Project	**IEEE 802.16 Broadband Wireless Access Working Group** **<**http://ieee802.org/16**>**
Title	**Codebooks for CL SU and MU MIMO**
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Re:	SDD Session 56 Cleanup, in response to the call for PHY details: "Any parts of Section 11 (PHY) that are incomplete, inconsistent, empty, TBD, or FFS."
Abstract	This document proposes details to be added to Section 11.8 (DL MIMO Transmission Scheme) of IEEE 802.16m-08/003r4. This document proposes a 2-Tx and 4-Tx codebook.
Purpose	Draft for further development of the IEEE 802.16m SDD
Notice	
Release	
Patent Policy	

2Tx and 4Tx Codebook Proposal for SU and MU MIMO

Introduction

This document presents a proposal for codebooks applicable for 2Tx and 4Tx antennas at the BS for adoption in the 802.16m SDD. The objective of this proposal is to achieve a high performance and to be competitive to LTE in terms of performance, feedback overhead and MS implementation complexity.

Proposal

The following is a list of properties that we believe is desired in a codebook and critical to consider when evaluating a codebook for adoption. The choice of a particular codebook depends on performance comparison of codebooks restricted by the following list.

1. **Single codebook:** A single codebook should be adopted as a baseline for use in different antenna correlation and polarization scenarios. At this point we don't see justifiable benefits in supporting a variety of codebooks optimized for different environments.

2. **Codebook size:** The codebook size is fundamentally a tradeoff between performance and search complexity of the MS. 802.16e supports two different codebook sizes. We propose to support a <u>3-bit codebook for 2Tx and a 4-bit codebook for 4Tx antennas</u> respectively. It is observed that there is no significant performance gain in supporting a 6-bit codebook for 4Tx antennas (see IEEE C802.16m-08/836) while increasing the search complexity by at least 4 times compared to a 4-bit codebook.

3. **Codebook search complexity:** The codebook search complexity at the MS should be considered a priority. Note that the search complexity increases with frequency selective PMI feedback and bandwidth. The codebooks in 802.16e are not optimized for reducing search complexity. To contain the search complexity we propose the following properties in a codebook –

   3.1. **Rank Nesting:** The rank nesting property means a rank-1 codebook entry is contained in a rank-2 codebook entry, a rank-2 codebook entry is contained in a rank-3 codebook entry and so on. This is a method that enables an MS to reuse computations for rank-1 for selecting a rank-2 entry and so on. Rank nesting property has not shown to have any impact on throughput performance and should be enabled in a 16m codebook.

   3.2. **8-PSK Alphabet:** Each element of a codebook matrix or vector should be restricted to an 8-PSK alphabet. This feature dramatically reduces the search complexity by eliminating floating-point multiplications and replacing them by conjugations and additions. It has been observed that a restriction to 8-PSK alphabet does not reduce the performance of codebooks.

4. **PA Efficiency (Constant Modulus):** It is important to guarantee that each transmit-antenna at the BS is able to operate with equal power. We propose to use constant modulus elements in the codebook that is sufficient to enable this.

5. **MU-MIMO Support (optional subset restriction):** Unitary MU-MIMO should be supported as a mode in 802.16m. A single codebook should be used to enable both SU-MIMO and unitary MU-MIMO. In the case of MU-MIMO, optionally the BS should be able to restrict the codebook size to 2-bits for 2Tx antennas and to 3-bits for 4-Tx antennas. The exact subset is FFS.

Preferred Codebooks

The proposed codebooks are tabulated in the following. They conform to all the properties listed above. In addition, all the codebook entries for all the ranks are combinations of 8 unique vectors for 2Tx codebook and 16 unique vectors for 4Tx codebook. This enables further simplification in search complexity.

11.8.2.1.2 Closed-loop SU-MIMO

11.8.2.1.2.1 Precoding technique

In FDD and TDD systems, unitary codebook based precoding are supported. The following tables define the codebook for 2Tx and 4Tx antennas.

Table 1: Proposed codebook for 2Tx antennas

index Rank-2 (only index=0,2,4,6)	Rank-k = Column-1:k for k=1,2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ -1 & 1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ \frac{(1+j)}{\sqrt{2}} & \frac{(-1-j)}{\sqrt{2}}\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ \frac{(-1-j)}{\sqrt{2}} & \frac{(1+j)}{\sqrt{2}}\end{bmatrix}$
4	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ \frac{(1-j)}{\sqrt{2}} & \frac{(-1+j)}{\sqrt{2}}\end{bmatrix}$
5	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ \frac{(-1+j)}{\sqrt{2}} & \frac{(1-j)}{\sqrt{2}}\end{bmatrix}$
6	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ j & -j\end{bmatrix}$
7	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ -j & j\end{bmatrix}$

Table 2: Proposed codebook for 4Tx antennas

index Rank-4 (only index 0,4,8,12)	Rank-k = Column-1:k for k=1,2,3,4		Rank-k = Column-1:k for k=1,2,3,4
0	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & 1 & -1 & -1\\ 1 & -1 & -1 & 1\\ 1 & -1 & 1 & -1\end{bmatrix}$	8	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -i & -i & i & i\\ -i & i & i & -i\\ -1 & 1 & -1 & 1\end{bmatrix}$
1	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & -1 & -1 & 1\\ -1 & -1 & 1 & 1\\ -1 & 1 & -1 & 1\end{bmatrix}$	9	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -i & i & i & -i\\ i & i & -i & -i\\ 1 & -1 & 1 & -1\end{bmatrix}$
2	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & -1 & 1 & 1\\ -1 & 1 & 1 & -1\\ 1 & -1 & 1 & -1\end{bmatrix}$	10	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ i & i & -i & -i\\ i & -i & -i & i\\ -1 & 1 & -1 & 1\end{bmatrix}$
3	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & 1 & 1 & -1\\ 1 & 1 & -1 & -1\\ -1 & 1 & -1 & 1\end{bmatrix}$	11	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ i & -i & -i & i\\ -i & -i & i & i\\ 1 & -1 & 1 & -1\end{bmatrix}$
4	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & -1 & 1 & 1\\ -i & i & i & -i\\ -i & i & -i & i\end{bmatrix}$	12	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ i & i & -i & -i\\ 1 & -1 & -1 & 1\\ -i & i & -i & i\end{bmatrix}$
5	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & 1 & 1 & -1\\ i & i & -i & -i\\ i & -i & i & -i\end{bmatrix}$	13	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ i & -i & -i & i\\ -1 & -1 & 1 & 1\\ i & -i & i & -i\end{bmatrix}$
6	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & 1 & -1 & -1\\ i & -i & -i & i\\ -i & i & -i & i\end{bmatrix}$	14	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -i & -i & i & i\\ -1 & 1 & 1 & -1\\ -i & i & -i & i\end{bmatrix}$
7	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -1 & 1 & -1 & -1\\ i & -i & -i & i\\ -i & i & -i & i\end{bmatrix}$	15	$\left(\frac{1}{2}\right)\begin{bmatrix}1 & 1 & 1 & 1\\ -i & i & i & -i\\ 1 & 1 & -1 & -1\\ i & -i & i & -i\end{bmatrix}$