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Title	Enhancements of Space-Time Codes for the OFDMA PHY
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Re:	802.16e/D3
Abstract	We propose improved Space-Time codes with full rate and full diversity for 2 Tx – rate 2, 4 Tx – rate 1, 4 Tx rate 2 and 4 Tx rate 4.
Purpose	To propose enhancements of the Space-Time codes in 802.16e/D3.
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Enhancements of Space-Time Codes for the OFDMA PHY

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Introduction

We propose improved Space-Time codes with full rate and full diversity for 2 Tx – rate 2, 4 Tx – rate 1, 4 Tx rate 2 and 4 Tx rate 4. While these codes are specified as Space-Time codes, they may also be used as Space-Frequency codes or as hybrids.

Proposed enhancements

STC for 2 Tx-Rate 2 transmission

We propose to add the transmission matrix:

$$C = \begin{bmatrix} s_1 + e^{j\pi/4}s_2 & (1+2j)(s_3 - e^{j\pi/4}s_4) \\ s_3 + e^{j\pi/4}s_4 & s_1 - e^{j\pi/4}s_2 \end{bmatrix}.$$

The proposed change is guided by the fact that the transmission new matrix C provides diversity gain while maintaining the rate and multiplexing gain of the existing transmission matrix B in Section 8.4.8.3.3. See [1] [2]. It is easily checked that any two entries of the matrix are statistically uncorrelated as in the case of the existing matrix B. The new matrix C has rank 2, indicating a transmit diversity order 2 which is due to "spreading" of the variables whereas the rank for the existing matrix B is 1. The code admits decoding with a simple decoding algorithm of similar complexity as the typical decoding algorithm for matrix B.

STC for 4 Tx – Rate 1 code:

We propose to replace the existing transmission matrix

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}.$$

with the new the transmission matrix A' given by

$$\frac{1}{2}\begin{bmatrix} x_1 - x_2 + j(y_3 + y_4) & x_1 + x_2 + j(y_3 - y_4) & x_1 - x_2 + j(y_3 + y_4) & x_1 + x_2 + j(y_3 - y_4) \\ x_1 + x_2 + j(-y_3 + y_4) & -x_1 + x_2 + j(y_3 + y_4) & x_1 + x_2 + j(-y_3 + y_4) & -x_1 + x_2 + j(y_3 + y_4) \\ x_3 - x_4 + j(y_1 + y_2) & x_3 + x_4 + j(y_1 - y_2) & -x_3 + x_4 - j(y_1 + y_2) & -x_3 - x_4 - j(y_1 - y_2) \\ x_3 + x_4 + j(-y_1 + y_2) & -x_3 + x_4 + j(y_1 + y_2) & -x_3 - x_4 - j(-y_1 + y_2) & x_3 - x_4 - j(y_1 + y_2) \end{bmatrix}.$$

where $x_i = s_{iI}\cos\theta - s_{iQ}\sin\theta$, $y_i = s_{iI}\sin\theta + s_{iQ}\cos\theta$ and $\theta = tan^{-1}2$. The complex symbols s_i take values from a QAM signal set.

This proposed change is guided by the following reasons: (i) The transmit diversity gain of A' is 4 whereas that of A is only 2, (ii) A' admits a decoupled symbol-by-symbol decoding for the variables which leads to a fast ML decoding with a simple slicer (analogous to the Alamouti code for 2TX). Fig. 1 shows the performance of this code using decoupled ML decoding of low complexity for QPSK.

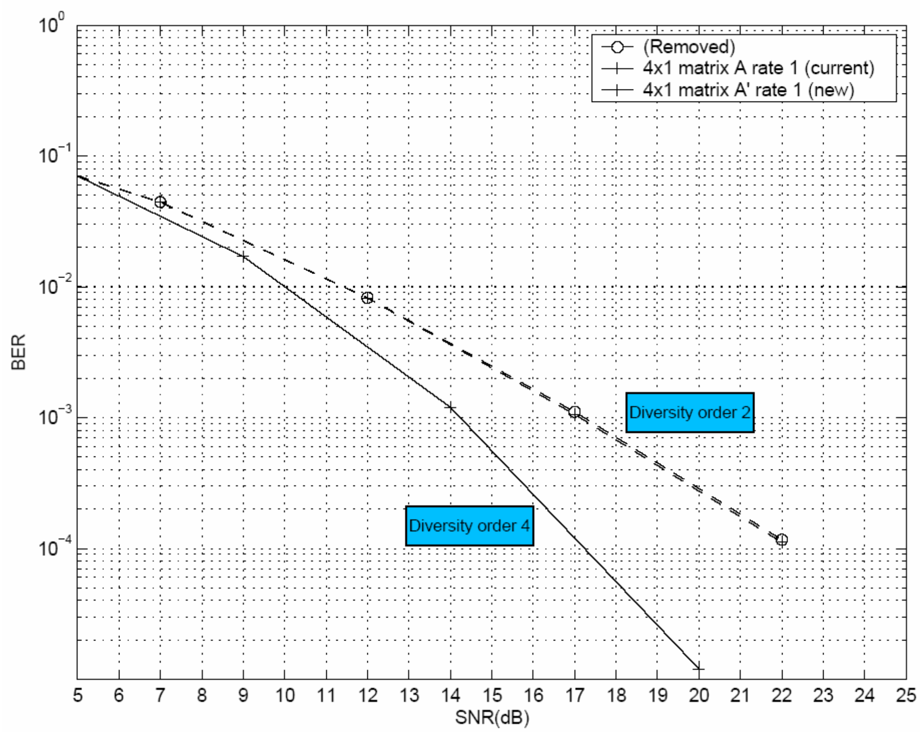

Figure 1: Performance comparison (uncoded) for 4Tx-Rate 1 the current matrix A in the standard and the new proposed matrix A' in a flat Rayleigh fading channel with QPSK modulation.

STC for 4Tx-Rate 2:

We propose add the transmission matrix D given by

$$B^{'} = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5 * \\ \tilde{s}_3 & -\tilde{s}_4^* & \tilde{s}_7 & -\tilde{s}_8^* \\ \tilde{s}_4 & \tilde{s}_3^* & \tilde{s}_8 & \tilde{s}_7^* \end{bmatrix}.$$

where, with $Re[s]$ and $Im[s]$ denoting the real and imaginary part of a complex variable s and $\theta = 0.5 tan^{-1} 2$,

$$\tilde{s}_1 = Re[s_1 e^{j\theta}] + jIm[s_7 e^{j\theta}]; \quad \tilde{s}_7 = Re[s_7 e^{j\theta}] + jIm[s_1 e^{j\theta}]$$
$$\tilde{s}_2 = Re[s_2 e^{j\theta}] + jIm[s_8 e^{j\theta}]; \quad \tilde{s}_8 = Re[s_8 e^{j\theta}] + jIm[s_2 e^{j\theta}]$$
$$\tilde{s}_3 = Re[s_3 e^{j\theta}] + jIm[s_5 e^{j\theta}]; \quad \tilde{s}_5 = Re[s_5 e^{j\theta}] + jIm[s_3 e^{j\theta}]$$
$$\tilde{s}_4 = Re[s_4 e^{j\theta}] + jIm[s_6 e^{j\theta}]; \quad \tilde{s}_6 = Re[s_6 e^{j\theta}] + jIm[s_4 e^{j\theta}].$$

The proposed code gives more coding gain than the current transmission matrix B with MMSE detection as shown in Figure 2.

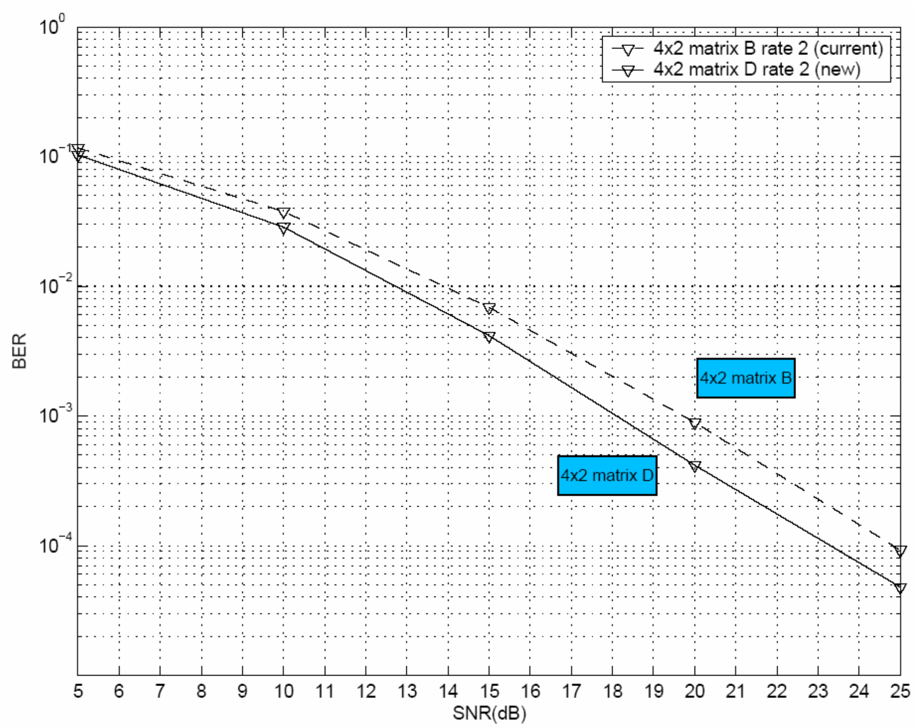

Figure 3: Performance comparison (uncoded) for the 4Tx-Rate 1 matrix B currently in the standard and the proposed matrix D for QPSK modulation in a flat Rayleigh fading channel with MMSE type receivers.

STC for 4Tx-Rate 4:

We propose to add a transmission matrix E given by:

$$E = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix},$$

where

$$c_{11} = s_1 + s_2 u + s_3 u^2 + s_4 u^3,$$
$$c_{12} = a\left(s_{13} + s_{14} uv + s_{15} u^2 v^2 + s_{16} u^3 v^3\right),$$

$$c_{13} = a\left(s_9 + s_{10}uv^2 + s_{11}u^2 + s_{12}u^3v^2\right),$$
$$c_{14} = a\left(s_5 + s_6uv^3 + s_7u^2v^2 + s_8u^3v\right),$$
$$c_{21} = s_5 + s_6u + s_7u^2 + s_8u^3,$$
$$c_{22} = s_1 + s_2uv + s_3u^2v^2 + s_4u^3v^3,$$
$$c_{23} = a(s_{13} + s_{14}uv^2 + s_{15}u^2 + s_{16}u^3v^2),$$
$$c_{24} = a\left(s_9 + s_{10}uv^3 + s_{11}u^2v^2 + s_{12}u^3v\right),$$
$$c_{31} = s_9 + s_{10}u + s_{11}u^2 + s_{12}u^3,$$
$$c_{32} = s_5 + s_6uv + s_7u^2v^2 + s_8u^3v^3,$$
$$c_{33} = s_1 + s_2uv^2 + s_3u^2 + s_4u^3v^2,$$
$$c_{34} = a\left(s_{13} + s_{14}uv^3 + s_{15}u^2v^2 + s_{16}u^3v\right),$$
$$c_{41} = s_{13} + s_{14}u + s_{15}u^2 + s_{16}u^3,$$
$$c_{42} = s_9 + s_{10}uv + s_{11}u^2v^2 + s_{12}u^3v^3,$$
$$c_{43} = s_5 + s_6uv^2 + s_7u^2v + s_8u^3v^2,$$
$$c_{44} = s_1 + s_2uv^3 + s_3u^2v^2 + s_4u^3v,$$

where $u = e^{\frac{2\pi}{16}j}$, $v = e^{\frac{2\pi}{4}j}$ and $a = 1 + 2j$.

This change is proposed since the transmission matrix E provides diversity gain while maintaining the rate and multiplexing gain of the transmission matrix C currently in the standard. As in the case of 2Tx-Rate 2 code, the matrix E has rank 4, indicating a transmit diversity order 4 which is due to spreading of the variables whereas the rank for the current code C is 1.

Specific text changes

[Modify the following sections of 802.16e/D3]

8.4.8.3.3 Transmission schemes for 2-antenna BS (page 97):

Add the transmission matrix C given by:

$$C = \begin{bmatrix} s_1 + e^{j\pi/4}s_2 & (1+2j)(s_3 - e^{j\pi/4}s_4) \\ s_3 + e^{j\pi/4}s_4 & s_1 - e^{j\pi/4}s_2 \end{bmatrix}.$$

8.4.8.3.4 Transmission schemes for 4-antenna BS (page 98):

Replace the transmission matrix A:

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}.$$

With the transmission matrix A' given by

$$\frac{1}{2}\begin{bmatrix} x_1 - x_2 + j(y_3 + y_4) & x_1 + x_2 + j(y_3 - y_4) & x_1 - x_2 + j(y_3 + y_4) & x_1 + x_2 + j(y_3 - y_4) \\ x_1 + x_2 + j(-y_3 + y_4) & -x_1 + x_2 + j(y_3 + y_4) & x_1 + x_2 + j(-y_3 + y_4) & -x_1 + x_2 + j(y_3 + y_4) \\ x_3 - x_4 + j(y_1 + y_2) & x_3 + x_4 + j(y_1 - y_2) & -x_3 + x_4 - j(y_1 + y_2) & -x_3 - x_4 - j(y_1 - y_2) \\ x_3 + x_4 + j(-y_1 + y_2) & -x_3 + x_4 + j(y_1 + y_2) & -x_3 - x_4 - j(-y_1 + y_2) & x_3 - x_4 - j(y_1 + y_2) \end{bmatrix}.$$

where $x_i = s_{iI}\cos\theta - s_{iQ}\sin\theta$, $y_i = s_{iI}\sin\theta + s_{iQ}\cos\theta$ and $\theta = tan^{-1}2$. The complex symbols s_i take values from a QAM signal set.

Add the transmission matrix D given by

$$D = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5* \\ \tilde{s}_3 & -\tilde{s}_4^* & \tilde{s}_7 & -\tilde{s}_8^* \\ \tilde{s}_4 & \tilde{s}_3^* & \tilde{s}_8 & \tilde{s}_7^* \end{bmatrix}.$$

where, with $Re[s]$ and $Im[s]$ denoting the real and imaginary part of a complex variable s and $\theta = 0.5tan^{-1}2$,

$$\begin{aligned} \tilde{s}_1 &= Re[s_1 e^{j\theta}] + jIm[s_7 e^{j\theta}]; \quad \tilde{s}_7 = Re[s_7 e^{j\theta}] + jIm[s_1 e^{j\theta}] \\ \tilde{s}_2 &= Re[s_2 e^{j\theta}] + jIm[s_8 e^{j\theta}]; \quad \tilde{s}_8 = Re[s_8 e^{j\theta}] + jIm[s_2 e^{j\theta}] \\ \tilde{s}_3 &= Re[s_3 e^{j\theta}] + jIm[s_5 e^{j\theta}]; \quad \tilde{s}_5 = Re[s_5 e^{j\theta}] + jIm[s_3 e^{j\theta}] \\ \tilde{s}_4 &= Re[s_4 e^{j\theta}] + jIm[s_6 e^{j\theta}]; \quad \tilde{s}_6 = Re[s_6 e^{j\theta}] + jIm[s_4 e^{j\theta}]. \end{aligned}$$

Add the transmission matrix E given by

$$E = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix},$$

where

$$c_{11} = s_1 + s_2 u + s_3 u^2 + s_4 u^3 ,$$
$$c_{12} = a\left(s_{13} + s_{14} uv + s_{15} u^2 v^2 + s_{16} u^3 v^3\right),$$
$$c_{13} = a\left(s_9 + s_{10} uv^2 + s_{11} u^2 + s_{12} u^3 v^2\right),$$
$$c_{14} = a\left(s_5 + s_6 uv^3 + s_7 u^2 v^2 + s_8 u^3 v\right),$$
$$c_{21} = s_5 + s_6 u + s_7 u^2 + s_8 u^3 ,$$
$$c_{22} = s_1 + s_2 uv + s_3 u^2 v^2 + s_4 u^3 v^3 ,$$
$$c_{23} = a(s_{13} + s_{14} uv^2 + s_{15} u^2 + s_{16} u^3 v^2) ,$$
$$c_{24} = a\left(s_9 + s_{10} uv^3 + s_{11} u^2 v^2 + s_{12} u^3 v\right),$$
$$c_{31} = s_9 + s_{10} u + s_{11} u^2 + s_{12} u^3 ,$$
$$c_{32} = s_5 + s_6 uv + s_7 u^2 v^2 + s_8 u^3 v^3 ,$$
$$c_{33} = s_1 + s_2 uv^2 + s_3 u^2 + s_4 u^3 v^2 ,$$
$$c_{34} = a\left(s_{13} + s_{14} uv^3 + s_{15} u^2 v^2 + s_{16} u^3 v\right),$$
$$c_{41} = s_{13} + s_{14} u + s_{15} u^2 + s_{16} u^3 ,$$
$$c_{42} = s_9 + s_{10} uv + s_{11} u^2 v^2 + s_{12} u^3 v^3 ,$$
$$c_{43} = s_5 + s_6 uv^2 + s_7 u^2 v + s_8 u^3 v^2 ,$$
$$c_{44} = s_1 + s_2 uv^3 + s_3 u^2 v^2 + s_4 u^3 v ,$$

where $u = e^{\frac{2\pi}{16} j}$, $v = e^{\frac{2\pi}{4} j}$ and $a = 1 + 2j$.

References

[1] B.A.Sethuraman, B.Sundar Rajan and V.Shashidhar, "Full-diversity, High-rate Space-Time Block Codes from Division Algebras," IEEE Transactions on Information Theory, Vol.49, No.10, Oct. 2003, pp.2596-2616.

[2] V. Shashidhar, B. Sundar Rajan and P. Vijay Kumar, "STBCs with optimal diversity-multiplexing trade-off for 2,3 and 4 transmit antennas," to appear Proceedings of IEEE International Symposium on Information Theory, June 27-July 3, 2004.