathbf{D}}(k;t=2q-4)$.

For the OFDM downlink, the 2×2 STBC coded signal is transmitted from N_{bs} antennas at BS after MRT-FDE and is received by 2 antennas at UE. The MRT-FDE weight is obtained at BS by PACE at t=0 and is represented by matrix $\mathbf{W}^{\text{MRT-FDE}}(k;\ t=0)$ of size $N_{bs}\times 2$. The downlink channel is represented by matrix $\mathbf{H}(k;\ t)$ of size $2\times N_{bs}$. The concatenation of $\mathbf{H}(k;\ t)$ and $\mathbf{W}^{\text{MRT-FDE}}(k;\ t=0)$ is defined as the equivalent channel $\mathbf{H}_{\text{eq}}(k;\ t)$ of size 2×2 and can be expressed as

$$\mathbf{H}_{\text{eq}}(k;t)=\mathbf{H}(k;t)\mathbf{W}^{\text{MRT-FDE}}(k;t=0), \tag{6}$$

where the (m, n)-th element of $\mathbf{W}^{\text{MRT-FDE}}(k;\ t=0)$ is given as [3]

$$W^{\text{MRT-FDE}}_{m,n}(k;t=0)=\frac{\hat{H}^{*}_{m,n}(k;t=0)}{\sqrt{\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left(\sum_{m=0}^{N_{bs}-1}\sum_{n=0}^{1}\left|\hat{H}_{m,n}(k;t=0)\right|^{2}\right)}}. \tag{7}$$

Since $\mathbf{H}(k;t)$ changes over a subframe period, the equivalent channel also changes and tends to differ from that of t=0. Therefore, the skew compensation is introduced to bring the equivalent channel back to that of t=0. The skew compensation is done to obtain the received signal vector $\tilde{\mathbf{R}}(k;t)$ of size 2×1, as [5]

$$\tilde{\mathbf{R}}(k;t)=\mathbf{W}^{\text{skew}}(k;t)\mathbf{R}_{\text{ue}}(k;t), \tag{8}$$

where $\mathbf{W}^{\text{skew}}(k;t)$ is the skew compensation weight matrix of size 2×2 and $\mathbf{R}_{\text{ue}}(k;t)$ is the received signal vector of size 2×1. $\mathbf{W}^{\text{skew}}(k;t)$ is computed as

$$\mathbf{W}_{\text{skew}}(k;t)=\mathbf{H}_{\text{eq}}(k;t=0)\tilde{\mathbf{H}}^{-1}_{\text{eq}}(k;t), \tag{9}$$

where $\mathbf{H}_{\text{eq}}(k;t=0)$ is unknown to UE and therefore, replaced by $\hat{\mathbf{H}}(k;t=1)\hat{\mathbf{W}}^{\text{MRT-FDE}}(k;t=1)$ (this is obtained by PACE at t=1). $\tilde{\mathbf{H}}_{\text{eq}}(k;t)$ is the estimated equivalent channel matrix of size 2×2. Each element of $\tilde{\mathbf{H}}_{\text{eq}}(k;t)$ is obtained by using DFLP similar to Eq. (5).

The data symbol hard-decision based on the best skew compensation weight selection is done as

$$\begin{aligned}\hat{\mathbf{D}}(k;t=2q) &= \begin{bmatrix}\hat{D}(k;t=2q)\\ \hat{D}(k;t=2q+1)\end{bmatrix}\\ &= \arg\min_{\{\mathbf{W}^{\mathrm{skew}}(k;t=2q)\}}\left(\sum_{k=0}^{N_c-1}\left(\min_{\{D\}}\left|\tilde{D}(k;t=2q)-D\right|^2+\min_{\{D\}}\left|\tilde{D}(k;t=2q+1)-D\right|^2\right)\right)\end{aligned}, \quad (10)$$

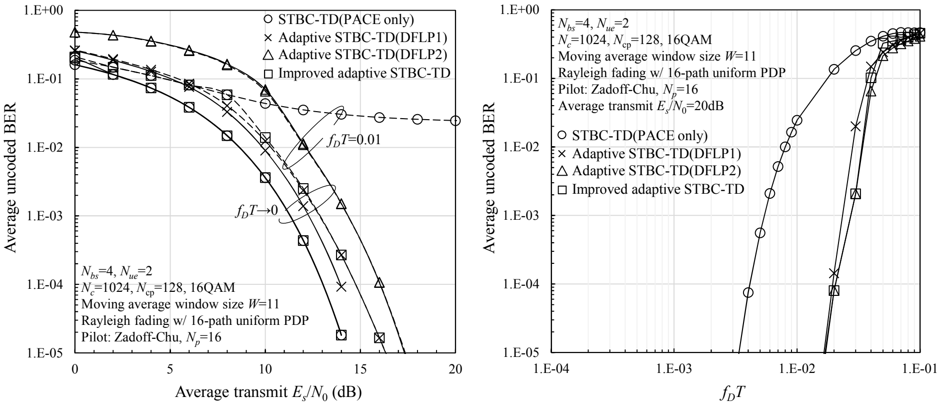
where $\{\mathbf{W}^{\mathrm{skew}}(k;t=2q)\}$ represents a set of three different skew compensation weight matrices constructed using PACE only, DFLP1, and DFLP2.

3 Computer simulation

The propagation channel is assumed to be a frequency-selective Rayleigh channel having L=16-path uniform power delay profile and the normalized maximum delay time $\tau_{\max}=L-1$. By computer simulation, the uncoded BER performance of 16 quadrature amplitude modulation (16QAM) achievable with the improved adaptive STBC-TD is evaluated for SC uplink and OFDM downlink assuming N_{ue}=2, N_{bs}=4, N_c=1024, the CP length N_{cp}=128, and N_p=16.

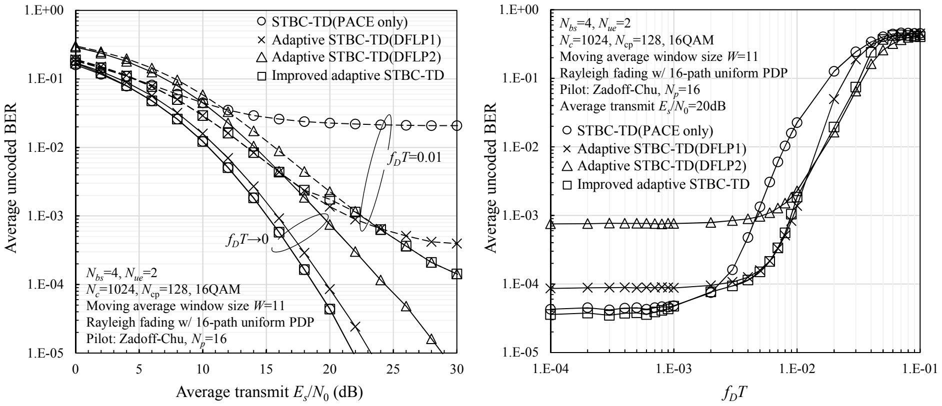
Figure 2 plots the uncoded BER of SC uplink as a function of the average transmit E_s/N_0 and that at the average transmit E_s/N_0=20dB as a function of the normalized maximum Doppler frequency (f_DT), where T represents the slot length in time. It can be seen from Fig. 2 that the proposed improved adaptive STBC-TD provides the best BER performance over wide ranges of the average transmit E_s/N_0 and f_DT. The improved adaptive STBC-TD achieves an allowable f_DT of 0.035 for keeping BER<10^{-2} similar to adaptive STBC-TD with DFLP2 (see Fig. 2 (b)), while it achieves much better performance when f_DT=0 and 0.01 (see Fig. 2 (a)). Figure 3 plots the average uncoded BER of OFDM downlink. Similar to the SC uplink, the proposed improved adaptive STBC-TD provides almost always the best performance. The improved adaptive STBC-TD achieves an allowable f_DT of 0.0175 similar to adaptive STBC-TD with DFLP2. Comparing Figs. 2 and 3 shows that the BER performance of SC uplink is superior to that of OFDM downlink. This is because of the frequency diversity effect obtained by the channel high frequency-selectivity.

From the above result, it can be said that, assuming the subcarrier spacing of 60 kHz and 5GHz carrier frequency, the allowable maximal travelling speed can be increased to about 400 km/h and 200 km/h for SC uplink and OFDM downlink, respectively.



(a) Average E_s/N_0 vs BER (b) f_DT vs BER

Fig. 2. SC uplink BER performance.



(a) Average E_s/N_0 vs BER (b) f_DT vs BER

Fig. 3. OFDM downlink BER performance.

4 Conclusion

In this paper, we proposed the improved adaptive STBC-TD and evaluated by computer simulation the achievable BER performances of SC uplink and OFDM downlink in a doubly-selective Rayleigh fading environment. It was confirmed that it achieves a good BER performance over wide ranges of the average transmit E_s/N_0 and f_DT.

Acknowledgments

This paper includes a part of results of “The research and development project for realization of the fifth-generation mobile communications system” commissioned to Tohoku University by The Ministry of Internal Affairs and Communications (MIC), Japan.