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Re:	
Abstract	
Purpose	Adoption of proposed changes into P802.16e ~~Crossed-out indicates deleted text,~~ underlined blue indicates new text change to the Standard
Notice	
Release	
Patent Policy and Procedures	

Compact Codebooks for Transmit Beamforming in Closed-loop MIMO

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1 Introduction

The codebooks tabulated in Section 8.4.5.4.11 consume 53 pages in D6 standard from page 282 to page 334. This is cumbersome for storage, implementation, proofread, and readability. Since 90% of the codebooks are generated from simple operations using IEEE floating point operations. Providing the generating operations is desirable for efficient implementation of the standard. Two remedies are proposed next. The first is to substitute the 53 pages with 13 expressions one per codebook. Each expression uniquely reproduces one tabulated codebook by using IEEE floating point operations and rounding the results to 4 decimal places. The second is to include two pages of expressions in an informative section to enhance the implementation and readability of the standard.

2 Specific Text Changes

2.1 Remedy One — Substitution Tables with Expressions

Replace tables for V(3,1,6), V(4,1,6), V(2,2,3), V(2,2,6), V(3,2,3), V(3,2,6), V(3,3,3), V(3,3,6), V(4,2,6), V(4,3,3), V(4,3,6), V(4,4,3), V(4,4,6), in section 8.4.5.4.11 on page 282-334 of [1] as follows

The three operations are employed and they employs floating point arithmetic in IEEE standard 754, whose final results are rounded to 4 decimal places. The first operation generates a unitary N by N matrix $\mathrm{H}(\mathbf{v})$ using a N vector $\mathbf{v}$ as

$$\mathrm{H}(\mathbf{v}) = \begin{cases} \mathbf{I}, & \mathbf{v} = \mathbf{e}_1 \\ \mathbf{I} - p\,\mathbf{w}\mathbf{w}^H, & \text{otherwise} \end{cases},$$

where $\mathbf{w} = \mathbf{v} - \mathbf{e}_1$ and $\mathbf{e}_1 = \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix}^T$; $p = \dfrac{2}{\left\| \mathbf{w}^H \mathbf{w} \right\|}$; $\mathbf{I}$ is the N by N identity matrix; ^{H} denotes the conjugate transpose operation. Two vector codebooks $V(3,1,6)$ and $V(4,1,6)$ are generated as follows. All the vector codewords $\mathbf{v}_i$, $i = 2, \cdots, 2^L$, are derived from the first codeword $\mathbf{v}_1$ as

$$\tilde{\mathbf{v}}_i = \mathrm{H}(\mathbf{s}) Q^i(\mathbf{u}) \mathrm{H}^H(\mathbf{s}) \mathbf{v}_1, \text{ for } i = 2, \cdots, 2^L,$$

$$\mathbf{v}_i = \tilde{\mathbf{v}}_i e^{-j\phi_i}, \text{ for } i = 2, \cdots, 2^L,$$

where $Q^i(\mathbf{u}) = \mathrm{diag}\left(e^{j\frac{2\pi}{2^L} u_1 i}, \cdots, e^{j\frac{2\pi}{2^L} u_{N_t} i} \right)$ is a diagonal matrix; $\mathbf{u} = \begin{bmatrix} u_1 & \cdots & u_{N_t} \end{bmatrix}$ is an integer vector;

$$\mathbf{v}_1 = \frac{1}{\sqrt{N_t}} \begin{bmatrix} 1 & e^{j\frac{2\pi}{N_t}} & \cdots & e^{j\frac{2\pi}{N_t}(N_t - 1)} \end{bmatrix}^T$$

; ϕ_i is the phase of the first entry of $\tilde{\mathbf{v}}_i$. The parameters for the generation of $V(3,1,6)$ and $V(4,1,6)$ are listed in Table 289j.

Table 289j Generating parameters for $V(3,1,6)$ and $V(4,1,6)$

N_t	L	$\mathbf{u}$ in $Q^i(\mathbf{u})$	$\mathbf{s}$ in $\mathrm{H}(\mathbf{s})$
3	6	$[1 \quad 26 \quad 57]$	$[1.2518 - j0.6409,\ -0.4570 - j0.4974,\ 0.1177 + j0.2360]^T$
4	6	$[1 \quad 45 \quad 22 \quad 49]$	$[1.3954 - j0.0738,\ 0.0206 + j0.4326,\ -0.1658 - j0.5445,\ 0.5487 - j0.1599]^T$

The second operation generates a N by $M+1$ unitary matrix from a unit N vector and a unitary $N-1$ by M matrix as

$$\mathrm{HC}\left(\mathbf{v}_N, \mathbf{A}_{(N-1)\times M}\right) = \mathrm{H}(\mathbf{v}_N)\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & & & \\ \vdots & & \mathbf{A}_{(N-1)\times M} & \\ 0 & & & \end{bmatrix},$$

where $N-1 \geq M$; the $N-1$ by M matrix unitary matrix has property $\mathbf{A}^H\mathbf{A} = \mathbf{I}$. The third operation generates a N by M matrix from a unit N vector, $\mathbf{v}_N$, by taking the last $N-1$ columns of $\mathrm{H}(\mathbf{v}_N)$ as

$$\mathrm{HE}(\mathbf{v}_N) = \mathrm{H}(\mathbf{v}_N)_{:,2:N}.$$

The three operations jointly generate eleven matrix codebooks from vector codebooks as shown in Table 289k, where each entry is the generating operation of one codebook.

Table 289k Operations to generate codebooks $V(N_t, S, L)$ for N_t = 2, 3, 4, S = 2, 3, 4, and L = 3 and 6.

N_t, L \ S	2	3	4
2, 3	$\mathrm{H}(V(2,1,3))$		
3, 3	$\mathrm{HE}(V(3,1,3))$	$\mathrm{H}(V(3,1,3))$	
4, 3		$\mathrm{HE}(V(4,1,3))$	$\mathrm{H}(V(4,1,3))$
2, 6	$\mathrm{H}(V(2,1,6))$		
3, 6	$\mathrm{HC}(V(3,1,3), V(2,1,3))$	$\mathrm{HC}(V(3,1,3), \mathrm{H}(V(2,1,3)))$	
4, 6	$\mathrm{HC}(V(4,1,3), V(3,1,3))$	$\mathrm{HE}(V(4,1,6))$	$\mathrm{H}(V(4,1,6))$

The set notation $V(N_t,1,L)$ in the input arguments of the operations denotes that each vector in the codebook $V(N_t,1,L)$ is sequentially taken as an input to the operations. The output of the operation with one or more codebooks as input arguments is also a codebook. For example, in $\mathrm{HC}(V(3,1,3), \mathrm{H}(V(2,1,3)))$, HC has two codebooks as input. The first is $V(3,1,3)$ with 8 vectors and the second is $\mathrm{H}(V(2,1,3))$ with 8 2 by 2 matrixes, which are computed from $V(2,1,3)$. The feedback index is constructed by sequentially concatenating all the indexes of the input argument vector codebooks in binary format. For example, the feedback index of $\mathrm{HC}(V(3,1,3), \mathrm{H}(V(2,1,3)))$ is constructed as $i_2 j_2$, where i_2 and j_2 are the indexes of the vectors in codebooks $V(3,1,3)$ and $V(2,1,3)$ in binary format respectively; $_2$ denotes binary format for the indexes.

2.2 Remedy Two — Adding an Informative Subsection

Add at the end of section 8.4.5.4.11 on page 334 of [1] as follows

[This subsection is informative] Thirteen codebooks tabulated in tables from 298j to 298ad are generated from operations depicted as follows. The operation employs floating point arithmetic in IEEE standard 754, whose final results are rounded to 4 decimal places. An operation, $\mathrm{H}(\mathbf{v})$, is defined. It generates a unitary N by N matrix using a N vector $\mathbf{v}$ as

$$\mathrm{H}(\mathbf{v}) = \begin{cases} \mathbf{I}, & \mathbf{v} = \mathbf{e}_1 \\ \mathbf{I} - p\,\mathbf{w}\mathbf{w}^H, & \text{otherwise} \end{cases},$$

where $\mathbf{w} = \mathbf{v} - \mathbf{e}_1$ and $\mathbf{e}_1 = \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix}^T$; $p = \dfrac{2}{\left\|\mathbf{w}^H\mathbf{w}\right\|}$; $\mathbf{I}$ is the N by N identity matrix; ^{H} denotes the conjugate transpose operation. Two vector codebooks $V(3,1,6)$ and $V(4,1,6)$ are generated as follows. All the vector codewords $\mathbf{v}_i$, $i = 2,\cdots,2^L$, are derived from the first codeword $\mathbf{v}_1$ as

$$\tilde{\mathbf{v}}_i = \mathrm{H}(\mathbf{s})Q^i(\mathbf{u})\mathrm{H}^H(\mathbf{s})\mathbf{v}_1, \text{ for } i = 2,\cdots,2^L,$$

$$\mathbf{v}_i = \tilde{\mathbf{v}}_i e^{-j\phi_i}, \text{ for } i = 2,\cdots,2^L,$$

where $Q^i(\mathbf{u}) = \mathrm{diag}\left(\mathrm{e}^{j\frac{2\pi}{2^L}u_1 i}, \cdots, \mathrm{e}^{j\frac{2\pi}{2^L}u_{N_t} i} \right)$ is a diagonal matrix; $\mathbf{u} = \begin{bmatrix} u_1 & \cdots & u_{N_t} \end{bmatrix}$ is an integer vector;

$\mathbf{v}_1 = \dfrac{1}{\sqrt{N_t}}\begin{bmatrix} 1 & \mathrm{e}^{j\frac{2\pi}{N_t}} & \cdots & \mathrm{e}^{j\frac{2\pi}{N_t}(N_t-1)} \end{bmatrix}^T$; ϕ_i is the phase of the first entry of $\tilde{\mathbf{v}}_i$. The parameters for the generation of $V(3,1,6)$ and $V(4,1,6)$ are listed in Table 289j.

Table 289j Generating parameters for $V(3,1,6)$ and $V(4,1,6)$

N_t	L	$\mathbf{u}$ in $Q^i(\mathbf{u})$	$\mathbf{s}$ in $\mathrm{H}(\mathbf{s})$
3	6	$\begin{bmatrix} 1 & 26 & 57 \end{bmatrix}$	$\begin{bmatrix} 1.2518 - j0.6409, & -0.4570 - j0.4974, & 0.1177 + j0.2360 \end{bmatrix}^T$
4	6	$\begin{bmatrix} 1 & 45 & 22 & 49 \end{bmatrix}$	$\begin{bmatrix} 1.3954 - j0.0738, & 0.0206 + j0.4326, & -0.1658 - j0.5445, & 0.5487 - j0.1599 \end{bmatrix}^T$

The second operation generates a N by $M+1$ unitary matrix from a unit N vector and a unitary $N-1$ by M matrix as

$$\mathrm{HC}(\mathbf{v}_N, \mathbf{A}_{(N-1)\times M}) = \mathrm{H}(\mathbf{v}_N)\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & & & \\ \vdots & & \mathbf{A}_{(N-1)\times M} & \\ 0 & & & \end{bmatrix},$$

where $N-1 \geq M$; the $N-1$ by M matrix unitary matrix has property $\mathbf{A}^H\mathbf{A} = \mathbf{I}$. The third operation generates a N by M matrix from a unit N vector, $\mathbf{v}_N$, by taking the last $N-1$ columns of $\mathrm{H}(\mathbf{v}_N)$ as

$$\mathrm{HE}(\mathbf{v}_N) = \mathrm{H}(\mathbf{v}_N)_{:,2:N}.$$

The three operations jointly generate eleven matrix codebooks from vector codebooks as shown in Table 289k, where each entry is the generating operation of one codebook.

Table 289k Operations to generate codebooks $V(N_t, S, L)$ for N_t = 2, 3, 4, S = 2, 3, 4, and L = 3 and 6.

S / N_t, L	2	3	4

2, 3	$\mathrm{H}(V(2,1,3))$		
3, 3	$\mathrm{HE}(V(3,1,3))$	$\mathrm{H}(V(3,1,3))$	
4, 3		$\mathrm{HE}(V(4,1,3))$	$\mathrm{H}(V(4,1,3))$
2, 6	$\mathrm{H}(V(2,1,6))$		
3, 6	$\mathrm{HC}(V(3,1,3),V(2,1,3))$	$\mathrm{HC}(V(3,1,3),\mathrm{H}(V(2,1,3)))$	
4, 6	$\mathrm{HC}(V(4,1,3),V(3,1,3))$	$\mathrm{HE}(V(4,1,6))$	$\mathrm{H}(V(4,1,6))$

The set notation $V(N_t,1,L)$ in the input arguments of the operations denotes that each vector in the codebook $V(N_t,1,L)$ is sequentially taken as an input to the operations. The output of the operation with one or more codebooks as input arguments is also a codebook. For example, in $\mathrm{HC}(V(3,1,3),\mathrm{H}(V(2,1,3)))$, HC has two codebooks as input. The first is $V(3,1,3)$ with 8 vectors and the second is $\mathrm{H}(V(2,1,3))$ with 8 2 by 2 matrixes, which are computed from $V(2,1,3)$. The feedback index is constructed by sequentially concatenating all the indexes of the input argument vector codebooks in binary format. For example, the feedback index of $\mathrm{HC}(V(3,1,3),\mathrm{H}(V(2,1,3)))$ is constructed as $i_2 j_2$, where i_2 and j_2 are the indexes of the vectors in codebooks $V(3,1,3)$ and $V(2,1,3)$ in binary format respectively; $_2$ denotes binary format for the indexes.

References:

[1] IEEE P802.16e/D5a Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, 2004.

[2] Q. Li, *et al*., “Improved feedback for MIMO precoding,” IEEE C80216e-04/527r4, 2004.