Double Space–Time Line Codes with Transmit Antenna Selection for Two Users

Youngjun Choi, Jingon Joung
Sch. of EEE, Chung-Ang Univ.
Seoul, South Korea
{chd12000; jgjoung}@cau.ac.kr

Jihoon Choi
Sch. of EIE, Korea Aerospace Univ.
Gyeonggi-do, South Korea
jihoon@kau.ac.kr

Bang Chul Jung
Dept. of EE, Chungnam National Univ.
Daejeon, South Korea
bcjung@cnu.ac.kr

***Abstract*—A double space-time line code (D-STLC) scheme is applied to support two users. With a sufficient number of transmit antennas, a transmit antenna selection scheme is proposed to improve the communication performance. At the cost of the additional transmit antennas and the computational complexity increase, we can dramatically improve the bit-error-rate performance of the two-user D-STLC system. The proposed scheme is relevant for the high-performance systems, such as 5G and beyond-5G systems.**

***Index Terms*—Double space-time line code, transmit antenna selection, 5G, B5G.**

I. Introduction

Recently, a new full-rate full-spatial diversity achieving scheme, called space–time line code (STLC), has been devised in [1], [2]. The STLC scheme is a fully symmetric scheme of space–time block code (STBC), a.k.a an Alamouti code [3], due to the reciprocity between a transmitter and a receiver (refer to [1] for the details.). The STLC transmitter requires channel state information (CSI), yet the STLC receiver does or does not require it. Furthermore, by virtue of the low-complexity linear processing for the STLC encoding and decoding, the STLC scheme has been applied to various communication systems, in which the CSI is available at the transmitter, such as the multiuser systems [2], [4], two-way relay systems [5]–[7], antenna shuffling systems [8], and machine learning-based blind decoding systems [9]. As mentioned, since the STLC allows a blind detection at the receiver without CSI, the STLC transmitter does not need to broadcast a long-training or pilot sequence for the CSI estimation at the receiver, which hinders an unauthorized intruder, i.e., an eavesdropper, from estimating the channels, resulting in the physical-layer security improvement [10].

The previous studies with STLC considered a single-data stream transmission. The single-stream STLC was extended to a double STLC (D-STLC) that can transmit multiple STLC streams in [11]. The multiple-STLC streams can be interpreted to be delivered to multiple receivers independently, i.e., a multiuser STLC system. Contrast to the multiuser STLC schemes in [2], [4], in which the STLC transmitter transmits multiple STLCs simultaneously by ignoring the multiuser (or inter-symbol) interferences, the D-STLC in [11] minimizes

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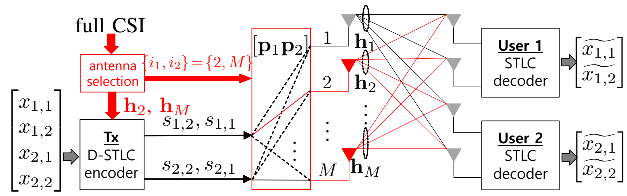

Fig. 1. D-STLC system with a transmit antenna selection scheme.

the inter-symbol interference based on minimum mean square error (MMSE) criterion.

In this study, we consider two users who are supported by D-STLC. Assuming a sufficient number of transmit antennas, we propose a transmit antenna selection (TAS) such that the effective signal-to-interference-plus-noise ratio (SINR) increases. From the numerical results, we verify that the proposed TAS scheme can significantly improve the bit-error-rate (BER) performance.

II. Proposed TAS D-STLC System

We consider an M-by-4 D-STLC system, in which a transmitter with M-transmit antennas support two users ($U = 2$) having two antennas each as shown in Fig. 1. The D-STLC signals are represented as follows [11]:

$$\mathbf{S} = \begin{bmatrix} s_{1,1} & s_{1,2} \\ s_{2,1} & s_{2,2} \end{bmatrix} = \mathbf{V}\mathbf{X} = \mathbf{V} \begin{bmatrix} x_{1,1} & x_{1,2} & x_{2,1} & x_{2,2} \\ -x_{1,2}^* & x_{1,1}^* & -x_{2,2}^* & x_{2,1}^* \end{bmatrix}^T \in \mathbb{C}^{2\times 2},$$

where $\mathbf{V} \in \mathbb{C}^{2\times 4}$ is the D-STLC preprocessing matrix and $x_{u,t}$ is the tth modulated information symbol that is intended to be delivered to user $u \in \{1, 2\}$, with $\mathrm{E}_t[|x_{u,t}|^2] = \sigma_x^2$. Considering D-STLC with two-transmit antenna selection, the receive signals are modeled as follows:

$$\begin{bmatrix} \mathbf{r}_{1,1} & \mathbf{r}_{1,2} \\ \mathbf{r}_{2,1} & \mathbf{r}_{2,2} \end{bmatrix} = [\mathbf{h}_1 \cdots \mathbf{h}_m \cdots \mathbf{h}_M] \begin{bmatrix} \mathbf{p}_1 & \mathbf{p}_2 \end{bmatrix} \mathbf{S} + \mathbf{N} \in \mathbb{C}^{4\times 2}, \quad (1)$$

where $\mathbf{r}_{u,t} \in \mathbb{C}^{2\times 1}$ is the received signal vector, whose nth element $r_{u,n,t}$ is the received signal at the nth receive antenna of user u at time t; $\mathbf{h}_m \in \mathbb{C}^{4\times 1} \sim \mathcal{CN}(0, \mathbf{I}_4)$ is a channel vector between the mth transmit antenna and users, which is static for $t = 1$ and 2; $\mathbf{p}_k$ is 4-by-1 antenna selection vector for the kth D-STLC symbols, namely $s_{k,1}$ and $s_{k,2}$, whose ith element $p_{k,i} = 1$ if the ith transmit antenna is selected, and $p_{k,i} = 0$ otherwise; and $\mathbf{N} \in \mathbb{C}^{4\times 2} \sim \mathcal{CN}(0, \sigma_n^2 \mathbf{I}_4)$ is the additive white Gaussian noise (AWGN) matrix. Here, $\sum_i p_{k,i} = 1, \forall k$ and $p_{1,i} p_{2,i} = 0, \forall i$ for the orthogonal antenna selection.

Suppose that the i_1th and the i_2th transmit antennas are selected, where $i_1 \neq i_2 \in \{1, \cdots, M\}$, the received signals in (1) can then be rewritten as

$$\begin{bmatrix} \mathbf{r}_{1,1} & \mathbf{r}_{1,2} \\ \mathbf{r}_{2,1} & \mathbf{r}_{2,2} \end{bmatrix} \triangleq [\mathbf{h}_{i_1} \ \mathbf{h}_{i_2}]\mathbf{S} + \mathbf{N} = \mathbf{H}_{i_1 i_2}\mathbf{V}\mathbf{X} + \mathbf{N} \in \mathbb{C}^{4\times 2}. \quad (2)$$

For the D-STLC decoding, (2) is alternatively reconstructed as a linear form as follows:

$$\mathbf{r} = [\mathbf{r}_{1,1}^T, \mathbf{r}_{2,1}^T, \mathbf{r}_{1,2}^H, \mathbf{r}_{2,2}^H]^T = \begin{bmatrix} \mathbf{H}_{i_1 i_2}\mathbf{V} \\ (\mathbf{H}_{i_1 i_2}\mathbf{V})^*\mathbf{P}_4 \end{bmatrix}\mathbf{x} + \mathbf{n} \in \mathbb{C}^{8\times 1}, \quad (3)$$

where $\mathbf{x} = [x_{1,1}, x_{1,2}, x_{2,1}, x_{2,2}]^T$; $\mathbf{P}_4 = \begin{bmatrix} \mathbf{P}_2 & \mathbf{0}_2 \\ \mathbf{0}_2 & \mathbf{P}_2 \end{bmatrix}$; $\mathbf{P}_2 = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$; and $\mathbf{n} \in \mathbb{C}^{8\times 1}$ is the corresponding AWGN vector. Here, D-STLC preprocessing matrix $\mathbf{V}$ can be designed for given $\mathbf{H}_{i_1 i_2} \in \mathbb{C}^{4\times 2}$ based on an MMSE criterion as $\mathbf{V} = \mathbf{V}_{i_1 i_2} = c\ \mathbf{H}_{i_1 i_2}^H \mathbf{Z}_{i_1 i_2} \in \mathbb{C}^{2\times 4}$, where $c = \|\mathbf{H}_{i_1 i_2}\mathbf{Z}_{i_1 i_2}\|_F^{-1}$ and $\mathbf{Z}_{i_1 i_2} = (\mathbf{H}_{i_1 i_2}\mathbf{H}_{i_1 i_2}^H + \mathbf{P}_4^T \mathbf{H}_{i_1 i_2}^* \mathbf{H}_{i_1 i_2}^T \mathbf{P}_4 + \sigma_n^2 \mathbf{I}_4)^{-1} \in \mathbb{C}^{4\times 4}$ [11]. The estimates of $\mathbf{x}$, denoted by $\widetilde{\mathbf{x}}$, are then obtained by simply combining the received signals in from (3) as

$$\widetilde{\mathbf{x}} = [\widetilde{x_{1,1}}\ \widetilde{x_{1,2}}\ \widetilde{x_{2,1}}\ \widetilde{x_{2,2}}]^T = c^{-1}\left[\mathbf{I}_4 \quad \mathbf{P}_4^T\right]\mathbf{r} \quad (4)$$

and from this, the maximized detection SINR is derived as follows [11]:

$$\rho_{i_1 i_2} = 2U\sigma_x^2(\sigma_n^2 \operatorname{tr}(\mathbf{Z}_{i_1 i_2}))^{-1}. \quad (5)$$

We now propose a TAS strategy such that the detection SINR in (5) is maximized, by solving the following optimization problem: $\min_{\{i_1,i_2\}\subset \mathcal{A}_M} \operatorname{tr}(\mathbf{Z}_{i_1 i_2})$, where $\mathcal{A}_M$ is the set of all possible sets indicating the selected antenna pair from M transmit antennas, e.g., $\mathcal{A}_4 = \{\{1,2\},\{1,3\},\{1,4\},\{2,3\},\{2,4\},\{3,4\}\}$ when $M = 4$.

In general, for M transmit antennas, $\binom{M}{2} = M(M-1)$ combinations are possible for the TAS pairs. Since $\mathcal{O}(M^3)$-complexity is typically required to compute for (5), the overall complexity of the proposed TAS is $\mathcal{O}(M^5)$, which is prohibitive if M is massive.

III. BER Performance Improvement from TAS

In this section, the BER performance of the proposed TAS D-STLC has been evaluated by varying the system SNR E_x/σ_n^2 and M. Quadrature phase-shift keying is used for $\mathbf{x}$. Note that two antennas are selected in TAS, and thus, the number of radiofrequency (RF) chains is the same as the conventional D-STLC systems, while multiuser STLC uses whole antennas. As we can observe from the results in Figs. 2 and 3, the multiuser STLC in [2] achieves the worst performance due to the huge interference. D-STLC in [11] outperforms the multiuser STLC, while the proposed TAS D-STLC can significantly improve the BER performance of the 2-by-4 D-STLC system, by using more transmit antennas, especially SNR is high.

IV. Conclusion

In this study, we have proposed a TAS scheme for D-STLC system with more than two transmit antennas. The proposed TAS can significantly improve communication performance with the cost of the computational complexity and additional antennas. The low-computational complexity TAS method will be studied as further work.

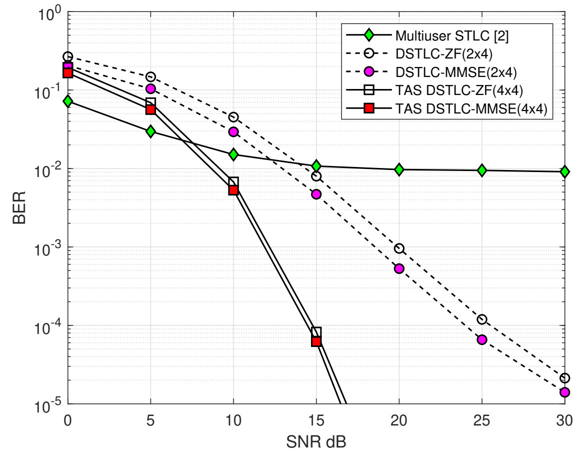

Fig. 2. BER performance comparison of the STLC systems when $M = 4$.

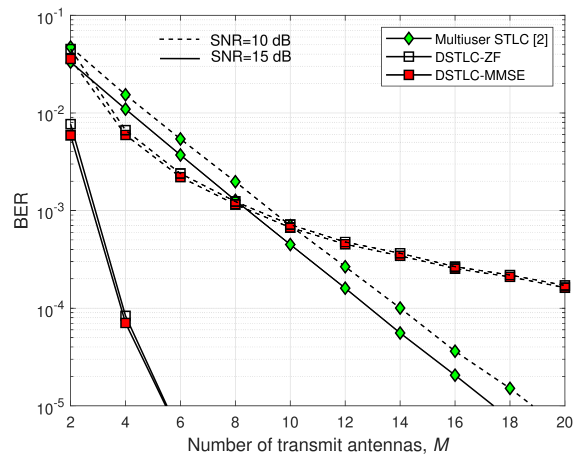

Fig. 3. BER performance over the number of transmit antennas when SNR$\in \{10, 15\}$ dB.

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