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(54) Title: CHANNEL STATE INFORMATION (CSI) FEEDBACK AND CODEBOOK SUBSAMPLING

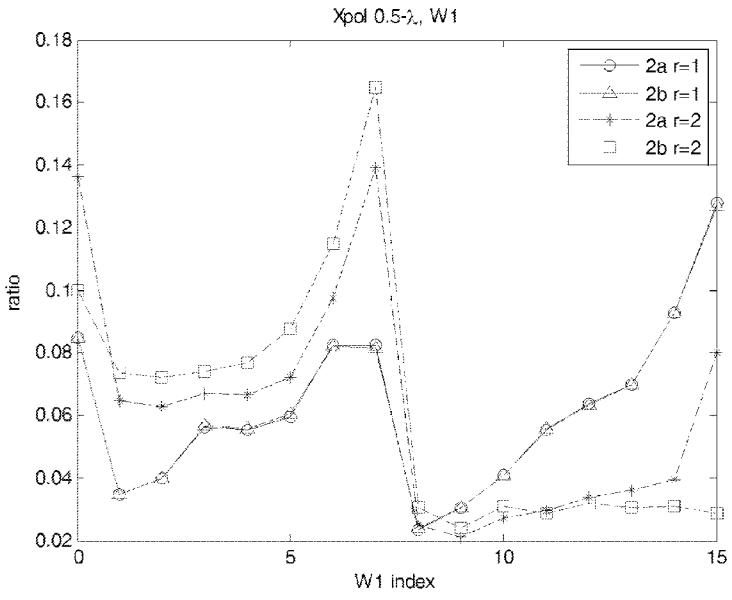


FIG. 1

(57) Abstract: A method implemented in a base station used in a wireless communications system is disclosed. The method comprises receiving, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1. Other methods, apparatuses, and systems also are disclosed.

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Channel State Information (CSI) Feedback and Codebook Subsampling

[0001] This application claims the benefit of U.S. Provisional Application No. 61/832,635, entitled "CSI Feedback and Subsampling of 4-Tx Codebook," filed on June 7, 2013, and U.S. Provisional Application No. 61/864,082, entitled "Subsampling of 4-Tx Codebook," filed on August 9, 2013, the contents of both of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to the codebook for wireless or mobile communications systems and, more particularly, to feedback information for the codebook.

[0003] **1. Introduction**

[0004] In recent 3GPP (3rd Generation Partnership Project) meetings, it has been agreed that 3GPP Release 12 (Rel. 12) or later LTE (Long Term Evolution), also known as LTE-Advanced or LTE-A, adopts a new codebook for the multiple-input and multiple-output (MIMO) with 4 transmission antennas (4-Tx) based on the double-codebook structure, i.e., the precoder G=W1W2, as for 8-Tx codebook in 3GPP Release 10.

[0005] In the latest RAN1 meeting, RAN1#73, two codebooks in [1], solution 2a and 2b, have been agreed as the only candidates for new 4-Tx codebook with 4-bit W1 codebook and 4-bit W2 codebook for both rank 1and 2. They share the same W1 codebook with wide-spaced beams and the W2 entries for rank 1. For rank-2 W2, the two codebooks have different entries.

[0006] Codebook solution 2a in [1] can be adopted as the enhanced 4Tx codebook for rank 1 and 2.

[0007] For rank-3 and 4, it is decided that W1 is an identity matrix and W2 uses Release 8 4-Tx codeword (rank 3 and 4).

[0008] On the other hand, for the uplink periodic channel state information (CSI) feedback in physical uplink control channel (PUCCH), the number of bits packed for each CSI report

is limited due to limited channel resources. Therefore, for the periodic CSI feedback based on new 4-Tx codebooks, subsampling is needed in some feedback modes.

[0009] We consider the design of subsampling of 4-Tx codebook for periodic CSI feedback in PUCCH, particularly mode 1-1 submode 1 and submode 2, and mode 2-1.

[0010] Transmission rank (sometimes called "rank") is the number of transmission layers (sometimes called "layers"). A codebook is a set of codewords. A codeword is also known as a precoder or precoding matrix.

[0011] **References**

[0012] [1] R1-132738, "Way Forward of 4Tx Rank 1 and 2 Codebook Design for Downlink MIMO Enhancement in Rel-12", Alcatel-Lucent, et. al.

[0013] [2] 3GPP TS36.211 "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation", v11.2.0, Mar. 2011.

[0014] [3] 3GPP TS36.213 "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures", v11.2.0, Mar. 2011.

BRIEF SUMMARY OF THE INVENTION

[0015] An objective of the present invention is to provide a solution to transmit from a user equipment to a base station feedback information for the codebook.

[0016] An aspect of the present invention includes a method implemented in a base station used in a wireless communications system. The method comprises receiving, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0017] Another aspect of the present invention includes a method implemented in a user equipment used in a wireless communications system. The method comprises transmitting, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0018] Still another aspect of the present invention includes a base station used in a wireless communications system. The base station comprises a receiver to receive, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0019] Still another aspect of the present invention includes a user equipment used in a wireless communications system. The user equipment comprises a transmitter to transmit, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0020] Still another aspect of the present invention includes a method implemented in a wireless communications system. The method comprises transmitting, from a user

equipment to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0021] Still another aspect of the present invention includes a wireless communications system. The wireless communications system comprises a base station; and a user equipment to transmit, to the base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI, the RI and the first PMI being jointly encoded, wherein 5 bits are used for transmission of the jointly encoded RI and first PMI, and wherein first 8 values of values expressed by the 5 bits are used for RI=1, second 8 values of the values expressed by the 5 bits are used for RI=2, a third value of the values expressed by the 5 bits is used for RI=3, a fourth value of the values expressed by the 5 bits is used for RI=4, and remaining 14 values of the values expressed by the 5 bits are reserved.

[0022] Still another aspect of the present invention includes a method implemented in a base station used in a wireless communications system. The method comprises receiving, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0023] Still another aspect of the present invention includes a method implemented in a user equipment used in a wireless communications system. The method comprises transmitting, to a base station, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0024] Still another aspect of the present invention includes a base station used in a wireless communications system. The base station comprises a receiver to receive, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0025] Still another aspect of the present invention includes a user equipment used in a wireless communications system. The user equipment comprises a transmitter to transmit, to a base station, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0026] Still another aspect of the present invention includes a method implemented in a wireless communications system. The method comprises transmitting, from a user equipment to a base station, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0027] Still another aspect of the present invention includes a wireless communications system. The wireless communications system comprises a base station, and a user equipment to transmit, to the base station, rank indication (RI), a first precoding matrix indicator (PMI) (codebook index i_1), and a second PMI, the RI and the first PMI being jointly encoded, wherein, for RI = 2, values 8-15 are assigned to the joint encoding of the RI and the first PMI ($I_{RI/PMI1}$).

[0028] Still another aspect of the present invention includes a method implemented in a base station used in a wireless communications system. The method comprises receiving, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

[0029] Still another aspect of the present invention includes a method implemented in a user equipment used in a wireless communications system. The method comprises transmitting, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

[0030] Still another aspect of the present invention includes a base station used in a wireless communications system. The base station comprises a receiver to receive, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

[0031] Still another aspect of the present invention includes a user equipment used in a wireless communications system. The user equipment comprises a transmitter to transmit, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

[0032] Still another aspect of the present invention includes a method implemented in a wireless communications system. The method comprises transmitting, from a user equipment to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

[0033] Still another aspect of the present invention includes a wireless communications system comprises a base station, and a user equipment to transmit, to the base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2), wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3

are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and wherein codebook index i_2 comprises I_{PMI2} for RI=1.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Fig. 1 depicts W1 statistics for codebook 2a and 2b for rank 1 and 2 in cross-polarized (Xpol) antennas with ½-λ antenna spacing.

[0035] Fig. 2 depicts W1 statistics for codebook 2a and 2b for rank 1 and 2 in cross-polarized (Xpol) antennas with 4-λ antenna spacing.

[0036] Fig. 3 depicts W2 statistics for codebook 2a and 2b for 2 in cross-polarized (Xpol) antennas with 0.5-λ antenna spacing.

[0037] Fig. 4 depicts W2 statistics for codebook 2a and 2b for 2 in cross-polarized (Xpol) antennas with 4-λ antenna spacing.

[0038] Fig. 5 depicts W2 statistics for codebook 2a and 2b for 2 in cross-polarized (Xpol) antennas (a) with 0.5-λ antenna spacing and (b) with 4-λ antenna spacing.

[0039] Fig. 6 is a block diagram of a MIMO system.

DETAILED DESCRIPTION

[0040] **2 Enhanced 4-Tx codebooks**

[0041] **2.1 Enhanced 4-Tx codebooks for rank 1 and 2**

[0042] In agreed work assumption, two solutions (solution 2a and 2b) in [1] are selected for enhanced 4-Tx codebook candidates for rank 1 and 2, which are described as follows.

[0043] **Solution 2a:**

$$\mathbf{W}_1 = \begin{bmatrix} \mathbf{X}_n & 0 \\ 0 & \mathbf{X}_n \end{bmatrix} \text{ where } n = 0,1,..,15$$

$$\mathbf{X}_n = \begin{bmatrix} 1 & 1 & 1 & 1 \\ q_1^{\,n} & q_1^{\,n+8} & q_1^{\,n+16} & q_1^{\,n+24} \end{bmatrix} \text{ where } q_1 = e^{j2\pi/32}$$

$$\text{For rank 1, } \mathbf{W}_{2,n} \in \left\{ \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ \alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ j\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -j\alpha(i)\mathbf{Y} \end{bmatrix} \right\}$$

and $\mathbf{Y} \in \{e_1, e_2, e_3, e_4\}$ and $\alpha(i) = q_1^{\,2(i-1)}$;

$$\text{For rank 2, } \mathbf{W}_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix} \right\}$$

and $(\mathbf{Y}_1, \mathbf{Y}_2) = (e_i, e_k) \in \{(e_1,e_1),(e_2,e_2),(e_3,e_3),(e_4,e_4),(e_1,e_2),(e_2,e_3),(e_1,e_4),(e_2,e_4)\}$;

[0044] **Solution 2b:**

$$\mathbf{W}_1 = \begin{bmatrix} \mathbf{X}_n & 0 \\ 0 & \mathbf{X}_n \end{bmatrix} \text{ where } n = 0,1,..,15$$

$$\mathbf{X}_n = \begin{bmatrix} 1 & 1 & 1 & 1 \\ q_1^{\,n} & q_1^{\,n+8} & q_1^{\,n+16} & q_1^{\,n+24} \end{bmatrix} \text{ where } q_1 = e^{j2\pi/32}$$

$$\text{For rank 1, } \mathbf{W}_{2,n} \in \left\{ \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ \alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ j\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -j\alpha(i)\mathbf{Y} \end{bmatrix} \right\}$$

and $\mathbf{Y} \in \{e_1, e_2, e_3, e_4\}$ and $\alpha(i) = q_1^{\,2(i-1)}$;

For rank 2,

$$\mathbf{W}_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & \mathbf{Y}_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ -\mathbf{Y}_1 & \mathbf{Y}_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ -\mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix} \right\} (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_2, e_4)\}$$

and

$$\mathbf{W}_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix} \right\} (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1,e_1),(e_2,e_2),(e_3,e_3),(e_4,e_4)\}$$

and

$$\mathbf{W}_{2,n} \in \left\{ \frac{1}{2} \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_2 & -\mathbf{Y}_1 \end{bmatrix}, \right\} (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1,e_3),(e_2,e_4),(e_3,e_1),(e_4,e_2)\}$$

[0045] In both codebooks, e_i denotes a 4 by 1 vector with the ith entry being 1 and zero for all other entries. We can see the only deference between codebook 2a and 2b are rank-2 W2 entries. Among 16 entries of rank-2 W2 entries, they share 9 entries.

[0046] Following the same W1W2 index structures for 8-Tx codebook in 3GPP TS36.213, we first fix the indices for these two codebooks as follows:

[0047] For W1 with index i_1, we have

$$\mathbf{W}_1 = \begin{bmatrix} \mathbf{X}_{i_1} & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_{i_1} \end{bmatrix}, \quad i_1 = 0,1,\cdots,15$$

where

$$\mathbf{X}_{i_1} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ q_1^{i_1} & q_1^{i_1+8} & q_1^{i_1+16} & q_1^{i_1+24} \end{bmatrix}, \quad q_1 = e^{2\pi j/16}.$$

[0048] For W2 rank 1, denote k as the index for the 4 entries of

$$\mathbf{W}_{2,n} \in \left\{ \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ \alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ j\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -\alpha(i)\mathbf{Y} \end{bmatrix}, \frac{1}{\sqrt{2}} \begin{bmatrix} \mathbf{Y} \\ -j\alpha(i)\mathbf{Y} \end{bmatrix} \right\}$$

and $\underline{i}$ as the index for the column selection e_i and co-phasing term $\alpha(i)$ as in

$$\mathbf{Y} \in \{e_1, e_2, e_3, e_4\}, \alpha(i) = q_1^{2(i-1)}.$$

[0049] We then define W2 index i_2=(i-1)*4+k-1, i=1, 2, 3, 4, k=1, 2, 3, 4, for rank-1 precoding matrix.

[0050] For W2 rank 2 in solution 2a, denote *k, k=1, 2,* as the index for the two entries in

$$\mathbf{W}_{2,n} \in \left\{ \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix} \right\}$$

and *i, i=1,..., 8,* as the index for the column selection pairs as in

$$(\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1, e_1), (e_2, e_2), (e_3, e_3), (e_4, e_4), (e_1, e_2), (e_2, e_3), (e_1, e_4), (e_2, e_4)\}$$

[0051] We then define rank-2 W2 index i_2 as i_2=(i-1)*2+k-1 for solution 2a.

[0052] We can see that rank-2 W2 of i_2 =0,…, 7 in solution 2a also appear in solution 2b, we adopt the same index i_2 for these 8 entries for rank-2 W2 in solution 2b.

[0053] Then we define i_2 =8,…, 11, for following 4 entries in the listed order

$$\mathbf{W}_{2,n} \in \left\{ \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & \mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ -\mathbf{Y}_1 & \mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ -\mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix} \right\}, (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_2, e_4)\}$$

and i_2 =12,…, 15, for following 4 entries in the listed order

$$\mathbf{W}_{2,n} \in \left\{ \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_2 & -\mathbf{Y}_1 \end{bmatrix} \right\}, (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1, e_3), (e_2, e_4), (e_3, e_1), (e_4, e_2)\}.$$

[0054] Note that the rank-2 W2 of $i_2 = 9$ in solution 2b is the same as the entry of $i_2 = 14$ in solution 2a.

[0055] **2.2 Enhanced 4-Tx codebooks for rank 3 and 4**

[0056] For rank 3 and 4 in the new codebooks, W1 is identity matrix, and W2 uses Release 8 codebook as in [2].

[0057] **3 CSI feedback in PUCCH based on new 4-Tx codbook**

[0058] For Release 8 4-Tx codebook, there are 16 precoding codewords for each rank, which requires a 4-bit overhead for precoding matrix indicator (PMI) feedback. This can be handled for periodic CSI feedback in PUCCH. Therefore, no subsampling on the codebook is needed.

[0059] However, when double codebook is adopted and each codebook is 4-bit size. The feedback overhead is too large if we send the full CSI feedbacks. To reduce the feedback overhead, we propose the following subsampling schemes on the enhanced 4-Tx codebook for various feedback modes.

W1 index i_1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Beams in W1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	24	25	26	27	28	29	30	31	0	1	2	3	4	5	6	7

Table 1 W1 beam components in enhanced 4Tx codebook.

[0060] **3.1 PUCCH CSI feedback mode 1-1 submode 1**

[0061] In PUCCH CSI feedback mode 1-1, users are configured to report a RI, a wideband channel quality indicator (CQI, quantized SINR or signal-to-interference-plus-noise ratio) and a wideband precoding matrix indicator (PMI) to the network in a CSI process. The feedback of rank indicator or rank indication (RI), CQI and PMI can be configured with

different periodicity. With double codebook structures, two indexes corresponding to W1 and W2 are feedback. Since W1 captures the channel condition in a relatively long term and large bandwidth, the feedback of W1 index (first PMI) can be configured in a longer period than that of W2. In submode 1of PUCCH feedback mode 1-1, the feedback of RI and W1 is configured in the same periodicity. Thus joint encoding of RI and W1 information has been adopted. In 3GPP Release 10, 5-bit is used to represent an entry of RI and W1 for 8-Tx codebook. Thus subsampling is required as total number of entries of RI and W1 for 8-Tx would be more than 32.

[0062] With the enhanced 4-Tx codebook, the total number of entries for RI and W1 information is 34 (16 each for rank 1 and 2, 2 entries for rank 3 and 4, assuming agreed 4-bit W1 for 4-Tx codebooks). Thus subsampling is also required for the enhanced 4-Tx codebook.

[0063] We now propose the following solutions for subsampling of RI and W1 (first PMI) entries for PUCCH mode 1-1, submode 1, for 4 antenna ports based on new 4-Tx codebook structure:

[0064] I. For the first 16 entries, we select 8 W1 entries (subsampled form 16 W1 codewords as in Section 2.1) each for rank 1 and rank 2, which can be represented by 4 bits. For rank 3 and 4, since W1 is fixed to the identity, we only needs two entries represent the rank. Thus for 4-antenna ports, 4-layer spatial multiplexing, total 5 bits are needed for the feedback of joint encoded RI and first PMI. Thus, there are 14 entries are not in use, which can be reserved for future usage. If 2-layer spatial multiplexing for 4-antenna ports, e.g., a rank restriction is indicated by the network, i.e., rank < =2, only 4-bit payload size is needed for feedback of joint encoded RI and PMI.

[0065] II. To reduce feedback and number of redundant, unused entries, we can pack all entries with a total 4-bit payload size for PUCCH feedback. This can be solved into two following alternatives:

[0066] a. For the first 8 entries, we select 4 W1 entries (subsampled form 16 W1 codewords as in Section 2.1) each for rank 1 and rank 2, which can be represented by a 3-bit payload. For rank 3 and 4, additional two entries representing the rank information are

included which makes the total 4 bits. Thus for 4-antenna ports, 4-layer spatial multiplexing, total 4 bits are needed for the feedback of joint encoded RI and first PMI. Thus, there are 6 entries are not in use, which can be reserved for future usage. If 2-layer spatial multiplexing for 4-antenna ports, e.g., a rank restriction is indicated by the network, i.e., rank < =2, only 3-bit payload size is needed for feedback of joint encoded RI and PMI.

[0067] b. In this approach, 14 entries are used to represent the joint RI and first PMI for rank 1 and 2. The entries can be equally split, i.e., 7 for each rank. Different numbers can also adopted as the statistics of rank 1 and rank 2 could be different. For rank 3 and 4, additional two entries representing the rank information are included which makes the total 4 bits. Thus total 4 bits are needed for the feedback of joint encoded RI and first PMI with or without rank restriction for the CSI feedback. Compared with 2a, this certainly brings some performance can as more W1 codewords are retained for rank 1 and 2. Compared alternative solution 1, it is expected only a slight performance degradation as only 1 less W1 codewords are in solution 2b than that in 1, but one bit feedback overhead is saved.

[0068] Based on above alternative subsampling schemes for PUCCH CSI feedback mode 1-1 submode 1, feedback of jointly encoder RI and the first PMI, we now provide some detailed design solutions as follows.

Value of joint encoding of RI and the first PMI $I_{RI/PMI1}$	RI	Codebook index i_1
0-7	1	0, 2, 4, 6, 8, 10, 12, 14, or $2I_{RI/PMI1}$
8-15	2	0, 2, 4, 6, 8, 10, 12, 14, or $2(I_{RI/PMI1}-8)$
16	3	NA
17	4	NA
18-31	reserved	NA

Table 1.1 A design subsampling based on Alternative I in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

[0069] A subsampling design based on Alt. I is provided in Table 1.1. It is a solution with simple specification. We now also provide several other designs which might have a certain performance improvement. First, we resort to the system level simulations to obtain statistics of W1 selections in codebook 2a and 2b. Note that although the W1 codebooks are same in 2a and 2b, the rank -2 codebooks are different, which could affect the W1 statistics slightly. The results of W1 statistics for Xpol antennas with ½-λ and 4-λ antenna spacing are presented in Fig. 1 and Fig. 2, respectively.

[0070] We can see that for rank-2, W1 codewords with index i_1=0, 1,…, 7 are most selected for both codebooks (The only exception is for 2a, i_1= 15 also has a high percentage.) For simplicity, we can use i_1=0, 1,…, 7 for rank-2. For rank-1, it is a little complicated. For the case of close spaced (0.5-λ) antennas, i_1=0, 6, 7, 13, 14, 15, have higher selection ratios than others. For the case of wide (4-λ) spaced antennas shown in Fig. 2, W1 with i_1=0, 15 have higher ratios than others. One design criterion for subsampling of W1 for rank-1 could be including {i_1=0, 7, 13, 15} as a subset for any subsampling codebooks for this feedback mode 1-1 submode 1. Since the same column (beam) in two

consecutive W1s have the small beam spacing, thus for rank-1, we can still adopt equal interval subsampling i_1, either the set {1, 3, 5, 7, 9, 11, 13, 15} or the set {0, 2, 4, 6, 8, 10, 12, 14}.

[0071] Also as shown in Table 1, since two W1s with index i_1 and i_1+8 consist of same beam components, for rank 2, there are many overlaps on the final codewords among these two W1 codeword sets. Thus one way is taking $\{i_1\}$={0,1,…, 7} as the subsampled W1 for mode 1-1, submode 1.

[0072] For rank 1, thanks to the co-phasing term, α(i), the codeword redundancy issue due to complete beam overlap among W1 is gone. It would be beneficial to have the beams span in all angle space with a uniform beam spacing for the same beam and co-phasing term selections from a W2 entry. Therefore, it is better to have the subsampling of W1 for rank 1 as $\{ i_1 | i_1$=0, 2, 4, 6, 8, 10, 12, 14}.

[0073] The design solution of 4-Tx codebook subsampling for PUCCH mode 1-1 submode 1 is then summarized in Table 1.2 in which we take {0, 2, 4, 6, 8, 10, 12, 14} for rank-1 based on above discussions.

Value of joint encoding of RI and the first PMI $I_{RI/PMI1}$	**RI**	**Codebook index** i_1
0-7	1	{0, 2, 4, 6, 8, 10, 12, 14} ($2I_{RI/PMI1}$)
8-15	2	0, 1, 2, 3, 4, 5, 6, 7 ($I_{RI/PMI1}$-8)
16	3	NA
17	4	NA
18-31	reserved	NA

Table 1.2 A codebook subsampling design based on Alternative I in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

[0074] Based on subsampling scheme Alt II-a, and the W1 statistics in Fig. 1 and Fig. 2, we form a codebook subsampling design solution shown in Table 1.3. Since for rank 2, as shown in Fig. 1, W1 with i1=0, 7 are quite dominant for close spaced antennas compared their neighbors, we then keep them and select {0, 3, 5, 7} as the subsampling results for rank-2. For rank 1, we still choose the equally spaced W1's.

Value of joint encoding of RI and the first PMI $I_{RI/PMI1}$	RI	Codebook index i_1
0-3	1	0, 4, 8, 12 $(4I_{RI/PMI1})$
4-7	2	0, 3, 5, 7
8	3	NA
9	4	NA
10-15	reserved	NA

Table 1.3 A codebook subsampling design example based on Alternative II-a in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

[0075] Based on subsampling scheme Alt II-b, and the W1 statistics in Fig. 1 and Fig. 2, we form a codebook subsampling design solution shown in Table 1.4. Since for Alt II-b, we have total 14 entries for joint RI and the first PMIs for rank 1 and 2, we cannot have equally spaced W1s. Based on the statistics shown in Figs. 1, and 2, we provide a solution in Table 1.4. Here we consider 7 entries for each rank. However, the number of entries can be different as the importance or statistics of rank 1 and rank 2 can be different. For example, for MU-MIMO pairing, it has been shown that paired user with rank-1

transmissions are better. Thus it would be better have more entries (less subsampling) for rank 1 than rank 2.

Value of joint encoding of RI and the first PMI $I_{RI/PMI1}$	RI	Codebook index i_1
0-6	1	0, 2, 4, 7, 10, 13, 15
7-13	2	0, 2, 4, 5, 6, 7, 15
14	3	NA
15	4	NA

Table 1.4 A codebook subsampling design example based on Alternative II-a in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

[0076] If one of the proposed alternatives is adopted, the report type (type-5 report [3]) shall be modified for 4 antenna ports when new codebook is configured. The modified type 5 report is given in Tables 2.1-2.3 for alternative I, II-a, and II-b, respectively.

PUCCH report type	Reported information	state	Number of bits
5	RI/ first PMI	4/8 antenna ports, 2-layer spatial multiplexing	4
		4/8 antenna ports, 4-layer spatial	5

		multiplexing	

Table 2.1 Modified report type to accommodate feedback alternative I in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

PUCCH report type	Reported information	state	Number of bits
5	RI/ first PMI	4 antenna ports, 2-layer spatial multiplexing	3
		4 antenna ports, 4-layer spatial multiplexing	4
		8 antenna ports, 2-layer spatial multiplexing	4
		8 antenna ports, 4-layer spatial multiplexing	5

Table 2.2 Report type defined for feedback alternative II-a in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

PUCCH report type	Reported information	state	Number of bits
5	RI/ first PMI	8 antenna ports, 2-layer spatial multiplexing or 4 antenna ports	4
		8 antenna ports, 4-layer spatial multiplexing	5

Table 2.3 Modified report type to accommodate feedback alternative II-b in PUCCH mode 1-1 submode 1 based on 4-Tx codebook with double codebook (W1W2) structure.

[0077] **3.2A PUCCH CSI feedback mode 1-1 submode 2**

[0078] In submode 2 of PUCCH CSI feedback mode 1-1, the user can be configured to report the CQI and complete preferred precoder information (first PMI for W1 and second PMI for W2). Thus total number of feedback bits would be 12 bits (4-bit CQI, 4-bit W1 and 4-bit W2) for rank 1 CSI feedback , 15 bits (two CQIs 7bit+4-bit W1, 4-bit W2) for rank 2 feedback, or 11 bits (7 bits for two CQIs, 4 bits for W2) for rank 3 or rank 4 feedback. For PUCCH, currently maximum number of bits for each report is 11-bits. Thus, codebook subsampling is needed for rank-1 and 2 feedback when PUCCH feedback mode 1-1 submode 2 is configured, while there is no need of codebook subsampling for rank-3 and 4.

[0079] We then propose the following two alternatives for rank-1/2 codebook subsampling for enhanced 4-Tx codebook:

[0080] III. For both rank-1 and rank -2, we select the total 16 entries for W1/W2 (the first PMI and second PMI). Thus the total number of bits for PMI is 4 for both rank-1 and 2.

[0081] IV. For rank-2, we select 16 entries for W1/W2. But for rank-1 since only one CQI is reported which uses 4 bits, we can subsample less for the rank-1 codewords to improve the performance. One design example is given below in which uses total 7 bits.

[0082] We now discuss the design based on above proposed two alternatives.

[0083] For alternative III, when 4 bits are allocated for W1/W2 reporting, we consider 3/1 splitting, i.e., 3 bits are allocated for W1 and 1 bit for W2.

[0084] For sub-sampling the inner codebook (W1) we can simply sub-sample the centers in a uniform manner. Note that the wideband codebook has the following 16 centers [0:15]/32.

[0085] To get a 3-bit subsampled version we can simply choose the 8 inner codewords (W1) with indexes {0, 2, 4, 6, 8, 10, 12, 14} or as discussed in section 3.1A, we consider {0, 2, 4, 6, 8, 10, 12, 14} for rank 1 and {0, 1, 2, 3, 4, 5, 6, 7} for rank-2.

[0086] For sub-sampling the outer codebook (W2), we can enforce a criterion in the rank-2 case that at-least one outer codeword in the sub-sampled codebook enables selecting orthogonal beams from the inner codeword. Using this criterion an example 2 bit rank-2 outer sub-sampled codebook 2a is to use (e_1,e_1) with the 2 co-phasing options and (e2,e4) with the 2 co-phasing options.

[0087] Or based on the average ratios of W2 selections for rank 2 from the original codebooks obtained via simulations shown in Figs. 3, and 4, we can select two of {(e_1,e_1), (e_2,e_2), (e_3,e_3) (e_4,e_4)} with the first co-phasing option.

[0088] Also based on the average ratios of W2 selections for rank 1 from the original codebooks obtained via simulations shown in Fig. 5, we can select two of {(e_1), (e_2), (e_3) (e_4)} with the first co-phasing option, e.g. {(e_1,e_1), (e_3,e_3) } with

$$\mathbf{W}_{2,n}\frac{1}{\sqrt{2}}\begin{bmatrix}\mathbf{Y}\\ \alpha(i)\mathbf{Y}\end{bmatrix} \text{ with } \mathbf{Y}\in\{e_1,,e_3\},\alpha(i)=q_1^{2(i-1)}.$$

	Relationship between the first PMI value and codebook index i_1		Relationship between the second PMI value and codebook index i_2		total
RI	Value of the first PMI I_{PMI1}	Codebook index i_1	Value of the second PMI I_{PMI2}	Codebook index i_2	#bits
1	0-7	{0, 2, 4, 6, 8, 10, 12, 14}	0-1	0, 8	4
2	0-7	{0, 1, 2, 3, 4, 5, 6, 7}	0-1	0, 4	4
3	NA	NA	0-15	I_{PMI2} (no subsampling)	4
4	NA	NA	0-15	I_{PMI2} (no subsampling)	4

Table 3.1A A codebook subsampling design example based on Alternative III in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

	Relationship between the first PMI value and codebook index i_1		Relationship between the second PMI value and codebook index i_2		total
RI	Value of the first PMI I_{PMI1}	Codebook index i_1	Value of the second PMI I_{PMI2}	Codebook index i_2	#bits
1	0-15	0-15	0-7	0,2,4,6,8,10,12,14	7
2	0-7	{0,1,2,3,4,5,6,7}	0-1	0,4	4
3	NA	NA	0-15	I_{PMI2} (no subsampling)	4
4	NA	NA	0-15	I_{PMI2} (no subsampling)	4

Table 3.2A A codebook subsampling design example based on Alternative IV in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

[0089] For alternative IV, for rank-1, total payload size is 7 for W1/W2. Thus we only need to sub-sampling rank-1 W2 codebooks. We now consider sub-sampling for the enhanced codebook in the rank-1 case. Since the inner codebooks are identical and the rank-1 outer codebooks are the same for codebooks 2a and 2b, we can consider either one of them in this procedure.

[0090] We consider the case when the sub-sampled outer codebook size is 8 so that Q=(8 choose 2)=28). For rank-1 both Chordal distance and Fubini Study are equivalent distance measures and the following 16 choices were found to have near-optimal metrics:

Columns 1 through 16

0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
4	4	4	4	5	5	5	5	4	4	4	4	5	5	5	5

6	6	6	6	7	7	7	7	6	6	6	6	7	7	7	7
8	8	9	9	8	8	9	9	8	8	9	9	8	8	9	9
10	10	11	11	10	10	11	11	10	10	11	11	10	10	11	11
12	13	12	13	12	13	12	13	12	13	12	13	12	13	12	13
14	15	14	15	14	15	14	15	14	15	14	15	14	15	14	15

[0091] Again, further down selection can be done by comparing with the average ratios of W2 selections from the original codebooks obtained via simulations.

[0092] Certain other criteria can be used (or can be imposed on top of the aforementioned procedures) for sub-sampling.

[0093] Based on the above and simulation results shown in Fig. 5 for average ratio of rank-1 W2 selections, {0, 2, 4, 6, 8, 10, 12, 14} can be adopted for codebook subsampling for PUCCH mode 1-1 submode 2.

[0094] If one of the proposed alternatives is adopted, the report type (type-2c report [3]) shall be modified for 4 antenna ports when new codebook is configured. The modified type 2c report is given in Tables 4.1A-4.2A for alternative III and IV, respectively.

PUCCH report type	Reported information	state	Number of bits
2c	Wideband CQI / first PMI / second PMI	4/8 antenna ports RI = 1	8
		4/8 antenna ports 1 < RI ≤ 4	11
		8 antenna ports 4 < RI ≤ 7	9
		8 antenna ports RI = 8	7

Table 4.1A Modified report type 2c to accommodate feedback alternative III in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

PUCCH report type	Reported information	state	Number of bits
2c	Wideband CQI / first PMI / second PMI	4/8 antenna ports RI = 1	11
		4/8 antenna ports 1 < RI ≤ 4	11
		8 antenna ports 4 < RI ≤ 7	9
		8 antenna ports RI = 8	7

Table 4.2A Modified report type 2c to accommodate feedback alternative IV in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

[0095] **3.2B PUCCH CSI feedback mode 1-1 submode 2**

[0096] In submode 2 of PUCCH CSI feedback mode 1-1, the user can be configured to report the CQI and complete preferred precoder information (first PMI for W1 and second PMI for W2). Thus total number of feedback bits would be 12 bits (4-bit CQI, 4-bit W1 and 4-bit W2) for rank 1 CSI feedback , 15 bits (two CQIs 7bit+4-bit W1, 4-bit W2) for rank 2 feedback, or 11 bits (7 bits for two CQIs, 4 bits for W2) for rank 3 or rank 4 feedback. For PUCCH, currently maximum number of bits for each report is 11-bits. Thus, codebook subsampling is needed for rank-1 and 2 feedback when PUCCH feedback mode 1-1 submode 2 is configured, while there is no need of codebook subsampling for rank-3 and 4.

[0097] We then propose the following two alternatives for rank-1/2 codebook subsampling for enhanced 4-Tx codebook:

[0098] III. For both rank-1 and rank -2, we select the total 16 entries for W1/W2 (the first PMI and second PMI). Thus the total number of bits is 4 for both rank-1 and 2.

[0099] IV. For rank-2, we select 16 entries for W1/W2. But for rank-1 since only one CQI is reported which uses 4 bits, we can subsample less for the rank-1 codewords to improve the performance. OneTwo design example isexamples are given below in which uses total 7 bits.

[00100] We now discuss the design based on proposed two alternatives.

[00101] For alternative III, when 4 bits are allocated for W1/W2 reporting, we first consider 3/1 splitting, i.e., 3 bits are allocated for W1 and 1 bit for W2.

[00102] For sub-sampling the inner codebook (W1) we can simply sub-sample the centers in a uniform manner. Note that the wideband codebook has the following 16 centers [0:15]/32.

[00103] To get a 3-bit subsampled version we can simply choose the 8 inner codewords (W1) with indexes {0, 2, 4, 6, 8, 10, 12, 14} or as discussed in section 3.1B, we can consider {0, 2, 4, 6, 8, 10, 12, 14} for rank 1 and {0, 1, 2, 3, 4, 5, 6, 7} for rank-2.

[00104] For sub-sampling the outer codebook (W2), we can optionally enforce a criterion in the rank-2 case that at-least one outer codeword in the sub-sampled codebook enables selecting orthogonal beams from the inner codeword. Using this criterion an example 1 bit rank-2 outer sub-sampled codebook is formed by (e2, e4) with the 2 co-phasing options corresponding to i2 in {14, 15}. This choice of W2 can be used with subsampled W1 {0, 1, 2, 3, 4, 5, 6, 7} or more preferably used with W1 indices {0, 2, 4, 6, 8, 10, 12, 14} for more balanced sampling.

[00105] Alternatively, based on the average ratios of W2 selections for rank 2 from the original codebooks obtained via simulations shown in Figs. 3, and 4, we can select two of $\{(e_1, e_1), (e_2, e_2), (e_3, e_3) (e_4, e_4)\}$ with the first co-phasing option. For instance, we can select $\{(e_1, e_1), (e_3, e_3)\}$ as W2 subsampling. Then we can select the first co-phasing entry for each beam pair, i.e, i_2=0, 4. However, with this selection, the selected beams are not in uniform beam spacing. Thus, if we do not restrict to have the same subsampling for W1 as in submode 1, we can apply the subsampling of $i_1 \in \{0, 2, 4, 6, 8, 10, 12, 14\}$ for W1. Then

with subsampling of $\{(e_1, e_1), (e_3, e_3)\}$, we have the beam selections with a uniform separation.

[00106] Also for rank 1 from the original codebooks, we can choose two of $\{(e_1), (e_2), (e_3) (e_4)\}$ which select two orthogonal beams. Thus two rank-1 codewords with same W1 will be orthogonal. Hence we can choose either $\{(e_1), (e_3)\}$ or $\{(e_2) (e_4)\}$ pair with a fixed cophasing term. For example with $\{(e_1), (e_3)\}$, we have

$$\mathbf{W}_{2,n}\frac{1}{\sqrt{2}}\begin{bmatrix}\mathbf{Y}\\ \alpha(i)\mathbf{Y}\end{bmatrix} \text{ with } \mathbf{Y}\in\{e_1, e_3\}, \alpha(i)=q_1^{2(i-1)}.$$

[00107] For the co-phasing terms, we can simply choose the first entry of each one, i.e. $(\alpha(1), k=1)$ or $i_2=0$ for e_1, $(\alpha(3), k=1)$ or $i_2=8$ for e_3. We can see for $i_2=0$, the co-phasing term is 1. Then it is just the beam selection. For $i_2=8$, the overall co-phasing term is q_1^4. The results are summarized in Table 3.1B.

	Relationship between the first PMI value and codebook index i_1		Relationship between the second PMI value and codebook index i_2		total
RI	Value of the first PMI I_{PMI1}	Codebook index i_1	Value of the second PMI I_{PMI2}	Codebook index i_2	#bits
1	0-7	{0,2,4,6,8,10,12,14} {0,1,2,3,4,5,6,7} or	0-1	0,8	4
2	0-7	{0,2,4,6,8,10,12,14}	0-1	0,4	4
3	NA	NA	0-15	I_{PMI2} (no subsampling)	4
4	NA	NA	0-15	I_{PMI2} (no subsampling)	4

Table 3.1B A codebook subsampling design example based on Alternative III in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

[00108] If different bit splitting is allowed for rank-1, we can have 2/2 bit splitting, i.e., allocate 2 bits for W1 subsampling and 2 bits for W2 subsampling. Under this option, we can select $i_1 \in \{0, 2, 4, 6\}$ for W1 and $\{(e_1), (e_2), (e_3) (e_4)\}$ for W2 subsampling with a certain k or set of k. With this solution, we can still cover beam space with a uniform beam spacing, just with a co-phasing term changed for every 4 codewords instead of 8. With k=1, we have overall co-phasing terms given by 1, q_1^2, q_1^4, q_1^6 for i=1, 2, 3, 4 (i.e., $\{(e_1), (e_2), (e_3), (e_4)\}$) respectively. The resulting subsampling for rank 1 W2 is $i_2 \in \{0, 4, 8, 12\}$. This subsampling design solution is summarized in Table 3.2B.

	Relationship between the first PMI value and codebook index i_1		Relationship between the second PMI value and codebook index i_2		total
RI	Value of the first PMI I_{PMI1}	Codebook index i_1	Value of the second PMI I_{PMI2}	Codebook index i_2	#bits
1	0-3	{0,2,4,6} {0,1,2,3,4,5,6,7} or	0-3	{0,4,8,12}	4
2	0-7	{0,2,4,6,8,10,12,14}	0-1	0,4	4
3	NA	NA	0-15	I_{PMI2} (no subsampling)	4
4	NA	NA	0-15	I_{PMI2} (no subsampling)	4

Table 3.2B A codebook subsampling design example based on Alternative III in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

	Relationship between the first PMI value and codebook index i_1		Relationship between the second PMI value and codebook index i_2		total
RI	Value of the first PMI I_{PMI1}	Codebook index i_1	Value of the second PMI I_{PMI2}	Codebook index i_2	#bits
1	0-15	0-15	0-7	0,2,4,6,8,10,12,14	7
2	0-7	{0,1,2,3,4,5,6,7} or {0,2,4,6,8,10,12,14}	0-1	0,4	4
3	NA	NA	0-15	I_{PMI2} (no subsampling)	4
4	NA	NA	0-15	I_{PMI2} (no subsampling)	4

Table 3.3B A codebook subsampling design example based on Alternative IV in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

[00109] For alternative IV, for rank-1, total payload size is 7 for W1/W2. We first consider sub-sampling only rank-1 W2 codebook in the enhanced codebook in the rank-1 case.

[00110] We consider the case when the sub-sampled outer codebook size is 8 (so that Q=(8 choose 2)=28). For rank-1 both Chordal distance and Fubini Study are equivalent distance measures and the following 16 choices were found to have near-optimal metrics:

Columns 1 through 16

0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
4	4	4	4	5	5	5	5	4	4	4	4	5	5	5	5
6	6	6	6	7	7	7	7	6	6	6	6	7	7	7	7

8	8	9	9	8	8	9	9	8	8	9	9	8	8	9	9
10	10	11	11	10	10	11	11	10	10	11	11	10	10	11	11
12	13	12	13	12	13	12	13	12	13	12	13	12	13	12	13
14	15	14	15	14	15	14	15	14	15	14	15	14	15	14	15

[00111] Again, further down selection can be done by comparing with the average ratios of W2 selections from the original codebooks obtained via simulations.

[00112] Certain other criteria can be used (or can be imposed on top of the aforementioned procedures) for sub-sampling.

[00113] Based on the above and simulation results shown in Fig. 5 for average ratio of rank-1 W2 selections, {0 2 4 6 8 10 12 14} can be adopted for codebook subsampling for PUCCH mode 1-1 submode 2, as summarized in Table 3.3B.

[00114] We also note in the rank-1 case with 7 bit total load, we can instead retain the 4 bit W2 codebook and subsample W1 codebook instead. In this case our preference is to uniformly subsample W1 as {0 2 4 6 8 10 12 14} to better cover the beam angular space.

[00115] If one of the proposed alternatives is adopted, the report type (type-2c report [3]) shall be modified for 4 antenna ports when new codebook is configured. The modified type 2c report is given in Tables 4.1B-4.2B for alternative III and IV, respectively.

PUCCH report type	Reported information	state	Number of bits
2c	Wideband CQI / first PMI / second PMI	4/8 antenna ports RI = 1	8
		4/8 antenna ports 1 < RI ≤ 4	11
		8 antenna ports 4 < RI ≤ 7	9
		8 antenna ports RI =	7

		8	

Table 4.1B Modified report type 2c to accommodate feedback alternative III in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

PUCCH report type	Reported information	state	Number of bits
2c	Wideband CQI / first PMI / second PMI	4/8 antenna ports 1 ≤ RI ≤ 4	11
		8 antenna ports 4 < RI ≤ 7	9
		8 antenna ports RI = 8	7

Table 4.2B Modified report type 2c to accommodate feedback alternative IV in PUCCH mode 1-1 submode 2 based on 4-Tx codebook with double codebook (W1W2) structure.

[00116] **3.3A PUCCH CSI feedback mode 2-1**

[00117] In PUCCH CSI feedback mode 2-1, the user can be configured to report the preferred subband with the corresponding preferred PMI and CQI. For the subband CQI/PMI report, L bits are allocated to report user preferred subband index. When double codebook structure is configured, the use needs to report the CQI and second PMI (for W2). With additional L bits for the subband reporting, the feedback payload size for CQI and second PMI is reduced. For 8-Tx codebook, maximum 9 bits are allocated for subband CQI/second PMI reporting. With the same payload size constraint, we propose the following codebook subsampling for different ranks, which is summarized in Table 5.1A:

[00118] For rank 1, only one CQI is reported. Thus subsampling is not needed. The total number of bits would be 8.

[00119] We now first discuss the subsampling of rank 3 and 4 codebook. Note that for W2, Release 8 codebooks have been adopted for rank-3 and 4. With 2 bits subsampling, we need to select 4 out of 16 codewords.

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2
1	0-15	I_{PMI2} (no subsampling)
2	0-3	4 entries as discussed in the text
3	0-3	4 entries as discussed in the text
4	0-3	4 entries as discussed in the text

Table 5.1A

[00120] **Rank-3:** The sub-sampling to select 4 out of 16 codewords can be done using either the Chordal distance or the Fubini-Study distance measure. Typically chordal distance is more suitable for lower SNRs whereas Fubini-Study is good at larger SNRs.

[00121] For any given choice of 4 codewords (comprising a sub-sampled codebook) we have 6 pairs. For each such pair (comprising of two 4x3 semi-unitary matrix codewords) we can compute a distance. The metric for that choice can be defined to be the minimum of the six distances. Finally, we can select the preferred choice as the one whose associated metric is the largest (i.e., maximum metric).

[00122] There can be multiple choices whose associated metrics are either equal to the maximum or are within a small margin (say 2% or 5%) of the maximum. All such choices are valid selections and represent good candidates.

[00123] In total there are 1820 choices (16 choose 4). We find that there are 5 choices whose metrics are equal to the maximum upon using the Chordal distance as the distance measure. Surprisingly these are the same choices whose metrics are again equal to the maximum when using the Fubini-Study distance as the distance measure. These indices are

{0 2 8 10}, {0 9 10 11}, {1 2 3 8}, {1 3 9 11},
{12 13 14 15}.

[00124] Indeed no other choices have metrics in either case that are within 5% of the maximum. Thus, any one of these 5 choices is a good selection.

[00125] **For rank-4**: each codeword is a 4x4 unitary matrix so the distance (either Chordal distance or Fubini-Study) among any two pair of codewords is zero. Thus, a convenient way for sub-sampling is to re-use the indices obtained for the rank-3 case in the rank-4 legacy codebook, to obtain a sub-sampled rank-4 codebook.

[00126] **For rank-2**, for the enhanced codebooks the situation is a bit more complex since there are multiple inner (wideband) codewords.

[00127] Consider the sub-sampling to obtain a size 4 (2-bit) outer codebook (W2) from the original outer codebook of size 16.

[00128] For each one of the 1820 choices, we can consider each one of the 16 inner codewords and determine the Q distances (where Q is the number of pairs in the sub-sampled outer codebook and is 6 in this example) and then associate the minimum among the Q distances with that inner codeword for that choice. Then, the 16 associated distances (with the 16 inner codewords for that choice) can be combined in a suitable manner into one metric associated with that choice (a suitable way can be a product of the distances or their geometric mean with some regularization etc.). The one or more choices whose metric s are equal to the maximum (or are within a margin of the maximum) can be determined to be suitable candidates.

[00129] Upon performing the aforementioned procedure for rank-2 (with sub-sampled outer codebook size 4 so that Q=6) and the enhanced **codebook 2a,** we

found the following 4 choices (sets of indices out of the 1820 possible ones) that have (near-) maximal metrics under both Chordal distance as well as the Fubini-Study distance:

{6 8 11 14}, {6 9 10 15}, {7 8 11 14}, {7 9 10 15}.

[00130] The following 8 choices (out of the 1820) have maximal metrics under Chordal distance:

{2 6 14 15}, {2 7 14 15}, {3 6 14 15}, {3 7 14 15},
{6 8 14 15}, {6 9 14 15}, {7 8 14 15}, {7 9 14 15}.

[00131] The following 164 choices (out of the 1820) have (near-) maximal metrics under Chordal distance. Each choice (comprising of 4 indices) is one column in the following:

Columns 1 through 20

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
4	4	4	4	5	5	5	5	6	6	7	7	14	4	4	4	4	5	5	5
6	7	14	15	6	7	14	15	14	15	14	15	15	6	7	14	15	6	7	14

Columns 21 through 40

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	7
5	6	6	7	7	14	6	6	7	7	14	6	6	7	7	14	10	11	14	10
15	14	15	14	15	15	14	15	14	15	15	14	15	14	15	15	15	14	15	15

Columns 41 through 60

0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	7	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
11	14	4	4	4	4	5	5	5	5	6	6	7	7	14	4	4	4	4	5
14	15	6	7	14	15	6	7	14	15	14	15	14	15	15	6	7	14	15	6

Columns 61 through 80

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	3	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6

5	5	5	6	6	7	7	14	6	6	7	7	14	6	6	7	7	14	10	11
7	14	15	14	15	14	15	15	14	15	14	15	15	14	15	14	15	15	15	14

Columns 81 through 100

1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	7	7	7	4	4	4	4	4	4	4	5	5	5	5	5	5	5	6	7
14	10	11	14	6	6	7	7	12	13	14	6	6	7	7	12	13	14	14	14
15	15	14	15	14	15	14	15	15	14	15	14	15	14	15	15	14	15	15	15

Columns 101 through 120

3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4
4	4	4	4	4	4	4	5	5	5	5	5	5	5	6	7	6	6	6	6
6	6	7	7	12	13	14	6	6	7	7	12	13	14	14	14	8	8	9	9
14	15	14	15	15	14	15	14	15	14	15	15	14	15	15	15	14	15	14	15

Columns 121 through 140

4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5
6	7	7	7	7	7	8	8	8	9	9	9	6	6	6	6	6	7	7	7
14	8	8	9	9	14	12	13	14	12	13	14	8	8	9	9	14	8	8	9
15	14	15	14	15	15	15	14	15	15	14	15	14	15	14	15	15	14	15	14

Columns 141 through 160

5	5	5	5	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7	7
7	7	8	8	8	9	9	9	8	8	8	9	9	9	8	8	8	9	9	9
9	14	12	13	14	12	13	14	10	11	14	10	11	14	10	11	14	10	11	14
15	15	15	14	15	15	14	15	15	14	15	15	14	15	15	14	15	15	14	15

Columns 161 through 164

8	8	9	9
10	11	10	11
12	13	12	13
15	14	15	14

[00132] Next, upon performing the aforementioned procedure for rank-2 and the enhanced codebook 2b we found the following 54 choices (out of the 1820) that have (near-) maximal metrics under both Chordal distance as well as the Fubini-Study distance:

Columns 1 through 20

0	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
4	4	5	5	4	4	5	5	6	6	6	6	6	6	6	7	7	7	7	7
8	13	8	13	8	13	8	13	8	8	8	9	9	10	12	8	8	8	9	9
11	15	11	15	11	15	11	15	9	10	11	10	11	11	14	9	10	11	10	11

Columns 21 through 40

2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	7	8	8	8	9	6	6	6	6	6	6	6	7	7	7	7	7	7	7
10	12	9	9	10	10	8	8	8	9	9	10	12	8	8	8	9	9	10	12
11	14	10	11	11	11	9	10	11	10	11	11	14	9	10	11	10	11	11	14

Columns 41 through 54

3	3	3	3	6	6	6	6	7	7	7	7	8	9
8	8	8	9	8	8	8	9	8	8	8	9	9	10
9	9	10	10	9	9	10	10	9	9	10	10	10	13
10	11	11	11	10	11	11	11	10	11	11	11	11	15

[00133] The following 42 choices (out of the 1820) have maximal metrics under Chordal distance:

Columns 1 through 20

2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
6	6	6	6	6	6	7	7	7	7	7	7	9	9	9	10	6	6	6	6
9	9	9	10	10	13	9	9	9	10	10	13	10	10	13	13	9	9	9	10
10	13	15	13	15	15	10	13	15	13	15	15	13	15	15	15	10	13	15	13

Columns 21 through 40

3	3	3	3	3	3	3	3	3	3	3	3	6	6	6	6	7	7	7	7
6	6	7	7	7	7	7	7	9	9	9	10	9	9	9	10	9	9	9	10
10	13	9	9	9	10	10	13	10	10	13	13	10	10	13	13	10	10	13	13
15	15	10	13	15	13	15	15	13	15	15	15	13	15	15	15	13	15	15	15

Columns 41 through 42

9	9
10	10
12	13
14	15

[00134] A majority (1462 out of 1820) of the choices have near-maximal metrics under Chordal distance which implies that achieving near-optimal metric under both Chordal and Fubini-Study distances is a better option for sub-sampling in this case.

[00135] Further down selection can be done by comparing with the average ratios of W2 selections from the original codebooks obtained via simulations.

[00136] We note that the Chordal distance and Fubini Study distance are more suitable to uncorrelated channels (such as those seen with wide antenna spacing).

[00137] For closely spaced antennas resulting in more correlated channels, we prefer to have more outer codebook entries for which the two columns in the resulting rank-2 codeword comprise of identical beam selections.

[00138] Based on above discussion and results shown in Figs. 3 and 4, we find {0, 2, 4, 8} could be a good option, for W2 subsampling, indicating that for 2a, and 2b,

$$\mathbf{W}_{2,n} \in \left\{ \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix} \right\} \text{ with } (\mathbf{Y}_1, \mathbf{Y}_2) \in \left\{ (e_1, e_1), (e_2, e_2), (e_3, e_3), (e_4, e_4) \right\}$$

are selected.

[00139] Thus the examples of the subsampling solutions for different ranks (each for one rank) for PUCCH feedback mode 2-1 are presented in Table 5.2A.

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2
1	0-15	I_{PMI2} (no subsampling)
2	0-3	{0 2 4 6}
3	0-3	{0 2 8 10}
4	0-3	{0 2 8 10}

Table 5.2A PUCCH mode 2-1 codebook subsampling for 4-Tx codebook.

[00140] **3.3B PUCCH CSI feedback mode 2-1**

[00141] In PUCCH CSI feedback mode 2-1, the user can be configured to report the preferred subband with the corresponding preferred PMI and CQI. For the subband CQI/PMI report, L bits are allocated to report user preferred subband index. When double codebook structure is configured, the use needs to report the CQI and second PMI (for W2). With additional L bits for the subband reporting, the feedback payload size for CQI and second PMI is reduced. For 8-Tx codebook, maximum 9 bits are allocated for subband CQI/second PMI reporting. With the same payload size constraint, we propose the following codebook subsampling for different ranks, which is summarized in Table 5.1B:

[00142] For rank 1, only one CQI is reported. Thus subsampling is not needed. The total number of bits would be 8.

[00143] We now first discuss the subsampling of rank 3 and 4 codebook. Note that for W2, Release 8 codebooks have been adopted for rank-3 and 4. With 2 bits subsampling, we need to select 4 out of 16 codewords.

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2
1	0-15	I_{PMI2} (no subsampling)
2	0-3	4 entries as discussed in the text
3	0-3	4 entries as discussed in the text
4	0-3	4 entries as discussed in the text

Table 5.1B

[00144] **Rank-3:** The sub-sampling to select 4 out of 16 codewords can be done using either the Chordal distance or the Fubini-Study distance measure. Typically chordal distance is more suitable for lower SNRs whereas Fubini-Study is good at larger SNRs.

[00145] For any given choice of 4 codewords (comprising a sub-sampled codebook) we have 6 pairs. For each such pair (comprising of two 4x3 semi-unitary matrix codewords) we can compute a distance. The metric for that choice can be defined to be the minimum of the six distances. Finally, we can select the preferred choice as the one whose associated metric is the largest (i.e., maximum metric).

[00146] There can be multiple choices whose associated metrics are either equal to the maximum or are within a small margin (say 2% or 5%) of the maximum. All such choices are valid selections and represent good candidates.

[00147] In total there are 1820 choices (16 choose 4). We find that there are 5 choices whose metrics are equal to the maximum upon using the Chordal distance as the distance measure. Surprisingly these are the same choices whose metrics are again equal to the maximum when using the Fubini-Study distance as the distance measure. These indices are

{0 2 8 10}, {0 9 10 11}, {1 2 3 8}, {1 3 9 11},
{12 13 14 15}.

[00148] Indeed no other choices have metrics in either case that are within 5% of the maximum. Thus, any one of these 5 choices is a good selection.

[00149] **For rank-4**: each codeword is a 4x4 unitary matrix so the distance (either Chordal distance or Fubini-Study) among any two pair of codewords is zero. Thus, a convenient way for sub-sampling is to re-use the indices obtained for the rank-3 case in the rank-4 legacy codebook, to obtain a sub-sampled rank-4 codebook.

[00150] **For rank-2**, for the enhanced codebooks the situation is a bit more complex since there are multiple inner (wideband) codewords.

[00151] Consider the sub-sampling to obtain a size 4 (2-bit) outer codebook (W2) from the original outer codebook of size 16.

[00152] For each one of the 1820 choices, we can consider each one of the 16 inner codewords and determine the Q distances (where Q is the number of pairs in the sub-sampled outer codebook and is 6 in this example) and then associate the minimum among the Q distances with that inner codeword for that choice. Then, the 16 associated distances (with the 16 inner codewords for that choice) can be combined in a suitable manner into one metric associated with that choice (a suitable way can be a product of the distances or their geometric mean with some regularization etc.). The one or more choices whose metric s are equal to the maximum (or are within a margin of the maximum) can be determined to be suitable candidates.

[00153] Upon performing the aforementioned procedure for rank-2 (with sub-sampled outer codebook size 4 so that Q=6) and the enhanced **codebook 2a,** we found the following 4 choices (sets of indices out of the 1820 possible ones) that have (near-) maximal metrics under both Chordal distance as well as the Fubini-Study distance:

{6 8 11 14}, {6 9 10 15}, {7 8 11 14}, {7 9 10 15}.

[00154] The following 8 choices (out of the 1820) have maximal metrics under Chordal distance:

{2 6 14 15}, {2 7 14 15}, {3 6 14 15}, {3 7 14 15},

{6 8 14 15}, {6 9 14 15}, {7 8 14 15}, {7 9 14 15}.

[00155] The following 164 choices (out of the 1820) have (near-) maximal metrics under Chordal distance. Each choice (comprising of 4 indices) is one column in the following:

Columns 1 through 20

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
4	4	4	4	5	5	5	5	6	6	7	7	14	4	4	4	4	5	5	5
6	7	14	15	6	7	14	15	14	15	14	15	15	6	7	14	15	6	7	14

Columns 21 through 40

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	7
5	6	6	7	7	14	6	6	7	7	14	6	6	7	7	14	10	11	14	10
15	14	15	14	15	15	14	15	14	15	15	14	15	14	15	15	15	14	15	15

Columns 41 through 60

0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	7	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
11	14	4	4	4	4	5	5	5	5	6	6	7	7	14	4	4	4	4	5
14	15	6	7	14	15	6	7	14	15	14	15	14	15	15	6	7	14	15	6

Columns 61 through 80

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	3	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6
5	5	5	6	6	7	7	14	6	6	7	7	14	6	6	7	7	14	10	11
7	14	15	14	15	14	15	15	14	15	14	15	15	14	15	14	15	15	15	14

Columns 81 through 100

1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	7	7	7	4	4	4	4	4	4	4	5	5	5	5	5	5	5	6	7

14 10 11 14 6 6 7 7 12 13 14 6 6 7 7 12 13 14 14 14
15 15 14 15 14 15 14 15 15 14 15 14 15 14 15 15 14 15 15 15

Columns 101 through 120

3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 4 4 4 4
4 4 4 4 4 4 4 5 5 5 5 5 5 5 6 7 6 6 6 6
6 6 7 7 12 13 14 6 6 7 7 12 13 14 14 14 8 8 9 9
14 15 14 15 15 14 15 14 15 14 15 15 14 15 15 15 14 15 14 15

Columns 121 through 140

4 4 4 4 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5
6 7 7 7 7 7 8 8 8 9 9 9 6 6 6 6 6 7 7 7
14 8 8 9 9 14 12 13 14 12 13 14 8 8 9 9 14 8 8 9
15 14 15 14 15 15 15 14 15 15 14 15 14 15 14 15 15 14 15 14

Columns 141 through 160

5 5 5 5 5 5 5 5 6 6 6 6 6 6 7 7 7 7 7 7
7 7 8 8 8 9 9 9 8 8 8 9 9 9 8 8 8 9 9 9
9 14 12 13 14 12 13 14 10 11 14 10 11 14 10 11 14 10 11 14
15 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15 15 14 15

Columns 161 through 164

8 8 9 9
10 11 10 11
12 13 12 13
15 14 15 14

[00156] Two of the aforementioned choices {2, 6, 14, 15} and {3, 7, 14, 15} are particularly interesting since they allow for orthogonal beam selection $(\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_2, e_4)\}$ with both co-phasing terms, $\mathbf{W}_{2,n} \in \left\{ \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix} \right\}$. These correspond to i2

indices {14, 15}. In addition beam selections $(\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_2, e_2), (e_4, e_4)\}$ with one of the two co-phasing terms, $\mathbf{W}_{2,n} \in \left\{\begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix}\right\}$ is allowed, corresponding to i2 {2, 6} or {3, 7}.

[00157] Further down selection can be done by comparing with the average ratios of W2 selections from the original codebooks obtained via simulations.

[00158] We note that the Chordal distance and Fubini Study distance are more suitable to uncorrelated channels (such as those seen with wide antenna spacing).

[00159] For closely spaced antennas resulting in more correlated channels, we prefer to have more outer codebook entries for which the two columns in the resulting rank-2 codeword comprise of identical beam selections.

[00160] Based on above discussion and results shown in Figs. 3 and 4, we find {0,2,4,6} could be a good option, for W2 subsampling, indicating that,

$$\mathbf{W}_{2,n} \in \left\{\begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}\right\} \quad \text{with} \quad (\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1, e_1), (e_2, e_2), (e_3, e_3), (e_4, e_4)\}$$

are selected.

[00161] However, due the issue of different W1 having the same beam group, with the above beam selections, the codeword redundancy cannot be avoided. One alternative solution is to choose only beam selections $(\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_1, e_1), (e_3, e_3)\}$ with both co-phasing terms, $\mathbf{W}_{2,n} \in \left\{\begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix}\right\}$, which corresponding to the W2 index $i_2 \in \{0, 1, 4, 5\}$. This beam selection scheme can still cover all 32 beams but avoid the codeword redundancy. In addition, it will be benefit to have one more co-phasing term. An analogous selection is $(\mathbf{Y}_1, \mathbf{Y}_2) \in \{(e_2, e_2), (e_4, e_4)\}$ with both co-phasing terms, $\mathbf{W}_{2,n} \in \left\{\begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ \mathbf{Y}_1 & -\mathbf{Y}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{Y}_1 & \mathbf{Y}_2 \\ j\mathbf{Y}_1 & -j\mathbf{Y}_2 \end{bmatrix}\right\}$, which corresponds to the W2 index $i_2 \in \{2, 3, 6, 7\}$.

[00162] Thus the examples of the subsampling solutions for different ranks for PUCCH feedback mode 2-1 are presented in Table 5.2B.

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2
1	0-15	I_{PMI2} (no subsampling)
2	0-3	{0 2 4 6} or {0 1 4 5} or {2 3 6 7} or {2 6 14 15} or {3 7 1415}
3	0-3	{0 2 8 10}
4	0-3	{0 2 8 10}

Table 5.2B PUCCH mode 2-1 codebook subsampling for 4-Tx codebook.

[00163] Referring now to FIG. 6, a multiple input multiple output (MIMO) system 100 in which the embodiments may be implemented is illustrated. In the downlink of system 100, one or more user equipments (UEs) 102 in cell 106 are served by base station (BS) 104. Each of user equipments 102 includes e.g. a transmitter, and base station 104 includes e.g. a receiver.

[00164] **4. Conclusion**

[00165] we propose several schemes for PUCCH period CSI feedback based on enhanced 4-Tx codebook with double codebook structure W1W2.

[00166] **Appendix**

[00167] System level simulation parameters are summarized in Table A-1.

Number of users per sector	10
Network synchronization	Synchronized
Antenna configuration (eNB)	4 TX cross-polarized/ULA ant., 0.5-λ/4-λ spacing
Antenna configuration (user)	2 RX cross-polarized/ULA ant.
Downlink transmission scheme	SU-MIMO or Dynamic SU/MU-MIMO scheduling. MU-MIMO pairing: Max 2 users/RB
Codebook	Rel. 8 codebook/Enhanced Codebooks
Downlink scheduler	PF in time and frequency
Scheduling granularity:	5 RBs
Feedback assumptions	5ms periodicity and 5ms delay; feedback mode 3-2 feedback without errors.
Sub-band granularity:	5 RBs
Downlink HARQ scheme	Chase Combining
Downlink receiver type	LMMSE-IRC
Interference estimation error	Wishart distribution model as in 3gpp.TR36.829
Feedback channel error	NA
Control channel and reference	3 OFDM symbols for control;
signal overhead	Used TBS tables in TS 36.213
TAE model (if considered)	Normal distribution $\mathcal{N}(0,\sigma^2)$, σ =12 ns

Table A-1 Simulation Parameters

[00168] The foregoing is to be understood as being in every respect illustrative and exemplary, but not restrictive, and the scope of the invention disclosed herein is not to be determined from the Detailed Description, but rather from the claims as interpreted according to the full breadth permitted by the patent laws. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the

present invention and that those skilled in the art may implement various modifications without departing from the scope and spirit of the invention. Those skilled in the art could implement various other feature combinations without departing from the scope and spirit of the invention.

What is claimed is:

1. A method implemented in a base station used in a wireless communications system, the method comprising:

receiving, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

2. A method implemented in a user equipment used in a wireless communications system, the method comprising:

transmitting, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

3. The method as in claim 1 or 2, wherein codebook indices i_2 for RI=3 are reused for RI=4.

4. The method as in claim 1 or 2, wherein codebook indices i_2 for RI=3 consist of one of {0, 2, 8, 10}, {0, 9, 10, 11}, {1, 2, 3, 8}, {1, 3, 9, 11}, and {12, 13, 14, 15}.

5. The method as in claim 1 or 2, wherein codebook indices i_2 for RI=4 consist of one of {0, 2, 8, 10}, {0, 9, 10, 11}, {1, 2, 3, 8}, {1, 3, 9, 11}, and {12, 13, 14, 15}.

6. The method as in claim 1 or 2, wherein codebook indices i_2 are for physical uplink control channel (PUCCH) mode 2-1 codebook subsampling with 4 antenna ports in LTE (Long Term Evolution).

7. The method as in claim 1 or 2, wherein codebook index i_2 for physical uplink control channel (PUCCH) mode 2-1 codebook subsampling with 4 antenna ports in LTE (Long Term Evolution) is determined according to a table comprising:

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2
1	0-15	I_{PMI2}
3	0-3	0, 2, 8, 10
4	0-3	0, 2, 8, 10

8. A base station used in a wireless communications system, the base station comprising:

a receiver to receive, from a user equipment, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

9. A user equipment used in a wireless communications system, the user equipment comprising:

a transmitter to transmit, to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

10. The user equipment as in claim 9, wherein codebook indices i_2 for RI=3 are reused for RI=4.

11. The user equipment as in claim 9, wherein codebook indices i_2 for RI=3 consist of one of {0, 2, 8, 10}, {0, 9, 10, 11}, {1, 2, 3, 8}, {1, 3, 9, 11}, and {12, 13, 14, 15}.

12. The user equipment as in claim 9, wherein codebook indices i_2 for RI=4 consist of one of {0, 2, 8, 10}, {0, 9, 10, 11}, {1, 2, 3, 8}, {1, 3, 9, 11}, and {12, 13, 14, 15}.

13. The user equipment as in claim 9, wherein codebook indices i_2 are for physical uplink control channel (PUCCH) mode 2-1 codebook subsampling with 4 antenna ports in LTE (Long Term Evolution).

14. The user equipment as in claim 9, wherein codebook index i_2 for physical uplink control channel (PUCCH) mode 2-1 codebook subsampling with 4 antenna ports in LTE (Long Term Evolution) is determined according to a table comprising:

RI	Relationship between the second PMI value and codebook index i_2	
	Value of the second PMI I_{PMI2}	Codebook index i_2

1	0-15	I_{PMI2}
3	0-3	0, 2, 8, 10
4	0-3	0, 2, 8, 10

15. A method implemented in a wireless communications system, the method comprising:

transmitting, from a user equipment to a base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

16. A wireless communications system comprising:

a base station; and

a user equipment to transmit, to the base station, rank indication (RI), a first precoding matrix indicator (PMI), and a second PMI (codebook index i_2),

wherein values 0-15 are assigned to the second PMI I_{PMI2} for RI=1 and values 0-3 are assigned to the second PMI I_{PMI2} for each of RI=2, RI=3, and RI=4, and

wherein codebook index i_2 comprises I_{PMI2} for RI=1.

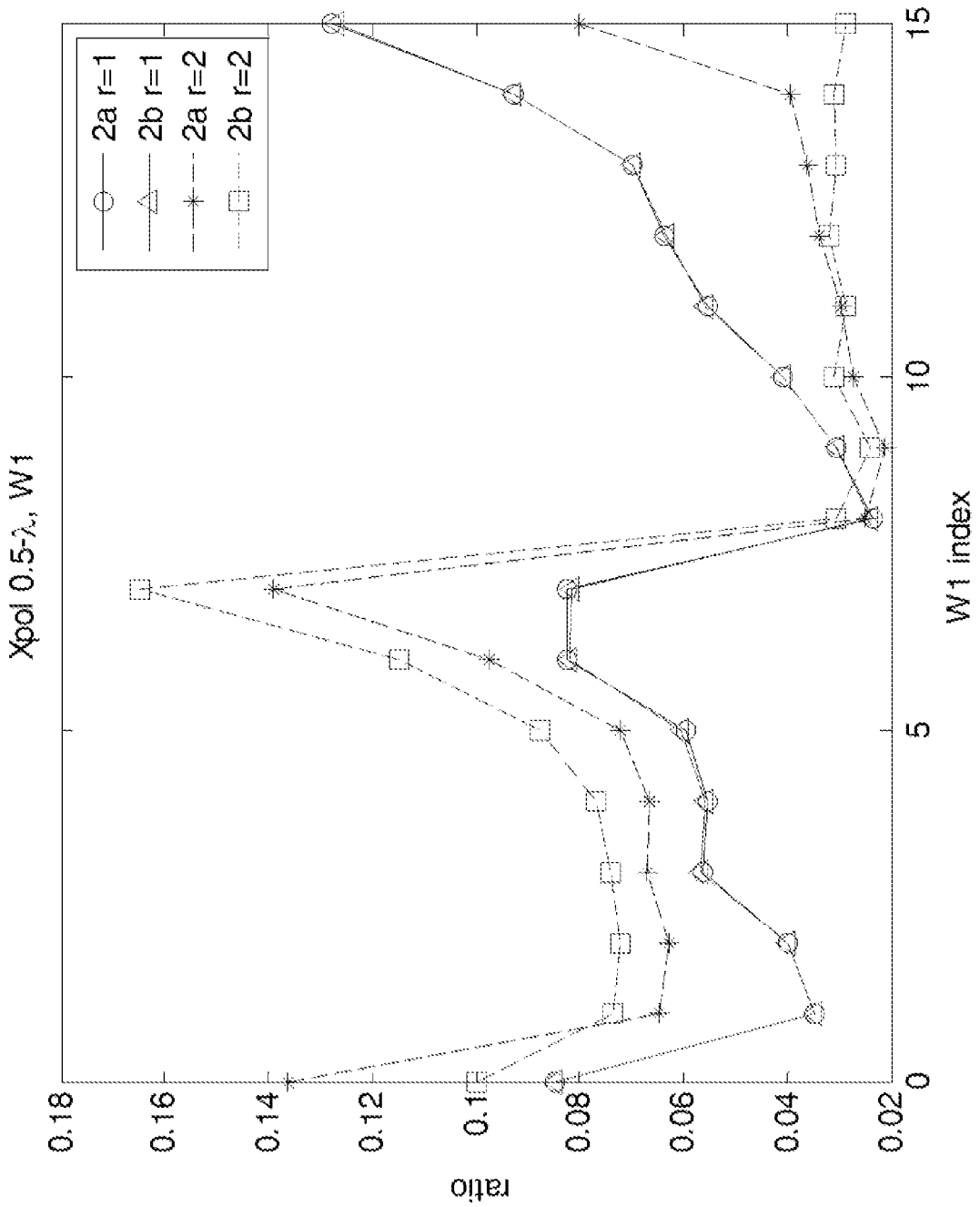

Xpol 0.5-λ, W1
ratio
W1 index
2a r=1
2b r=1
2a r=2
2b r=2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
5
10
15

FIG. 1

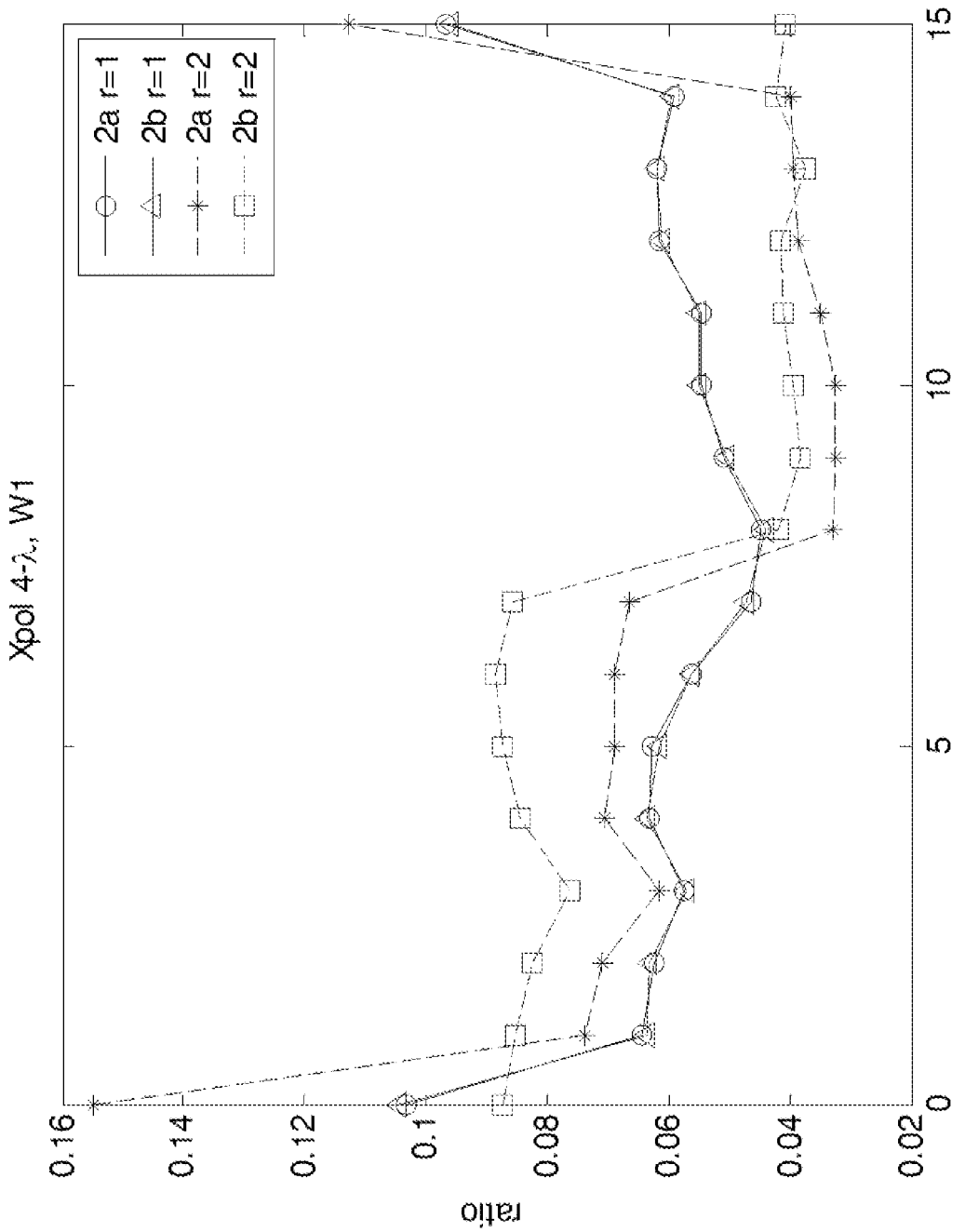

Xpol 4-λ, W1
ratio
W1 index
2a r=1
2b r=1
2a r=2
2b r=2
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
5
10
15

FIG. 2

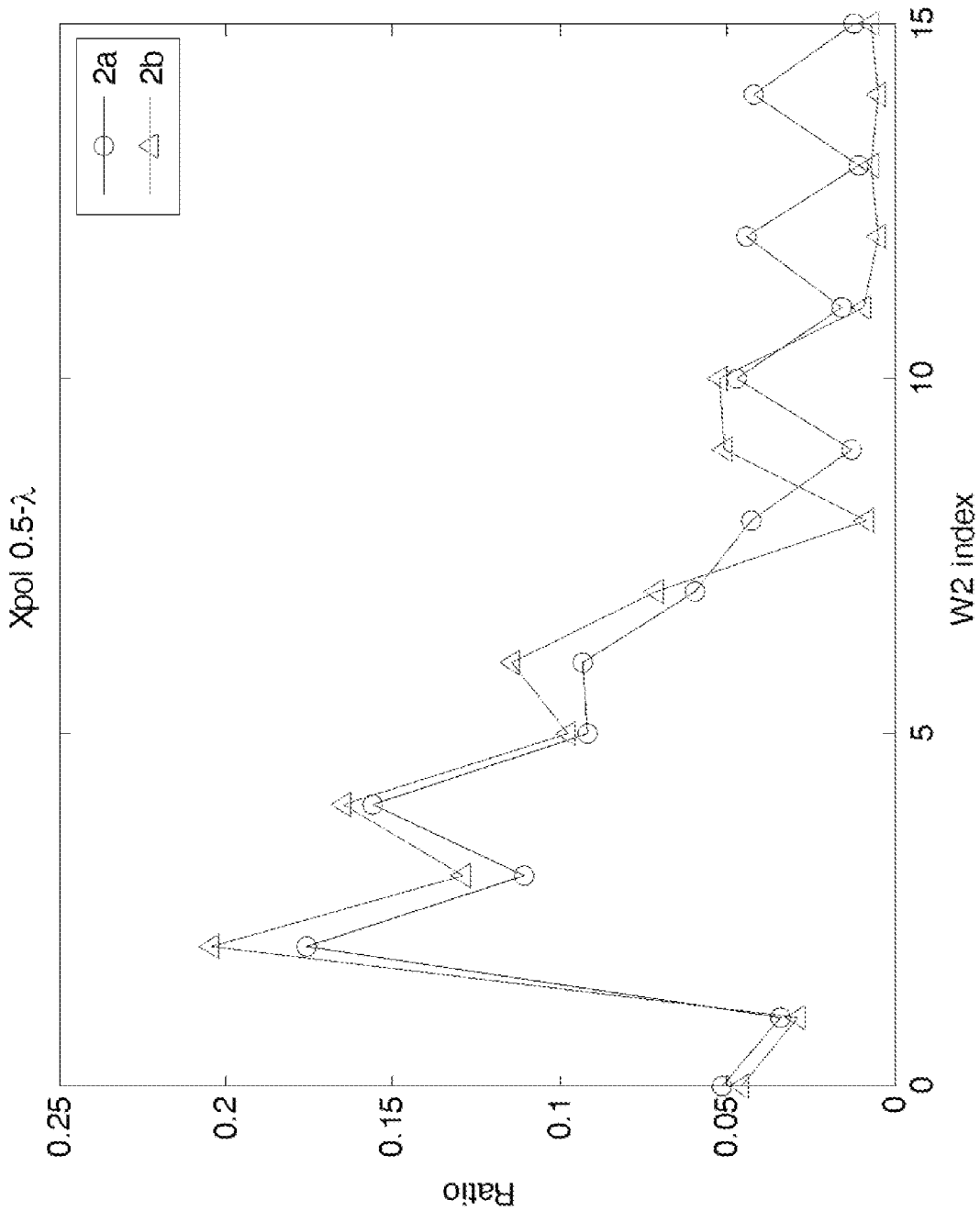


FIG. 3

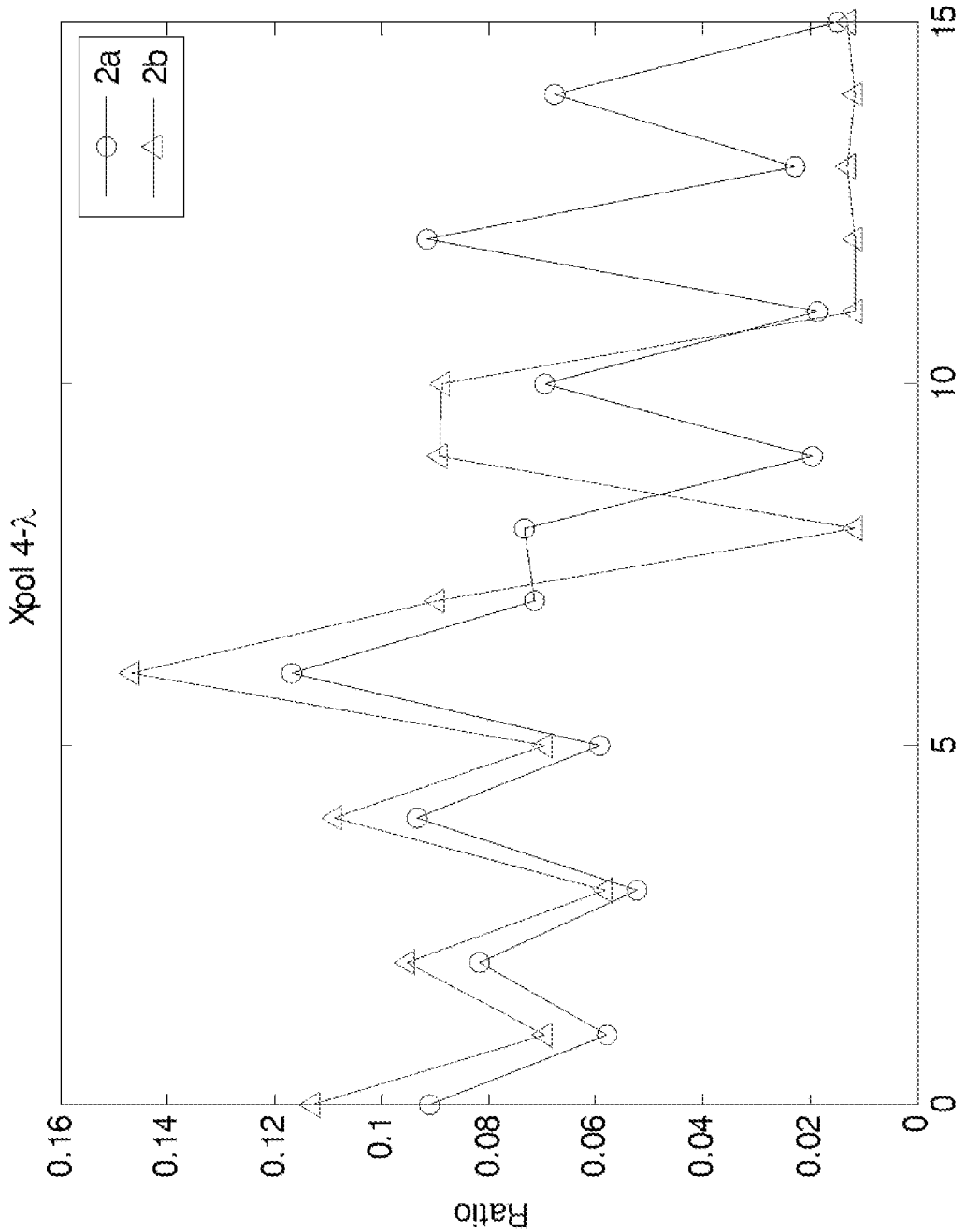

Xpol 4-λ
Ratio
W2 index
2a
2b
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
5
10
15

FIG. 4

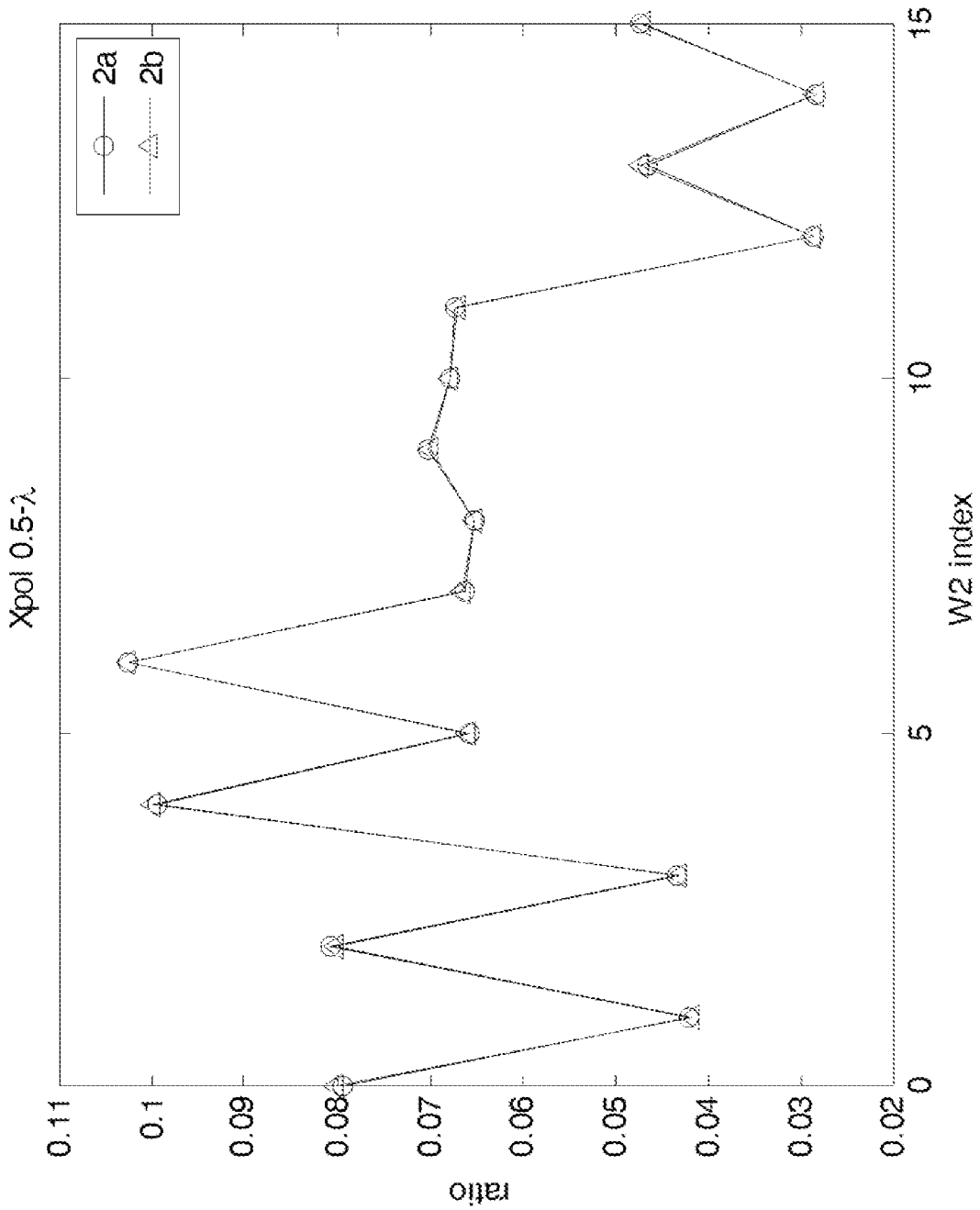

Xpol 0.5-λ
ratio
W2 index
2a
2b
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0
5
10
15

FIG. 5(a)

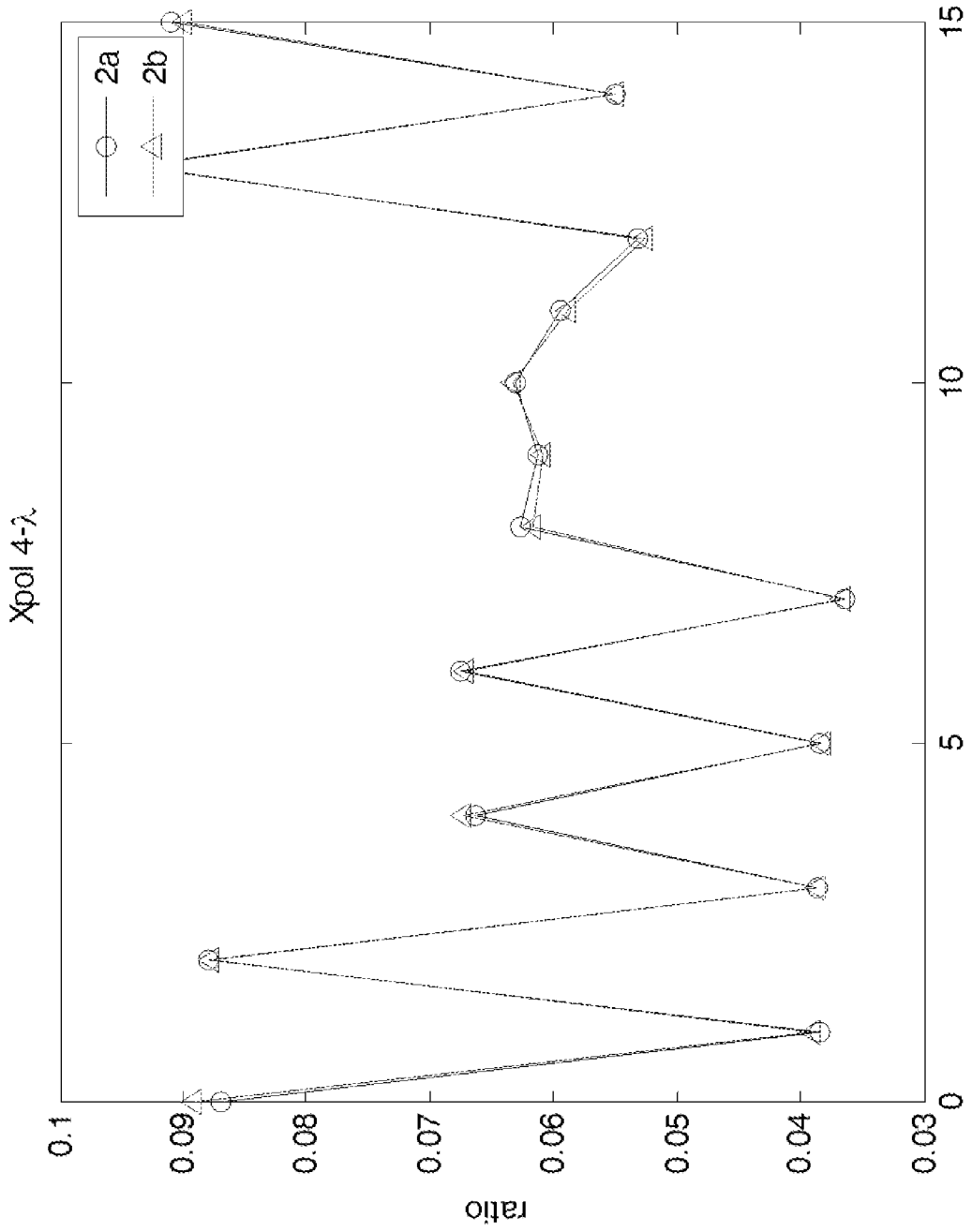

Xpol 4-λ
ratio
W2 index
2a
2b
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
5
10
15

FIG. 5(b)

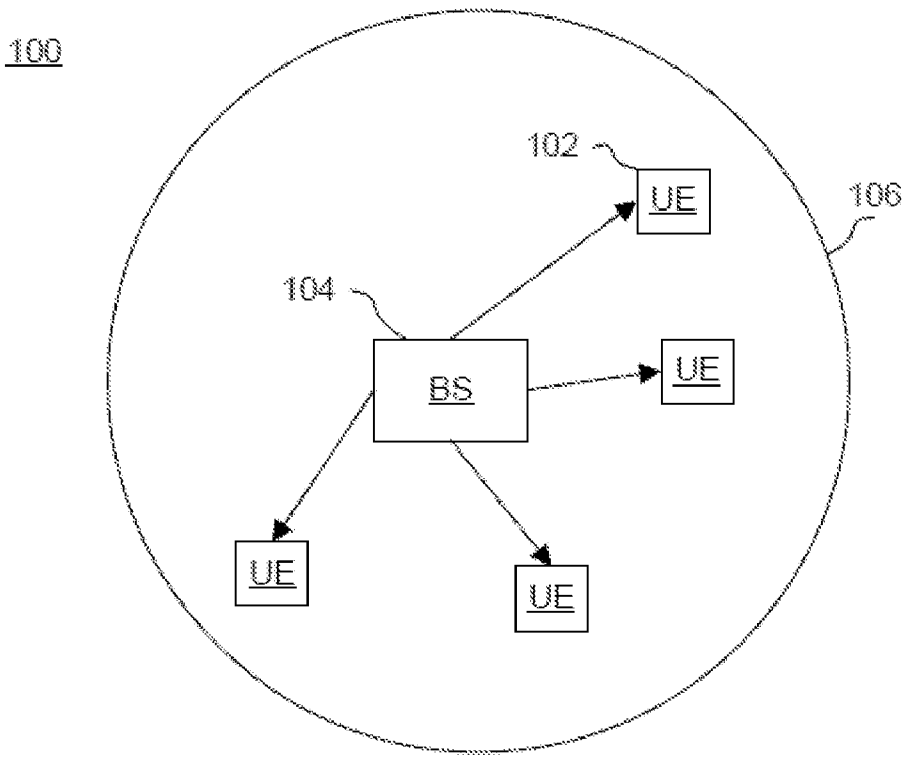


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/040978

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/26(2006.01)i, H04J 11/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B 7/26; H04L 27/00; H04B 17/00; H04B 7/02; H04L 27/28; H04B 1/02; H04W 40/00; H04B 1/38; H04J 11/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: mode 1-1 submode 1 and 2, mode 2-1, CSI, rank indication (RI), precoding matrix indicator (PMI), codebook index, codebook subsmapling

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009-0207784 A1 (MOON IL LEE et al.) 20 August 2009 See paragraphs 13-14, 38-50, 67-70; claims 1-3; and figure 1.	1-16
A	US 2013-0114656 A1 (KRISHNA KAMAL SAYANA et al.) 09 May 2013 See paragraphs 72-78; claims 1, 4, 23; and figures 11-14.	1-16
A	US 2012-0003945 A1 (LINGJIA LIU et al.) 05 January 2012 See paragraphs 56-57, 70-88; table 1; and figures 7A, 7B.	1-16
A	US 2012-0082248 A1 (JIN KYU HAN et al.) 05 April 2012 See paragraphs 51-55, 153-164; claims 1-3; and figure 4.	1-16
A	US 2012-0328039 A1 (DAVID MAZZARESE et al.) 27 December 2012 See paragraphs 43-59; and figure 1.	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 September 2014 (18.09.2014)	**22 September 2014 (22.09.2014)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/040978

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009-0207784 A1	20/08/2009	KR 10-1295384 B1	08/08/2013
		US 8045508 B2	25/10/2011
US 2013-0114656 A1	09/05/2013	CN 103918195 A	09/07/2014
		WO 2013-070577 A1	16/05/2013
US 2012-0003945 A1	05/01/2012	EP 2589160 A2	08/05/2013
		KR 10-2013-0028783 A	19/03/2013
		US 8639198 B2	28/01/2014
		WO 2012-002747 A2	05/01/2012
		WO 2012-002747 A3	23/02/2012
US 2012-0082248 A1	05/04/2012	AU 2011-313098 A1	04/04/2013
		CA 2813192 A1	12/04/2012
		CN 103222201 A	24/07/2013
		EP 2437408 A1	04/04/2012
		JP 2013-540401 A	31/10/2013
		KR 10-2012-0038366 A	23/04/2012
		WO 2012-046988 A2	12/04/2012
		WO 2012-046988 A3	31/05/2012
US 2012-0328039 A1	27/12/2012	CN 102835054 A	19/12/2012
		EP 2594030 A1	22/05/2013
		EP 2594030 A4	17/07/2013
		KR 10-2013-0036072 A	09/04/2013
		US 2014-133595 A1	15/05/2014
		US 8665984 B2	04/03/2014
		WO 2012-024837 A1	01/03/2012