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| Project                      | IEEE 802.16 Broadband Wireless Access Working Group < <a href="http://ieee802.org/16">http://ieee802.org/16</a> >   |  |
| Title                        | Enhancements of Space-Time Codes for the OFDMA PHY  |  |
| Date Submitted               | 2004-06-25  |  |
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| Re:                          | 802.16e/D8  |  |
| 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/D8.  |  |
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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.

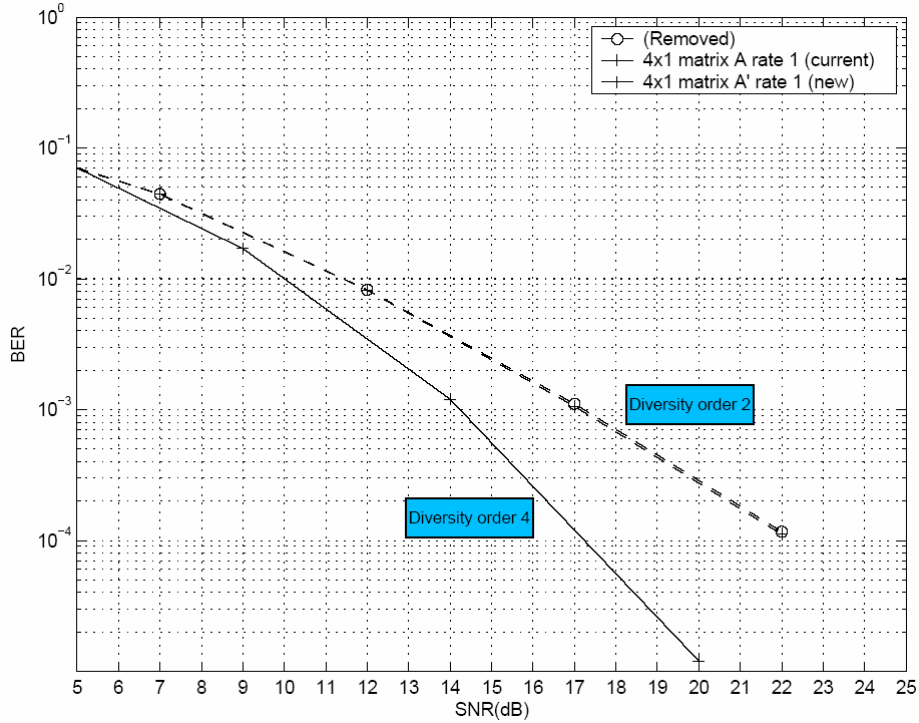


Figure 1: Performance comparison (uncoded) for 4Tx-Rate 1 the current matrix A in the standard and the new proposed matrix A' in a flat Rayleigh fading channel with QPSK modulation.

### 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  $\theta = 0.5 \tan^{-1} 2$ ,

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

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

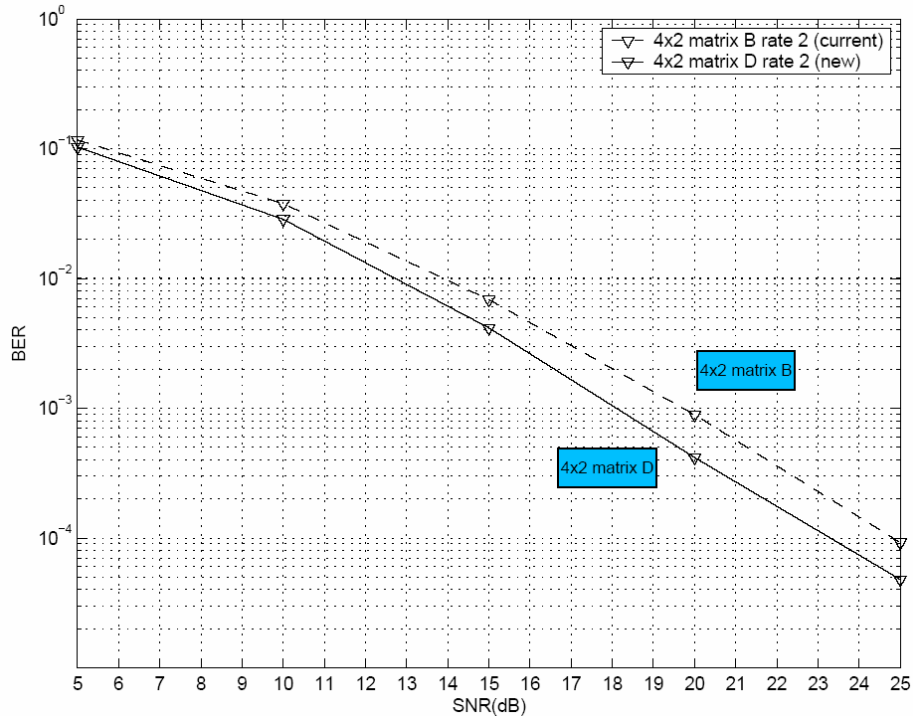


Figure 3: Performance comparison (uncoded) for the 4Tx-Rate 1 matrix B currently in the standard and the proposed matrix D for QPSK modulation in a flat Rayleigh fading channel with MSE type receivers.

#### 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

$$c_{11} = s_1 + s_2 u + s_3 u^2 + s_4 u^3,$$

$$c_{12} = a(s_{13} + s_{14} uv + s_{15} u^2 v^2 + s_{16} u^3 v^3),$$

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

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  $\theta = 0.5 \tan^{-1} 2$ ,

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

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

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

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. Shashi dhar, 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.