Enhancements of Space-Time Codes for the OFDMA PHY

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Low decoding complexity improved space-time codes with full rate and full diversity for 4 Tx – rate 1 configuration.

To propose enhancements of the space-time codes in 802.16e/D3.

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Introduction

We propose a low decoding complexity (symbol by symbol decoding) improved space-time code with full rate and full diversity for \(2\) Tx—rate 2, \(4\) Tx – rate 1 configuration. 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:

**Removed 2x2 STC code**

The proposed change is guided by the fact that the transmission new matrix \(C\) provides diversity gain while maintaining the rate and multiplexing gain [1] [2] of the existing transmission matrix \(B\) in Section 8.4.8.3.3. 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 \(B\).

**Removed BER Curve for 2x2 STC code**

![Figure 1: FEC-Block error rate of proposed matrix C compared with the FEC-block error rate of existing matrix B (pure spatial multiplexing).](image)

The simulation was performed in a 802.16 simulation using the FUSC subcarrier allocation scheme and using the ITU-Pedestrian B channel model in a 5 MHz channel. The transmit and receive antennas were assumed to be uncorrelated. The coding was performed with rate \(\frac{1}{2}\) tailbiting convolutional coding.

**STC for 4 Tx – Rate 1 code:**

We propose to replace the existing transmission matrix
with the new the transmission matrix $A_i$ which is defined as follows:

\[
A_i = \begin{bmatrix}
  s_1 & -s_2^* & 0 & 0 \\
  s_2 & s_1^* & 0 & 0 \\
  0 & 0 & s_3 & -s_4^* \\
  0 & 0 & s_4^* & s_3^*
\end{bmatrix}.
\]

Let the complex symbols to be transmitted be $x_1, x_2, x_3, x_4$ which take values from a square QAM constellation. Let $s_i = x_i e^{j \theta}$ for $i=1,2,3,4$, where $\theta = \frac{1}{2} \tan^{-1} \frac{q_1}{q_2}$ and let

$\tilde{s}_1 = s_{11} + js_{1Q}; \tilde{s}_2 = s_{21} + js_{2Q}; \tilde{s}_3 = s_{31} + js_{3Q}; \tilde{s}_4 = s_{41} + js_{4Q}$, where $s_i = s_{ii} + js_{iQ}$.

The proposed Space-Time-Frequency code for 4Tx-Rate 1 configuration is

\[
A_i = \begin{bmatrix}
  \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\
  \tilde{s}_2 & \tilde{s}_1^* & 0 & 0 \\
  0 & 0 & \tilde{s}_3 & -\tilde{s}_4^* \\
  0 & 0 & \tilde{s}_4^* & \tilde{s}_3^*
\end{bmatrix}
\]

where $x_i = s_{ii} \cos \theta - s_{iQ} \sin \theta$, $y_i = s_{ii} \sin \theta + s_{iQ} \cos \theta$ and $\theta = \frac{1}{2} \tan^{-1} \frac{q_1}{q_2}$. The first two columns correspond to the two OFDM symbols and one subcarrier. Similarly the last two columns correspond to the same two OFDM symbols, but for the next subcarrier. Let $H^{(1)} = \begin{bmatrix} H_1(1) & H_2(1) & H_3(1) & H_4(1) \end{bmatrix}$ be the channel coefficients for the first subcarrier. The channel is assumed to be quasi-static for two OFDM symbols, but could be varying across the subcarriers. Let $H^{(2)} = \begin{bmatrix} H_1(2) & H_2(2) & H_3(2) & H_4(2) \end{bmatrix}$ be the channel coefficients for the second subcarrier. Then, the received signal (assuming a single receive antenna) on the first sub-carrier is given by

\[
\begin{bmatrix}
  Y_1^1 \\
  Y_2^1
\end{bmatrix} = H^{(1)} A_1 (1 : 2) + \text{noise}
\]

and for the second sub-carrier is given by

\[
\begin{bmatrix}
  Y_1^2 \\
  Y_2^2
\end{bmatrix} = H^{(2)} A_1 (3 : 4) + \text{noise}
\]

where $Y_k^j$ denotes the received symbol on the $j^{th}$ subcarrier at time $k$. $A_i (1 : 2)$ denotes the 1st and 2nd columns of $A_i$ and similarly, $A_i (3 : 4)$ denotes the 3rd and 4th columns of $A_i$. The above measurements can be re-written as follows:

\[
\begin{bmatrix}
  Y_1^1 & Y_1^2 & Y_2^1 & Y_2^2
\end{bmatrix} = \begin{bmatrix}
  H_1(1) & H_2(1) & H_3(2) & H_4(2)
\end{bmatrix} \begin{bmatrix}
  Alamouti(\tilde{s}_1, \tilde{s}_2) \\
  0 \\
  Alamouti(\tilde{s}_3, \tilde{s}_4)
\end{bmatrix} + \text{noise}
\]
This proposed change is guided by the following reasons: (i) The transmit diversity gain of $A_1$ is 4 whereas that of $A$ in [1] is only 2; (ii) $A_1$ admits a decoupled symbol-by-symbol decoding for the variables which leads to a fast ML decoding (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 for 4Tx-Rate 1 the current matrix $A$ in the standard and proposed matrix $A_1$ for Pedestrian-B channel model, QPSK modulation, and Tail-biting Convolutional Code with Hard Decision Decoding.
Figure 2: Performance comparison for 4Tx-Rate 1 the current matrix $A$ in the standard and proposed matrix $A_1$ for Vehicular-A channel model, QPSK modulation, and rate $\frac{3}{4}$ Convolutional Turbo Code with Soft Decision Decoding.

**STC for 4Tx-Rate 2:**

We propose to replace the transmission matrix $B$ with the transmission matrix $B'$ given by

\[
\text{Removed } 4 \times 2 \text{ STC code}
\]

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

**Removed BER Curve for 4x2 STC code**

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 $B'$ 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 $D$ given by:

$$
\begin{align*}
&c_{11} = \frac{1}{2}(s_1 + s_2u + s_3u^2 + s_4u^3), \\
&c_{12} = a \left( s_{13} + s_{14}uv + s_{15}u^2v^2 + s_{16}u^3v^3 \right), \\
&c_{13} = a \left( s_9 + s_{10}uv^2 + s_{11}u^2v^2 + s_{12}u^3v^3 \right), \\
&c_{14} = a \left( s_5 + s_6u^3 + s_7u^2v^2 + s_8u^3v \right), \\
&c_{21} = s_5 + s_6u + s_7u^2 + s_8u^3, \\
&c_{22} = s_1 + s_2uv + s_3u^2v^2 + s_4u^3v^3, \\
&c_{23} = a \left( s_{13} + s_{14}uv^2 + s_{15}u^2v^2 + s_{16}u^3v^3 \right), \\
&c_{24} = a \left( s_9 + s_{10}uv^2 + s_{11}u^2v^2 + s_{12}u^3v^3 \right), \\
&c_{31} = s_9 + s_{10}uv^2 + s_{11}u^2v^2 + s_{12}u^3v^3, \\
&c_{32} = s_5 + s_6u^2 + s_7u^3v^2 + s_8u^3v, \\
&c_{33} = s_1 + s_2uv + s_3u^2v^2 + s_4u^3v^3, \\
&c_{34} = a \left( s_{13} + s_{14}uv^2 + s_{15}u^2v^2 + s_{16}u^3v^3 \right), \\
&c_{41} = s_{13} + s_{14}uv + s_{15}u^2v^2 + s_{16}u^3v^3, \\
&c_{42} = s_9 + s_{10}uv^2 + s_{11}u^2v^2 + s_{12}u^3v^3, \\
&c_{43} = s_5 + s_6u^2 + s_7u^3v^2 + s_8u^3v, \\
&c_{44} = s_1 + s_2uv^3 + s_3u^2v^2 + s_4u^3v^3.
\end{align*}
$$

where $u = e^{\frac{2\pi i}{16}}$, $v = e^{\frac{2\pi i}{4}}$, and $a = e^{j0.5}$. 

**Removed 4x4 STC code with Rate 4**
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:

\[
C = \begin{bmatrix}
  s_1 & -s_2^* & 0 & 0 \\
  s_2 & s_1^* & 0 & 0 \\
  0 & 0 & s_3 & -s_4^* \\
  0 & 0 & s_4 & s_3^*
\end{bmatrix}.
\]

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

Replace the existing transmission matrix $A$:

\[
A = \begin{bmatrix}
  1 & 2 \\
  2 & 1 \\
  3 & 4 \\
  4 & 3
\end{bmatrix}
\]

With $A_1$ shown below:

\[
A_1 = \begin{bmatrix}
  \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\
  \tilde{s}_2 & \tilde{s}_1^* & 0 & 0 \\
  0 & 0 & \tilde{s}_3 & -\tilde{s}_4^* \\
  0 & 0 & \tilde{s}_4 & \tilde{s}_3^*
\end{bmatrix}.
\]

where the complex symbols to be transmitted are $x_1, x_2, x_3, x_4$ which take values from a square QAM constellation and $s_i = x_i e^{i\theta}$ for $i=1,2,3,4$, where $\theta = \frac{1}{2} \tan^{-1} 2$ and also let

\[
\tilde{s}_1 = s_{1I} + js_{1Q}; \tilde{s}_2 = s_{2I} + js_{2Q}; \tilde{s}_3 = s_{3I} + js_{3Q}; \tilde{s}_4 = s_{4I} + js_{4Q}
\]

with the transmission matrix given by
where \( x_i = s_{ii} \cos \theta - s_{1i} \sin \theta \) and \( y_i = s_{ii} \sin \theta + s_{1i} \cos \theta \) and \( \theta = \tan^{-1} \frac{2}{1} \). The complex symbols \( s_i \) take values from a QAM signal set.

Replace the existing transmission matrix \( B \) with the transmission matrix by

\[
\text{removed matrix } B
\]

where, with \( \text{Re}(s) \) and \( \text{Im}(s) \) denoting the real and imaginary part of a complex variable \( s \) and \( \theta = \frac{1}{2} \tan^{-1} 2 \).

Add the transmission matrix \( D \) given by

\[
\text{removed matrix } D
\]

where

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

where \( u = e^{\frac{2\pi i}{4}} \) \( v = e^{\frac{2\pi i}{2}} \) and \( u = e^{i0.5} \).

[Modify the Table 277a in Section 8.4.5.3.4 in page 73 in [3].]

### Table 277a – OFDMA downlink STC_ZONE_IE format

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Size (bits)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>STC_ZONE_IE()</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Extended DIUC</td>
<td>4</td>
<td>STC/ZONE=0x01</td>
</tr>
<tr>
<td>- Length</td>
<td>4</td>
<td>Length = 0x02</td>
</tr>
<tr>
<td>- Permutation</td>
<td>2</td>
<td>00 = PUSC permutation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>01 = FUSC permutation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 = Optional FUSC permutation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 = Optional adjacent subcarrier permutation</td>
</tr>
<tr>
<td>- Use All SC indicator</td>
<td>1</td>
<td>0 = Do not use all subchannels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Use all subchannels</td>
</tr>
<tr>
<td>- STC</td>
<td>2</td>
<td>00 = No STC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>01 = STC using 2 antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 = STC using 4 antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 = FHDC using 2 antennas</td>
</tr>
<tr>
<td>- Matrix indicator</td>
<td>2</td>
<td>Antenna STC/FHDC matrix (see 8.4.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00 = Matrix A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>01 = Matrix B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 = Matrix C (applicable to 4 antennas only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 = Matrix D (applicable to 4 antennas only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reserved</td>
</tr>
<tr>
<td>- IDcell</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>- Reserved</td>
<td>3</td>
<td>Shall be set to zero</td>
</tr>
<tr>
<td>†</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Modify the Table 281a in Section 8.4.5.3.8 in page 74 in [3].]

### Table 281aa – MIMO DL basic IE format

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Size (bits)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8
Matrix indicator 2

STC = STC mode indicated in the latest STC_Zone_IE().

If (STC == 01):
  00 = Matrix A
  01 = Matrix B
  10-11 = Reserved Matrix C
  11 = Reserved

elseif (STC == 10):
  00 = Matrix A
  01 = Matrix B
  10 = Matrix C
  11 = Reserved Matrix D

[Modify the Table 282a in Section 8.4.5.3.9 in page 74 in [3].]

<table>
<thead>
<tr>
<th>Matrix indicator</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>STC matrix (see 8.4.8.1.4)</td>
<td></td>
</tr>
<tr>
<td>STC = STC mode indicated in the latest STC_Zone_IE().</td>
<td></td>
</tr>
</tbody>
</table>
| If (STC == 01):
  00 = Matrix A
  01 = Matrix B
  10-11 = Reserved Matrix C
  11 = Reserved |
| elseif (STC == 10):
  00 = Matrix A
  01 = Matrix B
  10 = Matrix C
  11 = Reserved Matrix D |

Table 99d—Compact_DL-MAP_IE format for MIMO-Control

<table>
<thead>
<tr>
<th>Syntax</th>
<th>Size (bits)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIMO_Compact_DL-MAP_IE()</td>
<td>1</td>
<td>Type = 7</td>
</tr>
<tr>
<td>DL-MAP Type</td>
<td>1</td>
<td>MIMO Control = 0x04</td>
</tr>
<tr>
<td>DL-MAP Sub-type = 3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>BITMAP length</td>
<td>4</td>
<td>in-nibble</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------</td>
<td>----------</td>
</tr>
<tr>
<td>BITMAP</td>
<td>variable</td>
<td>size = BITMAP length x 4 bits</td>
</tr>
<tr>
<td>-for (i = 0; i&lt;count; i++) {</td>
<td></td>
<td></td>
</tr>
<tr>
<td>count = the number of ‘1’ in BITMAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STC</td>
<td>1</td>
<td>STC order</td>
</tr>
<tr>
<td>0 = STC using 2 antennas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 = STC using 4 antennas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed-loop</td>
<td>1</td>
<td>0 = Open-loop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Closed-loop</td>
</tr>
<tr>
<td>Matrix indicator</td>
<td>2</td>
<td>STC matrices (see 8.4.8.3)</td>
</tr>
<tr>
<td>if (STC == 0) {</td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 = Matrix A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01 = Matrix B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:11 = ReservedMatrix C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 = Reserved</td>
<td></td>
<td></td>
</tr>
<tr>
<td>else if (STC == 1) {</td>
<td></td>
<td></td>
</tr>
<tr>
<td>00 = Matrix A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01 = Matrix B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 = Matrix C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 = ReservedMatrix D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Num_layer</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>-for (j=0;j&lt;Num_layer; j++) {</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer_index</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>DIUC</td>
<td>4</td>
<td>0-11 burst profiles</td>
</tr>
<tr>
<td>Padding</td>
<td>variable</td>
<td>The padding bits are used to ensure the IE size is integer number of bytes</td>
</tr>
<tr>
<td>}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References

