Closed Loop MIMO Precoding

IEEE 802.16 Presentation Submission Template (Rev. 8.3)

Document Number:
IEEE S802.16e-04/293r2

Date Submitted:
2004-11-22

Source:

Venue:
IEEE 802 Plenary, San Antonio, Texas, U.S.A.

Base Document:
IEEE C80216e-04/293r2

Purpose:
Introduce changes according to IEEEC80216e-04/293r2 to 802.16e/D4

Notice:
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.

Release:
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.

IEEE 802.16 Patent Policy:
The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, 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 <mailto:chair@wirelessman.org> 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 <http://ieee802.org/16/ipr/patents/notices>.
General Approach

• Exploit all available information
  • Instantaneous channel knowledge
  • Long term channel statistics
    • Mean
    • Spatial covariance

• Switch between short term and long term precoder

• Mobility cases
  • Low mobility => Use short term precoder
  • High mobility => Use long term precoder
Short Term Precoding

- Precoding matrix selected based on short term channel knowledge.
- Select precoding matrix from code book with 64 entries
  - Six bits quantization per precoding matrix irrespective of nr Tx antennas and spatial rate.
  - One CQICH channel
- Code books consists of unitary matrices selecting a subspace of rank equal to the spatial rate used.
- No STBC used, simply Eigenbeamforming with 1,2 or 3 spatial streams.
Long Term Precoding

- Precoding matrix selected based on long term channel knowledge.
- Same code books as for short term precoding.
- The code book rank is selected depending on how many dimensions one wants to put energy into.
- Use standard space time code for nr Tx antennas equal to the rank of the code book used:
  - Rank 1 code book – Use SISO transmission
  - Rank 2 code book – Use 2 Tx antenna STC matrices
  - Rank 3 code book – Use 3 Tx antenna STC matrices
  - Rank 4 – Open loop is used
- Very low feedback bandwidth requirements
  - For 200 users/sector and 6 bit per user per second, we need only the equivalent of a single CQICH slot per 5 ms frame.
Long Term and Short Term Precoding Setup

- BS can start long term precoding for a relatively larger number of active users.
- SS feeds back long term code book rank and long term precoding matrix index as well as life span of short term precoding matrix.
- The short term precoding matrix life span helps the BS choose the short term precoding feedback rate.
- BS can set up short term precoding when desired.
- SS feeds back short term precoding matrix index from code book of rank matching the spatial rate recommended by the SS link-adaptation algorithm.
- BS uses short term precoder when available and valid.
- BS uses long term precoder if available otherwise.
Precoding Matrix Selection

- Short term precoding rate 1
  - Maximize received power:
    \[ W = \arg \max_i \| HW_i \|_{Frob} \]

- Short term precoding rate 2 and 3 or 4
  - Use Adhoc selection criteria

- Long term precoder matrix rate 1
  - Optimal or simplified Adhoc criteria

- Long term precoder rate 2 and 3 or 4
  - Use Adhoc selection criteria.
Code Book

• $L$ is the total number of entries in the codebook. Similar to [Hochwald et al], given the $s \times Mt$ matrix $U = [I \ U]$, $Mt \times Mt$ diagonal matrices

$$[C_k]_{m,m} = e^{\frac{j2\pi[U]_{k,m}}{L}}, k=1,2; m=1,...,M_t; C_k^{L} = I$$

and $Mt \times B$ matrix $Y (B<=Mt)$, the entries in the codebook are given as

$$W_l = C_1^{l_1} C_2^{l_2} \cdots C_2^{l_s} Y$$

where $l_i$ are elements in the ring of integers mod $L^s$. For simplicity, the basis matrix $Y$ is given as selection of total of $B$ columns (set of indexes $Bc$) of the DFT matrix

$$[DFT]_{m,b} = e^{\frac{j2\pi(Mt-1)(b-1)}{M}}, \quad m,b = 1,...,M_t$$

• General approach to codebook set partitioning which could enable more degrees of freedom for variety of feedback rates (e.g., for $s=2$, sending back $l_1$ with one rate and $l_2$ with another)

• In the current simulations, $L=64$, $s=1$ and $U$ chosen as in Nokia's proposal
Short Term Results
Short Term Example 1

- 4, 16 and 64 QAM
- FEC rate 0.5 and 0.75
- 2 frames delay
- STC rate 1
Short Term Example 2

- 4, 16 and 64 QAM
- FEC rate 0.5 and 0.75
- 2 frames delay
- STC rate 1
Short Term Example 3

- 4, 16 and 64 QAM
- FEC rate 0.75
- 2 frames delay
- STC rate 1
Short Term Example 4

- 4, 16 and 64 QAM
- FEC rate 0.5 and 0.75
- 2 frames delay
- STC rate 1

![Graph showing goodput vs SNR for different scenarios and precoding methods.](image)

- 4 ANT MATRIX A without precoding
- Ideal precoding without delay
- Ideal precoding with delay
- Codebook short term precoding with delay

6.5 dB difference in performance.
Short Term Example 5

- 4,16 and 64 QAM
- FEC rate 0.5 and 0.75
- 2 frames delay
- STC rate 1
Short Term Example 6

- 4, 16, and 64 QAM
- FEC rate 0.5 and 0.75
- 2 frames delay
- STC rate 1

<table>
<thead>
<tr>
<th>Goodput [bits/carrier]</th>
<th>SNR [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>30</td>
</tr>
<tr>
<td>4.0</td>
<td>25</td>
</tr>
<tr>
<td>3.5</td>
<td>20</td>
</tr>
<tr>
<td>3.0</td>
<td>15</td>
</tr>
<tr>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>2.0</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>0</td>
</tr>
</tbody>
</table>

20 Hz Doppler - 0.2 spatial correlation - CONVOLUTIONAL rate 0.5
- Ideal precoding without delay
- Ideal precoding with delay
- Codebook short term precoding with delay
Long Term Results
Antenna Correlations

• SCM channel model with:
  • 4 lambda antenna spacing
  • 2 degrees Lapacian angular spread
  • 4 antennas makes a total width of ~1.5 m for a 2.5 GHz system.
  • Spatial correlation between adjacent antennas: 0.8624
  • Reference: 3GPP TR 25.996 V6.1.0 or SMC V7.0.

• SUI Channel models
  • Large K-factors are frequent, e.g.
    • SUI-1: 14.0 (linear, 90% cell coverage, 30 degree antenna)
    • SUI-2: 6.9 (same)
Reasoning why transmit antenna covariance matrix and channel mean is frequency independent

- Tx antenna covariance matrix reflects angular power spectrum.
- Angular power spectrum is frequency independent.
- Channel mean comes from a Ricean component.
- With a single Ricean component the channel mean is frequency independent.
Long Term Example 1

- 0.7 spatial correlation
- 6dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 5.5dB gain over open-loop STBC
Long Term Example 2

- 0.2 spatial correlation
- 6dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 4.5dB gain over open-loop STBC
Long Term Example 3

- 0.7 spatial correlation
- 3.5dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 5dB gain over open-loop STBC
Long Term Example 4

- 0.2 spatial correlation
- 3.5dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 4dB gain over open-loop STBC
Long Term Example 5

- 0.7 spatial correlation
- 0dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 3dB gain over open-loop STBC
Long Term Example 6

- 0.2 spatial correlation
- 0dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 3dB gain over open-loop STBC
Long Term Example 7

- 0.7 spatial correlation
- -6dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 2dB gain over open-loop STBC
Long Term Example 8

- 0.2 spatial correlation
- -6dB K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has about 1dB gain over open-loop STBC
Long Term Example 9

- 0.7 spatial correlation
- No K factor
- 2 frames delay
- 4QAM
- FEC rate 0.75
- 70 Hz Doppler

Long term precoding has about 3dB gain over open-loop STBC
Long Term Example 10

- 0.2 spatial correlation
- No K factor
- 2 frames delay
- 4QAM
- FEC rate 0.5
- 70 Hz Doppler

Long term precoding has no gain over open-loop STBC, but no loss either
Summary of Precoding Results

• Short term precoding gains of 6-7 dB for fading rates below 10 Hz using a single CQICH channel.
• Long term precoding gains from 1 to 5.5 dB depending on antenna correlation and K-factor.
• Presence of a modest K-factor, e.g. 0 dB, gives long term precoding gains of 3 dB even for low antenna correlation!
• Long term precoding gains are applicable to the broadband diversity allocation and to the case of high fading rates.