<table>
<thead>
<tr>
<th><strong>Project</strong></th>
<th>IEEE 802.16 Broadband Wireless Access Working Group <a href="http://ieee802.org/16">http://ieee802.org/16</a></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Enhancements to 4 transmit antenna rate 2 space-time codes for the OFDMA PHY</td>
</tr>
<tr>
<td><strong>Date Submitted</strong></td>
<td>2004-08-17</td>
</tr>
<tr>
<td><strong>Source(s)</strong></td>
<td>Erik Lindskog, V. Shashidhar, B. Sundar Rajan, Djordje Tajkovic, Tareq Al-Naffouri, Erik Stauffer, Taiwen Tang, David Garrett, K. Giridhar, Bob Lorenz, Babu Mandava, A. Paulraj, Trevor Pearman, Kamlesh Rath, Aditya Agrawal, Mai Vu</td>
</tr>
<tr>
<td></td>
<td>Beceem Communications, Inc. Freedom Circle, Suite 101 Santa Clara, CA 95054</td>
</tr>
<tr>
<td><strong>Re:</strong></td>
<td>802.16e/D5</td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>We propose improved space-time codes for 4 Tx rate 2.</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>To propose enhancements of the space-time codes in 802.16e/D4.</td>
</tr>
<tr>
<td><strong>Notice</strong></td>
<td>This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.</td>
</tr>
<tr>
<td><strong>Release</strong></td>
<td>The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE’s name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE’s sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.</td>
</tr>
<tr>
<td><strong>Patent Policy and Procedures</strong></td>
<td>The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <a href="http://ieee802.org/16/ipr/patents/policy.html">http://ieee802.org/16/ipr/patents/policy.html</a>, including the statement “IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard.” Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <a href="mailto:chair@wirelessman.org">mailto:chair@wirelessman.org</a> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <a href="http://ieee802.org/16/ipr/patents/notices">http://ieee802.org/16/ipr/patents/notices</a>.</td>
</tr>
</tbody>
</table>
Enhancements to 4 Transmit Antenna Rate 2 Space-Time Codes for the OFDMA PHY

Erik Lindskog, V. Shashidhar, B. Sundar Rajan, Djordje Tajkovic, Tareq Al-Naffouri, Erik Stauffer, Taiwen Tang, David Garrett, K. Giridhar, Bob Lorenz, Babu Mandava, A. Paulraj, Trevor Pearman, Kamlesh Rath, Aditya Agrawal, Mai Vu

Beceem Communications, Inc.

Introduction
We propose a improved space-time code for 4 Tx rate 2.

Proposed enhancement

STC for 4Tx-Rate 2:
We propose to replace the transmission matrix \( B \) with the transmission matrix \( B' \) given by

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

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

\[
\begin{align*}
\tilde{s}_1 &= \text{Re}[s_1e^{j\theta}] + j\text{Im}[s_1e^{j\theta}] ; \quad \tilde{s}_7 = \text{Re}[s_7e^{j\theta}] + j\text{Im}[s_1e^{j\theta}] \\
\tilde{s}_2 &= \text{Re}[s_2e^{j\theta}] + j\text{Im}[s_2e^{j\theta}] ; \quad \tilde{s}_8 = \text{Re}[s_8e^{j\theta}] + j\text{Im}[s_2e^{j\theta}] \\
\tilde{s}_3 &= \text{Re}[s_3e^{j\theta}] + j\text{Im}[s_3e^{j\theta}] ; \quad \tilde{s}_5 = \text{Re}[s_5e^{j\theta}] + j\text{Im}[s_3e^{j\theta}] \\
\tilde{s}_4 &= \text{Re}[s_4e^{j\theta}] + j\text{Im}[s_4e^{j\theta}] ; \quad \tilde{s}_6 = \text{Re}[s_6e^{j\theta}] + j\text{Im}[s_4e^{j\theta}].
\end{align*}
\]

This code is intended to be used as a space-time-frequency code with the two first columns on one tone and the second two columns on a second tone.

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.

**Specific text changes**

[Modify the following sections of 802.16e/D3]

### 8.4.8.3.4 Transmission schemes for 4-antenna BS:

Replace the existing transmission matrix B with $B_1$ shown below:

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

$$
\begin{align*}
\tilde{s}_1 &= \text{Re}[s_1e^{j\theta}] + j\text{Im}[s_1e^{j\theta}] \\
\tilde{s}_2 &= \text{Re}[s_2e^{j\theta}] + j\text{Im}[s_2e^{j\theta}] \\
\tilde{s}_3 &= \text{Re}[s_3e^{j\theta}] + j\text{Im}[s_3e^{j\theta}] \\
\tilde{s}_4 &= \text{Re}[s_4e^{j\theta}] + j\text{Im}[s_4e^{j\theta}]
\end{align*}
$$

$\tilde{s}_5 = \text{Re}[s_6e^{j\theta}] + j\text{Im}[s_6e^{j\theta}]$ 

$\tilde{s}_6 = \text{Re}[s_8e^{j\theta}] + j\text{Im}[s_8e^{j\theta}]$
where the complex symbols to be transmitted are $x_1, \ldots, x_8$ which take values from a square QAM constellation and $s_i = x_i e^{j\theta}$ for $i=1,2,\ldots,8$, where $\theta = \frac{1}{2} \tan^{-1} 2$ and

$$\tilde{s}_1 = s_{1I} + js_{1Q}; \quad \tilde{s}_2 = s_{2I} + js_{2Q}; \quad \tilde{s}_3 = s_{3I} + js_{3Q}; \quad \tilde{s}_4 = s_{4I} + js_{4Q} \quad \text{where} \quad s_i = s_{ii} + js_{iq}.$$ 

This code should be used as a space-time-frequency code with the two first columns on a first tone and the second two columns on the second tone.

References


