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Abstract	For 3 or 4 BS antenna systems when STC matrix A and B with antenna grouping are used together with closed loop MIMO precoding there is no optimized codebook defined in the standard. A proposal for the corresponding codebook is thus presented in this contribution together with simulation results.
Purpose	Adoption of the proposed text into P802.16e
Notice	
Release	
Patent Policy and Procedures	

Closed Loop MIMO Codebook for STC Matrix A and B

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1 Introduction

In 802.16e/D6 [1] there are at least two distinct transmitter structures for providing closed loop MIMO encoding. These are the spatial multiplexing with antenna selection or codebook precoding, which can provide spatial rates up to four and the Alamouti encoding together with antenna grouping which can provide a spatial rate of one or two.

The closed loop MIMO precoding codebooks in 802.16e/D6 [1] are designed and optimized for the use with spatial multiplexing. However, closed loop MIMO precoding can also be used together with Alamouti encoding with antenna grouping [1]. In this case, the precoding operation is applied after the antenna grouping operation. The problem is that there is no codebook defined in 802.16e/D6 for this mode of operation although the spatial multiplexing codebook can in principle be used.

However, as is shown in this contribution, the existing codebooks which are optimized for spatial multiplexing (STC matrix C), gives only a small or no gain when used together with STC matrix A or B plus antenna grouping. This can be explained by the fact that the current codebooks are "beamforming codebooks", which are suitable for spatial multiplexing systems but do not take into account the space-time diversity structure of the Alamouti encoders in its design.

In this contribution we propose a codebook, compact in its description and designed to be used with 3 or 4 BS antenna systems when STC matrix A and B plus antenna grouping is used. This codebook is optimized for this type of operation and when compared using the existing codebook in 802.16e/D6 it shows significant gains.

2 The new codebook and its use

We propose two codebooks, one for the 4 BS antenna systems and one for 3 BS antenna systems. Hence, the same codebook is used independently if matrix A or matrix B STC encoders are used. However, the MSS selection criteria will depend on which STC matrix is used for the transmission but note that the selection criteria are not part of the standard. Since the number of STC output streams is equal to the number of transmit antennas, the precoding matrices will be square. The suggested precoding matrices are diagonal and can thus be compactly described and stored in memory. Also, the precoding operation becomes a simple scalar multiplication per antenna signal.

The operation of the new codebook is the same as for the codebook based on spatial multiplexing for closed loop MIMO. The MSS selects a preferred matrix from the codebook and signals the corresponding codebook index to the BS. The antenna grouping (AG) selection and precoding (PRC) matrix selection may or may not be done jointly, which allows the flexibility to have different reporting periods for the AG selection and the PRC selection. When both AG and PRC are selected in the MIMO Compact DL-MAP IE, it is implicitly assumed that both BS and MSS use the codebook proposed in this contribution.

2.1 Codebook for 4 antenna, STC matrix B

The spatial rate for this encoder is two and hence the two groups of Alamouti space time encoded signals will interfere with each other in the receiver. The output from the antenna grouping operation is 4 streams and there are 4 transmit antennas, so all the elements in the proposed codebook set are 4 by 4 matrices. According to [2], it is sufficient to consider the following precoding matrix structure

$$\begin{pmatrix} c_1 e^{j\theta} & 0 & 0 & 0 \\ 0 & c_2 & 0 & 0 \\ 0 & 0 & c_3 & 0 \\ 0 & 0 & 0 & c_4 \end{pmatrix} \qquad (1)$$

where $c_i \quad i = 1,2,3,4$ are real valued and θ is a phase which is selected to make the interference between the two subspaces corresponding to the two Alamouti encoded signal groups as small as possible. It was shown in [2] that it is sufficient if one of the four diagonal elements of the precoding matrix is complex valued, nothing is gained by adding more complex valued coefficients.

The elements $c_i \quad i = 1,2,3,4$ and θ in (1) are selected using a 6 bit CQICH. The variables $c_i \quad i = 1,2,3,4$ can take the values 1, $\sqrt{2/17} \approx 0.343$ or $\sqrt{32/17} \approx 1.372$ and the phase angle θ is selected from the set 0°, ±10° and ±60°. Note that these phases do not sample the whole 360° angle space. The reason is due to the preceding antenna grouping, which has effectively reduced the useful angle space (in other words, angles $|\theta| > 90^\circ$ are obsolete since they would reduce the SNR in the receiver and can thus be removed, thereby increasing the resolution in the useful range of angles).

Not all possible combinations of $c_i \quad i = 1,2,3,4$ can be used in the codebook, since the total radiated power should be invariant to the selection, hence $c_1^2 + c_2^2 + c_3^2 + c_4^2 = 4$ must hold for all matrices in the codebook.
The proposed codebook can be seen in detail in Section 5.

At the MSS, the selection of a codebook matrix can be determined based on any desired criteria such as minimum BER, minimum mean square error or minimized cross interference between the two Alamouti encoded signal groups. The selection can be made jointly with the antenna grouping selection or separately, that is, antenna grouping selection is performed first and then the best possible precoding matrix is selected given the antenna grouping selection. This allows a use of different CQICH reporting periods for the precoder and the antenna grouping, if desired. Furthermore, more advanced selection methods (filtering, prediction …) can also be used to reduce the effects of feedback delay.

2.2 Codebook for 4 antenna, STC matrix A

For this mode, we use the same codebook as in the STC matrix B case in Section 2.1. However, in this mode, the spatial rate is one and therefore, there is no cross-interference between the two groups of antenna signals to consider in the receiver. Therefore the value of the phase angle θ has no impact on the performance and need not be taken into account in the selection criteria. Also, the selection of the precoding for antenna[1] 1 and 2 can be made independently of the precoding selection for antenna 3 and 4.

To make the scheme more robust to feedback delay, the following selection criteria can be adopted. At the MSS, the index of the transmission matrix can be determined based as follows; if

[1] Where it was assumed that antenna 1 and 2 are grouped to one Alamouti encoded signal and 3 and 4 to the other. This is of course dependent on the selection in the preceding antenna grouping operation.

$$\begin{array}{ll} |h_1|^2 > T|h_2|^2 & \text{choose } c_1 = \sqrt{32/17},\ c_2 = \sqrt{2/17} \\ |h_1|^2 > T^{-1}|h_2|^2 & \text{choose } c_1 = \sqrt{2/17},\ c_2 = \sqrt{32/17} \\ \text{otherwise} & \text{choose } c_1 = 1,\ c_2 = 1 \end{array}$$

where $T>1$ is a threshold parameter and h_1, h_2 are the channels from BS antenna 1 and 2 respectively (where these two antennas transmit one Alamouti encoded signal group. Hence they may not correspond to the physical antenna 1 and 2 due to the preceding antenna grouping operation). A similar selection is made for antenna 3 and 4 independently of the selection for antenna 1 and 2. This scheme is robust to feedback delays since when $|h_1|^2 \approx |h_2|^2$ open loop ($c_1 = 1, c_2 = 1$) transmission is used. So, in effect, when there is a large uncertainty about the order relation between the two channels in the future (i.e. $|h_1|^2 \approx |h_2|^2$), the open loop scheme is selected.

2.3 Codebook for 3 antenna, STC matrix B

In this mode, the spatial rate is two, so there is cross-interference to consider in the receiver. However, it can be seen from the discussion in [2] that complex antenna weights has no impact on the performance and we propose the matrix structure

$$\begin{pmatrix} c_1 & 0 & 0 \\ 0 & c_2 & 0 \\ 0 & 0 & c_3 \end{pmatrix} \qquad (2)$$

where $c_i, i = 1,2,3$ are real valued. The variables $c_i \quad i = 1,2,3$ can take the values $\sqrt{2/17} \approx 0.343$, $\sqrt{32/17} \approx 1.372$ or 1 under the constraint $c_1^2 + c_2^2 + c_3^2 = 3$, hence 3 bits are needed to select a precoding matrix from the codebook. At the MSS, the index of the transmission matrix can be determined based on for example minimizing BER, minimum square error or maximizing SNR

2.4 Codebook for 3 antenna, STC matrix A

For this mode, we reuse the codebook for 3 antenna STC matrix B in Section 2.3.

3 Simulation results

The codebook performance is evaluated by simulations. To make comparisons, we compare with the case without precoding (antenna grouping only). We also compare with using the existing codebook for spatial multiplexing, to give information about the best possible performance with the only codebook currently available in the standard.

The channel model is ITU pedestrian A, 3 km/h, with a transmit correlation of 0.2 and receive correlation of 0. The feedback delay for both the antenna grouping feedback and the precoding matrix feedback is 2 frames, i.e. 10 ms. The system bandwidth is 10 MHz and the packet size is 64 byte mapped to a single AMC band with a 2-by-6 block. The feedback error probability is 1%. When the number of spatial streams is two, the MMSE receiver is used; otherwise the ML receiver is used.

3.1 4 antenna matrix B

Figure 1 shows the packet error rate comparison for different modulation and code rates. Clearly the new codebook improves the performance over using antenna grouping only. Furthermore, the spatial multiplexing codebook in [1] shows only a small gain over antenna grouping. The performance gain of the new codebook compared to antenna grouping only at 10% PER varies between 0.4 dB for QPSK, Rate _ to 0.7 dB for 64QAM, rate _.

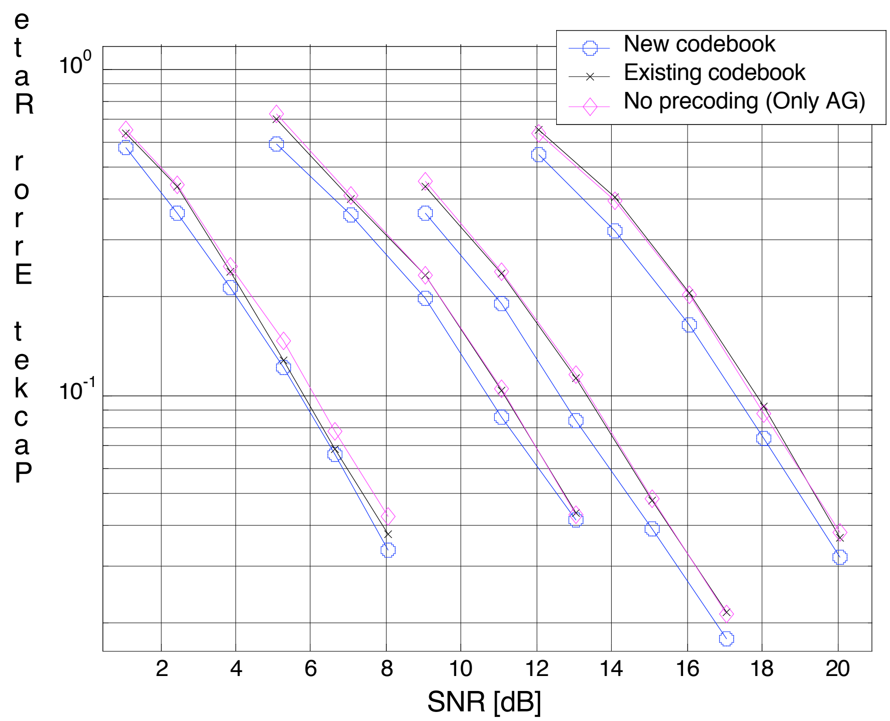

Figure 1 Simulation results for a 4x2 MIMO system with antenna grouping only and with antenna grouping plus codebook precoding. The "Existing codebook" is the 4-by-4 matrix codebook in [1] using 6 bit feedback. The labels stand for **A**: QPSK, Rate _, **B**: 16QAM, Rate _, **C**: 64QAM, Rate _ and finally **D**: 64QAM, Rate _.

3.2 4 antenna matrix A

The simulation results for the 4x1 MISO system with matrix A STC encoder is shown in Figure 2 below. The gain of the new codebook over no precoding (antenna grouping only) is about 0.7 dB at PER 10% for the rate _ transmissions.

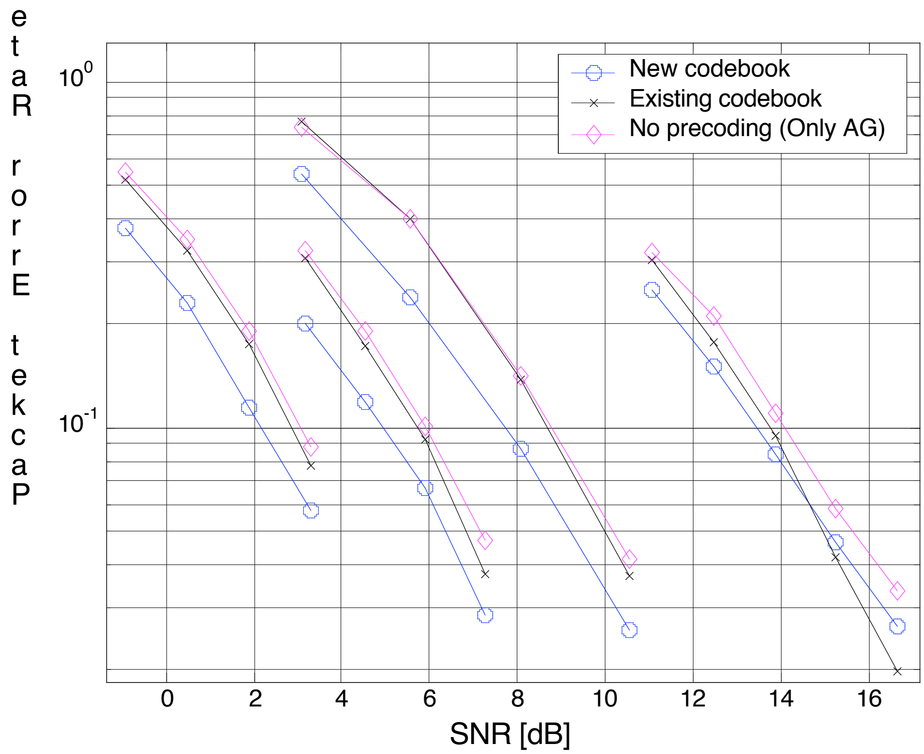

Figure 2 Simulation results for a 4x1 MISO system with antenna grouping only and with antenna grouping plus codebook precoding. The "Existing codebook" is the 4-by-4 matrix codebook in [1] using 6 bit feedback. The labels stand for **A**: QPSK, Rate _, **B**: 16QAM, Rate _, **C**: 64QAM, Rate _ and finally **D**: 64QAM, Rate _.

3.3 3 antenna matrix B

For the 3x2 MIMO system with STC matrix B the performance improvement for the proposed codebook over the spatial multiplexing codebook ranges between 1.5 dB and 0.9 dB at PER 10% for the particular modulation and coding settings in Figure 3.

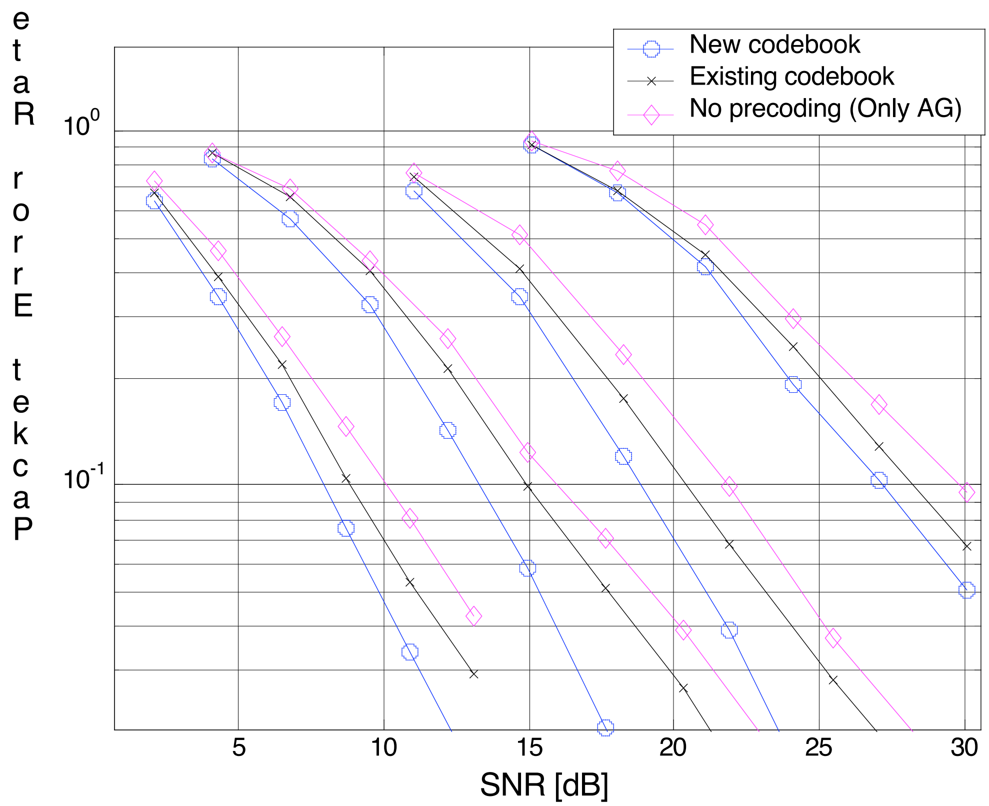

Figure 3 Simulation results for a 3x2 MIMO system with antenna grouping only and with antenna grouping plus codebook precoding. The "Existing codebook" is the 3-by-3 matrix codebook in [1] using 3 bit feedback. The labels stand for **A**: QPSK, Rate _, **B**: 16QAM, Rate _, **C**: 64QAM, Rate _ and finally **D**: 64QAM, Rate _.

3.4 3 antenna matrix A

For the 3x1 MISO system with STC matrix A we see the simulation results in Figure 4 where the gain for the proposed codebook over the spatial multiplexing codebook varies between 1.5 dB and 1.1 dB at PER 10%.

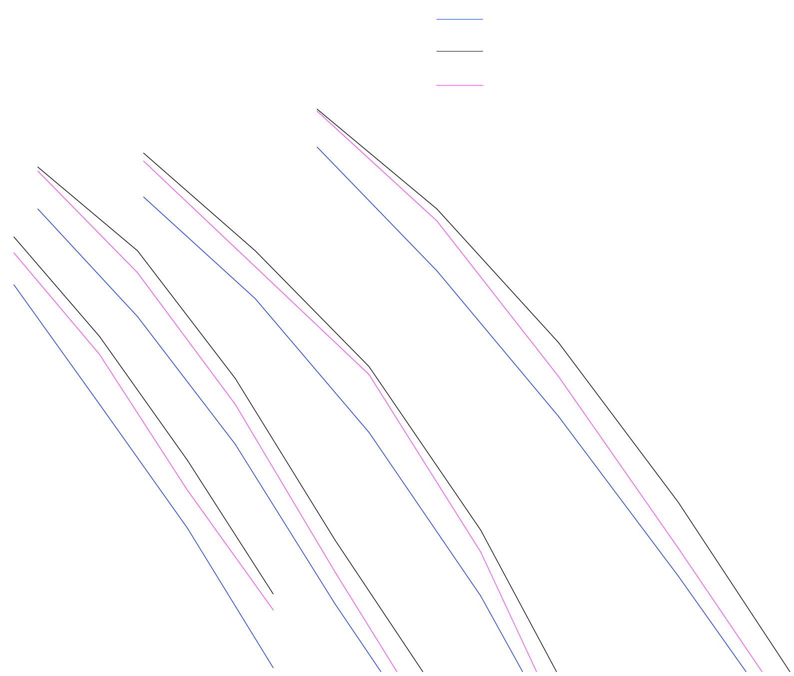

Figure 4 Simulation results for a 3x1 MISO system with antenna grouping only and with antenna grouping plus codebook precoding. The "Existing codebook" is the 3-by-3 matrix codebook in [1] using 3 bit feedback. The labels stand for **A**: QPSK, Rate _, **B**: 16QAM, Rate _, **C**: 64QAM, Rate _ and finally **D**: 64QAM, Rate _. Note that the existing codebook shows worse performance than without precoding at all.

4 Summary

The proposed codebooks designed for 3 and 4 TX antenna BS using STC matrix A and B gives for the simulated modulation and coding settings up to 1.5 dB gain over antenna grouping (no precoding) at PER 10%. The codebooks can be compactly described and stored since the precoding matrices are diagonal, which also a simple scalar multiplication in the precoding operation.

5 Specific text changes

[Modify the text in the beginning of 8.4.5.4.11 as suggested in the following]

8.4.5.4.11 ~~MIMO f~~Feedback for ~~transmit beamforming~~MIMO codebook precoding

Codebooks are defined for the feedback of MIMO transmit ~~beamforming~~precoding with STC matrix A and B with antenna grouping or STC matrix C. These~~, whose codeword~~code words may be employed as the ~~beamforming~~ precoding matrix in MIMO precoding in 8.4.8.3.6. The codebook for 4 antenna and 3 antenna BS using antenna grouping and when the number of STC output streams equals the number of BS transmitter antennas consists of diagonal matrices. The diagonal elements are listed in Table NNNa and Table NNNb respectively. An all other cases, the codebooks are listed in Tables 298g to 298ad. ~~The vector codebooks for 2x1, 3x1,~~
~~and 4x1 with 3 bit feedback index are listed in Table 299a, Table 299b, and Table 299c~~ ~~,~~

[End of "Modify the text in the beginning of 8.4.5.4.11 as suggested in the following"]

[Add the following tables in section 8.4.5.4.11]

Table NNNa 6 bit code-book for 4 TX antenna BS using antenna grouping

Index	W_{11}	W_{22}	W_{33}	W_{44}
w1	1	1	1	1
w2	1	1	$\sqrt{2/17}$	$\sqrt{32/17}$
w3	1	1	$\sqrt{32/17}$	$\sqrt{2/17}$
w4	$\sqrt{2/17}$	$\sqrt{32/17}$	1	1
w5	$\sqrt{32/17}$	$\sqrt{2/17}$	1	1
w6	1	$\sqrt{2/17}$	1	$\sqrt{32/17}$
w7	1	$\sqrt{32/17}$	1	$\sqrt{2/17}$
w8	$\sqrt{2/17}$	1	$\sqrt{32/17}$	1
w9	$\sqrt{32/17}$	1	$\sqrt{2/17}$	1
w10	1	$\sqrt{2/17}$	$\sqrt{32/17}$	1
w11	1	$\sqrt{32/17}$	$\sqrt{2/17}$	1
w12	$\sqrt{2/17}$	1	1	$\sqrt{32/17}$
w13	$\sqrt{32/17}$	1	1	$\sqrt{2/17}$
w14	$e^{j\pi/18}$	1	1	1
w15	$e^{j\pi/18}$	1	$\sqrt{2/17}$	$\sqrt{32/17}$
w16	$e^{j\pi/18}$	1	$\sqrt{32/17}$	$\sqrt{2/17}$
w17	$\sqrt{2/17}\ e^{j\pi/18}$	$\sqrt{32/17}$	1	1
w18	$\sqrt{32/17}\ e^{j\pi/18}$	$\sqrt{2/17}$	1	1
w19	$e^{j\pi/18}$	$\sqrt{2/17}$	1	$\sqrt{32/17}$
w20	$e^{j\pi/18}$	$\sqrt{32/17}$	1	$\sqrt{2/17}$
w21	$\sqrt{2/17}\ e^{j\pi/18}$	1	$\sqrt{32/17}$	1
w22	$b\,e^{j\pi/18}$	1	$\sqrt{2/17}$	1
w23	$e^{j\pi/18}$	$\sqrt{2/17}$	$\sqrt{32/17}$	1
w24	$e^{j\pi/18}$	$\sqrt{32/17}$	$\sqrt{2/17}$	1
w25	$\sqrt{2/17}\ e^{j\pi/18}$	1	1	$\sqrt{32/17}$
w26	$\sqrt{32/17}\ e^{j\pi/18}$	1	1	$\sqrt{2/17}$
w27	$e^{-j\pi/18}$	1	1	1
w28	$e^{-j\pi/18}$	1	$\sqrt{2/17}$	$\sqrt{32/17}$
w29	$e^{-j\pi/18}$	1	$\sqrt{32/17}$	$\sqrt{2/17}$
w30	$\sqrt{2/17}\ e^{-j\pi/18}$	$\sqrt{32/17}$	1	1
w31	$\sqrt{32/17}\ e^{-j\pi/18}$	$\sqrt{2/17}$	1	1

w32	$e^{-j\pi/18}$	$\sqrt{2/17}$	1	$\sqrt{32/17}$
w33	$e^{-j\pi/18}$	$\sqrt{32/17}$	1	$\sqrt{2/17}$
w34	$\sqrt{2/17}$ $e^{-j\pi/18}$	1	$\sqrt{32/17}$	1
w35	$\sqrt{32/17}$ $e^{-j\pi/18}$	1	$\sqrt{2/17}$	1
w36	$e^{-j\pi/18}$	$\sqrt{2/17}$	$\sqrt{32/17}$	1
w37	$e^{-j\pi/18}$	$\sqrt{32/17}$	$\sqrt{2/17}$	1
w38	$\sqrt{2/17}$ $e^{-j\pi/18}$	1	1	$\sqrt{32/17}$
w39	$\sqrt{32/17}$ $e^{-j\pi/18}$	1	1	$\sqrt{2/17}$
w40	$e^{j\pi/3}$	1	1	1
w41	$e^{j\pi/3}$	1	$\sqrt{2/17}$	$\sqrt{32/17}$
w42	$e^{j\pi/3}$	1	$\sqrt{32/17}$	$\sqrt{2/17}$
w43	$\sqrt{2/17}$ $e^{j\pi/3}$	$\sqrt{32/17}$	1	1
w44	$\sqrt{32/17}$ $e^{j\pi/3}$	$\sqrt{2/17}$	1	1
w45	$e^{j\pi/3}$	$\sqrt{2/17}$	1	$\sqrt{32/17}$
w46	$e^{j\pi/3}$	$\sqrt{32/17}$	1	$\sqrt{2/17}$
w47	$\sqrt{2/17}$ $e^{j\pi/3}$	1	$\sqrt{32/17}$	1
w48	$\sqrt{32/17}$ $e^{j\pi/3}$	1	$\sqrt{2/17}$	1
w49	$e^{j\pi/3}$	$\sqrt{2/17}$	$\sqrt{32/17}$	1
w50	$e^{j\pi/3}$	$\sqrt{32/17}$	$\sqrt{2/17}$	1
w51	$\sqrt{2/17}$ $e^{j\pi/3}$	1	1	$\sqrt{32/17}$
w52	$\sqrt{32/17}$ $e^{j\pi/3}$	1	1	$\sqrt{2/17}$
w53	$e^{-j\pi/3}$	1	1	1
w54	$e^{-j\pi/3}$	1	$\sqrt{2/17}$	$\sqrt{32/17}$
w55	$e^{-j\pi/3}$	1	$\sqrt{32/17}$	$\sqrt{2/17}$
w56	$\sqrt{2/17}$ $e^{-j\pi/3}$	$\sqrt{32/17}$	1	1

w57	$\sqrt{32/17}$ $e^{-j\pi/3}$	$\sqrt{2/17}$	1	1
w58	$e^{-j\pi/3}$	$\sqrt{2/17}$	1	$\sqrt{32/17}$
w59	$e^{-j\pi/3}$	$\sqrt{32/17}$	1	$\sqrt{2/17}$
w60	$\sqrt{2/17}$ $e^{-j\pi/3}$	1	$\sqrt{32/17}$	1
w61	$\sqrt{32/17}$ $e^{-j\pi/3}$	1	$\sqrt{2/17}$	1
w62	$e^{-j\pi/3}$	$\sqrt{2/17}$	$\sqrt{32/17}$	1
w63	$e^{-j\pi/3}$	$\sqrt{32/17}$	$\sqrt{2/17}$	1
w64	$\sqrt{2/17}$ $e^{-j\pi/3}$	1	1	$\sqrt{32/17}$

Table NNNb Interpretation of codeword 0b101110-0b110110 in Table 298 e in the case of 3 antenna BS precoding using antenna grouping

Value	W_{11}	W_{22}	W_{33}
0b101110	1	1	1
0b101111	1	$\sqrt{2/17}$	$\sqrt{32/17}$
0b110000	1	$\sqrt{32/17}$	$\sqrt{2/17}$
0b110001	$\sqrt{2/17}$	1	$\sqrt{32/17}$
0b110010	$\sqrt{32/17}$	1	$\sqrt{2/17}$
0b110011	$\sqrt{2/17}$	$\sqrt{32/17}$	1
0b110100	$\sqrt{32/17}$	$\sqrt{2/17}$	1
0b110101	Reserved		
0b110110	Reserved		

[End of "Add the following tables in section 8.4.5.4.11 "]

6 References

[1] IEEE P802.16e/D6 "Air interface for Fixed and Mobile Broadband Wireless Access Systems- Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operations in Licensed Bands", 2004.
[2] M.Wennström, B. Popovic, "Closed Loop Precoding for STC", IEEE C802.16e-04/451r1.