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Codebook issues in 16m CL-SU-MIMO

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1. Introduction

Several types of codebook scheme such as single codebook, scenario-dependant codebooks, and differential codebook have been suggested until now for 16m Closed-loop SU-MIMO.

The adoption of single codebook is very desirable for simplicity if it performs well regardless of channel scenario. But, in reality, it is not possible to design a single codebook that shows robust performance in various correlated channel condition. Because DFT based codebook shows better performance than any other proposed codebooks in spatially correlated channel, whereas 16e legacy codebook shows optimal performance in uncorrelated channel.

Therefore, scenario-dependant multiple codebooks shall be the solution for the performance enhancement in 16m CL-SU-MIMO. BS can indicate what kind of codebook type is to be used for the MS in a certain channel scenario or antenna configuration.

2. Scenario-dependant Multiple Codebooks

It is well known that DFT based codebook shows optimal performance in correlated channel while Chordal distance maximized codebook (IEEE 802.16e codebook) shows optimal performance in uncorrelated channel.

Table 1 shows the performances of various combinations of spatial correlations and codebooks. 802.16e codebook is the best in spatially uncorrelated channel while DFT based codebook gives the best performance in terms of sector throughput.

Table 1. Average sector throughput comparison [6]

	Codebook type	IEEE802.16e (6bit)	Phase-adapted DFT (Max. 5bit : Phase shift 2 bit + basic matrix (4, 6))	3GPP LTE (4bit)	IEEE802.16e (3bit)	DFT + AS (Max.5bit (32,24))
Correlated Channel	Avg. sector throughput	1.685	1.75	1.72	1.61	1.73
	Relative gain	0%	3.9%	2%	-4%	2.7%
Uncorrelated Channel	Avg. sector throughput	1.68	1.64	1.64	1.58	1.675
	Relative gain	0%	-2.4%	-2.4%	-6%	-0.3%

DFT based codebook shall be one of the multiple codebooks for spatially highly correlated channel and other codebooks like 16e codebook shall be selected as one of the multiple codebooks for low correlated channel. Even if there are multiple codebooks, there is no additional complexity for MS to compute PMI compared to when there is single codebook because BS can indicate which codebook is used for SU-MIMO precoding.

3. Conclusion

In this contribution, we discuss MIMO operating scenario and CL-SU-MIMO codebook.

- Multiple codebooks shall be supported.
- DFT based codebook shall be supported for spatially correlated channel.
- BS can indicate which codebook is used for CL-SU-MIMO.

[Remedy 1: Modify the text of 11.8.2.1.2.1 as follow]

In FDD and TDD systems, ~~unitary codebook based precoding are supported~~ precoding based on unitary codebook which is one of multiple codebooks is supported. BS can indicate which codebook is used for closed-loop SU-MIMO precoding.
In TDD systems, sounding based precoding is supported.

[Remedy 2: Add the following texts at the end of 11.8.2.1.2.1]

- 2Tx case: 3 bit codebook (ϕ_i =0, π/4, π/2, 3π/4)

$$\mathbf{W}_0 = \mathbf{P}(\phi_0)\mathbf{W}_{2x2} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$\mathbf{W}_1 = \mathbf{P}(\phi_1)\mathbf{W}_{2x2} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 0.7071 + j0.7071 & -0.7071 - j0.7071 \end{bmatrix}$$

$$\mathbf{W}_2 = \mathbf{P}(\phi_2)\mathbf{W}_{2x2} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$$

$$\mathbf{W}_3 = \mathbf{P}(\phi_3)\mathbf{W}_{2x2} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 0.7071 - j0.7071 & 0.7071 - j0.7071 \end{bmatrix}$$

Precoding Matrix Index	Rank 1	Rank 2
0	$W_0(:,1)$	W_0

1	$W_0(:,2)$	W_1
2	$W_1(:,1)$	W_2
3	$W_1(:,2)$	W_3
4	$W_2(:,1)$	-
5	$W_2(:,2)$	-
6	$W_3(:,1)$	-
7	$W_3(:,2)$	-

Table xxx Codebook for 2Tx CL-SU-MIMO

- 4Tx case: 4 bit codebook (ϕ_i =0, π/8, π/4, 3π/8)

$$\mathbf{W}_0 = \mathbf{P}(\phi_0)\mathbf{W}_{4x4} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

$$\mathbf{W}_1 = \mathbf{P}(\phi_1)\mathbf{W}_{4x4} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.9239+j0.3827 & -0.3827+j0.9239 & -0.9239-j0.3827 & 0.3827-j0.9239 \\ 0.7071+j0.7071 & -0.7071-j0.7071 & 0.7071+j0.7071 & -0.7071-j0.7071 \\ 0.3827+j0.9239 & 0.9239-j0.3827 & -0.3827-j0.9239 & -0.9239+j0.3827 \end{bmatrix}$$

$$\mathbf{W}_2 = \mathbf{P}(\phi_2)\mathbf{W}_{4x4} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.7071+j0.7071 & -0.7071+j0.7071 & -0.7071-j0.7071 & 0.7071-j0.7071 \\ j & -j & j & -j \\ -0.7071+j0.7071 & 0.7071+j0.7071 & 0.7071-j0.7071 & -0.7071-j0.7071 \end{bmatrix}$$

$$\mathbf{W}_3 = \mathbf{P}(\phi_3)\mathbf{W}_{4x4} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.3827+j0.9239 & -0.9239+j0.3827 & -0.3827-j0.9239 & 0.9239-j0.3827 \\ -0.7071+j0.7071 & 0.7071-j0.7071 & -0.7071+j0.7071 & 0.7071-j0.7071 \\ -0.9239-j0.3827 & -0.3827+j0.9239 & 0.9239+j0.3827 & 0.3827-j0.9239 \end{bmatrix}$$

Precoding Matrix Index	Rank 1	Rank 2	Rank 3	Rank 4
0	$W_0(:,1)$	$W_0(:,12)$	$W_0(:,123)$	W_0

1	W_0(:,2)	W_0(:,13)	W_0(:,124)	W_1
2	W_0(:,3)	W_0(:,14)	W_0(:,134)	W_2
3	W_0(:,4)	W_0(:,23)	W_0(:,234)	W_3
4	W_1(:,1)	W_0(:,24)	W_1(:,123)	-
5	W_1(:,2)	W_0(:,34)	W_1(:,124)	-
6	W_1(:,3)	W_2(:,12)	W_1(:,134)	-
7	W_1(:,4)	W_2(:,13)	W_1(:,234)	-
8	W_2(:,1)	W_2(:,14)	W_2(:,123)	-
9	W_2(:,2)	W_2(:,23)	W_2(:,124)	-
10	W_2(:,3)	W_2(:,24)	W_2(:,134)	-
11	W_2(:,4)	W_2(:,34)	W_2(:,234)	-
12	W_3(:,1)	W_1(:,12)	W_3(:,123)	-
13	W_3(:,2)	W_1(:,13)	W_3(:,124)	-
14	W_3(:,3)	W_1(:,14)	W_3(:,134)	-
15	W_3(:,4)	W_1(:,23)	W_3(:,234)	-

Table yyy Codebook for 4Tx CL-SU-MIMO

- 4Tx case: 5 bit codebook (ϕ_i =0, π/16, π/8, 3π/16, π/4, 5π/16, 3π/8, 7π/16)

$$\mathbf{W}_i = \mathbf{P}(\phi_i)\mathbf{W}_{4x4}$$

Precoding Matrix Index	Rank 1	Rank 2	Rank 3	Rank 4
0	W_0(:,1)	W_0(:,12)	W_0(:,123)	W_0
1	W_0(:,2)	W_0(:,13)	W_0(:,124)	W_1
2	W_0(:,3)	W_0(:,14)	W_0(:,134)	W_2
3	W_0(:,4)	W_0(:,23)	W_0(:,234)	W_3
4	W_1(:,1)	W_0(:,24)	W_1(:,123)	W_4
5	W_1(:,2)	W_0(:,34)	W_1(:,124)	W_5
6	W_1(:,3)	W_2(:,12)	W_1(:,134)	W_6
7	W_1(:,4)	W_2(:,13)	W_1(:,234)	W_7
8	W_2(:,1)	W_2(:,14)	W_2(:,123)	-
9	W_2(:,2)	W_2(:,23)	W_2(:,124)	-
10	W_2(:,3)	W_2(:,24)	W_2(:,134)	-

11	$W_2(:,4)$	$W_2(:,34)$	$W_2(:,234)$	-
12	$W_3(:,1)$	$W_4(:,12)$	$W_3(:,123)$	-
13	$W_3(:,2)$	$W_4(:,13)$	$W_3(:,124)$	-
14	$W_3(:,3)$	$W_4(:,14)$	$W_3(:,134)$	-
15	$W_3(:,4)$	$W_4(:,23)$	$W_3(:,234)$	-
16	$W_4(:,1)$	$W_4(:,24)$	$W_4(:,123)$	-
17	$W_4(:,2)$	$W_4(:,34)$	$W_4(:,124)$	-
18	$W_4(:,3)$	$W_6(:,12)$	$W_4(:,134)$	-
19	$W_4(:,4)$	$W_6(:,13)$	$W_4(:,234)$	-
20	$W_5(:,1)$	$W_6(:,14)$	$W_5(:,123)$	-
21	$W_5(:,2)$	$W_6(:,23)$	$W_5(:,124)$	-
22	$W_5(:,3)$	$W_6(:,24)$	$W_5(:,134)$	-
23	$W_5(:,4)$	$W_6(:,34)$	$W_5(:,234)$	-
24	$W_6(:,1)$	$W_1(:,12)$	$W_6(:,123)$	-
25	$W_6(:,2)$	$W_1(:,13)$	$W_6(:,124)$	-
26	$W_6(:,3)$	$W_1(:,14)$	$W_6(:,134)$	-
27	$W_6(:,4)$	$W_1(:,23)$	$W_6(:,234)$	-
28	$W_7(:,1)$	$W_1(:,24)$	$W_7(:,123)$	-
29	$W_7(:,2)$	$W_1(:,34)$	$W_7(:,124)$	-
30	$W_7(:,3)$	$W_3(:,12)$	$W_7(:,134)$	-
31	$W_7(:,4)$	$W_3(:,13)$	$W_7(:,234)$	-

Table zzz Codebook for 4Tx CL-SU-MIMO

Appendix; SU-MIMO DFT based codebook construction rule

We have proposed two step codebook design; basic matrix and its extension [7]. Basic matrix for codebook design of 2 and 4Tx antenna pre-coding is as follows;

1. 2Tx antenna case:

$$\mathbf{W}_{2x2} = [\mathbf{b_0}\,\mathbf{b_1}\,] = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

2. 4Tx antenna case:

$$\mathbf{W}_{4x4} = [\mathbf{b_0}\,\mathbf{b_1}\,\mathbf{b_2}\,\mathbf{b_3}] = \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

We use the following phase shift matrix for the extension of codebook size.

3. 2Tx antenna case:

$$\mathbf{P}_{2x2}(\phi_i) = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi_i} \end{bmatrix}$$

4. 4Tx antenna case:

$$\mathbf{P}_{4x4}(\phi_i) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{j\phi_i} & 0 & 0 \\ 0 & 0 & e^{j2\phi_i} & 0 \\ 0 & 0 & 0 & e^{j3\phi_i} \end{bmatrix}$$

Here, for the case of n extension bits of 2Tx antenna codebook, $\phi_i = \frac{\pi * i}{N}$ (i = 0, …, N-1, where $N = 2^n$), and for 4Tx antenna codebook, $\phi_i = \frac{\pi * i}{2N}$ (i = 0, …, N-1, where $N = 2^n$).

The final extended codebook can be represented as $\mathbf{P}(\phi_i)\mathbf{W}$.

Reference

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[6] C802.16m-08/862, "Introduction of Multiple Codebooks to the 16m System."

[7] C80216m-08/431, ”Codebook based pre-coding MIMO”