

METHODS AND APPARATUSES FOR ENHANCED TYPE I MULTI-PANEL CODEBOOK

TECHNICAL FIELD

[0001] The present disclosure relates to wireless communications, and more specifically to methods and apparatuses for enhanced Type I multi-panel codebook.

BACKGROUND

[0002] A wireless communications system may include one or multiple network communication devices, such as base stations (BSs), which may support wireless communications for one or multiple user communication devices, which may be otherwise known as user equipment (UE), or other suitable terminology. The wireless communications system may support wireless communications with one or multiple user communication devices by utilizing resources of the wireless communication system (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers, or the like). Additionally, the wireless communications system may support wireless communications across various radio access technologies including third generation (3G) radio access technology, fourth generation (4G) radio access technology, fifth generation (5G) radio access technology, among other suitable radio access technologies beyond 5G (e.g., sixth generation (6G)).

SUMMARY

[0003] An article "a" before an element is unrestricted and understood to refer to "at least one" of those elements or "one or more" of those elements. The terms "a," "at least one," "one or more," and "at least one of one or more" may be interchangeable. As used herein, including in the claims, "or" as used in a list of items (e.g., a list of items prefaced by a phrase such as "at least one of" or "one or more of" or "one or both of") indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Also, as used herein, the phrase "based on" shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as "based on condition A" may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase "based on" shall be

construed in the same manner as the phrase "based at least in part on." Further, as used herein, including in the claims, a "set" may include one or more elements.

[0004] Some implementations of the methods and apparatuses described herein may include a UE for wireless communication. The UE may include: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the UE to: receive configuration information for an antenna array with a first number of channel state information reference signal (CSI-RS) ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; determine a precoding matrix indicator (PMI) based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and transmit a channel state information (CSI) report, wherein the CSI report includes the PMI.

[0005] In some implementations of the UE described herein, in the case that the first number is 48, the configuration of (N_g, N_1, N_2) includes (2, 12, 1), (2, 6, 2), (2, 4, 3), (3, 8, 1), (3, 4, 2), (4, 6, 1), or (4, 3, 2); in the case that the first number is 64, the configuration of (N_g, N_1, N_2) includes (2, 16, 1), (2, 8, 2), (2, 4, 4), (4, 8, 1), or (4, 4, 2); in the case that the first number is 96, the configuration of (N_g, N_1, N_2) includes (2, 24, 1), (2, 12, 2), (2, 8, 3), (2, 6, 4), (3, 16, 1), (3, 8, 2), (3, 4, 4), (4, 12, 1), (4, 6, 2), or (4, 4, 3); or in the case that the first number is 128, the configuration of (N_g, N_1, N_2) includes (2, 32, 1), (2, 16, 2), (2, 8, 4), (4, 16, 1), (4, 8, 2), or (4, 4, 4).

[0006] In some implementations of the UE described herein, the configuration of (O_1, O_2) is jointly configured with the configuration of (N_g, N_1, N_2) in the configuration information or separately configured in another configuration information, and wherein the configuration of (O_1, O_2) includes (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) or (4, 4).

[0007] In some implementations of the UE described herein, the codebook includes a first codebook for 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports, each codeword in the first codebook is associated with two orthogonal beams, and one beam of the two orthogonal beams is determined based on a horizontal beam offset value and a vertical beam offset value with respect to the other beam of the two orthogonal beams, wherein the first codebook is based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , $i_{1,3}$ is a codebook index of the first codebook, k_1 is the horizontal beam offset value, and k_2 is the vertical beam offset value.

[0008] In some implementations of the UE described herein, the PMI includes a 2-bit indication for indicating $i_{1,3}$, and the mapping table indicates that: in the case that $N_1 = 3$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$; in the case that $N_1 \geq 6$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$; or in the case that $N_1 \geq N_2 \geq 2$ except $N_1 = 2$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$.

[0009] In some implementations of the UE described herein, the PMI includes a 2-bit or 3-bit indication for indicating $i_{1,3}$, and the mapping table indicates that: in the case that $N_1 = 3$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$; in the case that $N_1 = 6$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$; in the case that $N_1 > 8$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, $(7O_1, 0)$, or $(8O_1, 0)$; in the case that $N_1 = 3$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$; or in the case that $N_1 \geq 4$ and $N_2 \geq 2$ except $N_1 = 4$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , $(2O_1, 0)$, $(2O_1, O_2)$, $(2O_1, 2O_2)$, $(0, 2O_2)$, or $(O_1, 2O_2)$.

[0010] In some implementations of the UE described herein, the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor and a second wideband cophasing factor respectively corresponding to two polarization directions for a second panel, a third wideband cophasing factor and a fourth wideband cophasing factor respectively corresponding to two polarization directions for a third panel, a

first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

[0011] In some implementations of the UE described herein, the PMI indicates a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the third wideband cophasing factor, the fourth wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, and the fourth subband cophasing factor.

[0012] In some implementations of the UE described herein, the second codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$, wherein $W_{l,m,p,n}^{1,3,2} =$

$$\frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ a_{p_4} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ -a_{p_4} b_{n_4} v_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first number,}$$

$$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T, \quad u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}, \quad \varphi_{n_0} = e^{j\pi n_0/2}, \quad a_{p_1} \text{ is the first wideband cophasing}$$

factor, a_{p_2} is the second wideband cophasing factor, a_{p_3} is the third wideband cophasing factor, a_{p_4} is the fourth wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

[0013] In some implementations of the UE described herein, the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel,

and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

[0014] In some implementations of the UE described herein, the PMI indicates a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, the fourth subband cophasing factor.

[0015] In some implementations of the UE described herein, the second codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$, wherein $W_{l,m,p,n}^{1,3,2} =$

$$\frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first}$$

number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m =$

$\begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & & & & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband cophasing factor, a_{p_2} is the second wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

[0016] In some implementations of the UE described herein, the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor for both polarization directions for the second panel, and a second subband cophasing factor for both polarization directions for the third panel.

[0017] In some implementations of the UE described herein, the PMI indicates a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, and the second subband cophasing factor.

[0018] In some implementations of the UE described herein, the second codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$, wherein $W_{l,m,p,n}^{1,3,2} =$

$$\frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first}$$

number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m =$

$$\begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}, \varphi_{n_0} = e^{j\pi n_0/2}, a_{p_1} \text{ is the first wideband cophasing}$$

factor, a_{p_2} is the second wideband cophasing factor, b_{n_1} is the first subband cophasing factor, and b_{n_2} is the second subband cophasing factor.

[0019] In some implementations of the UE described herein, the codebook includes a third codebook for three panels for codebook mode 1 for CSI reporting using the first number of CSI-RS ports, and the third codebook is determined based on a first wideband cophasing factor for a second panel and a second wideband cophasing factor for a third panel.

[0020] In some implementations of the UE described herein, the PMI indicates an index corresponding to the first wideband cophasing factor and an index corresponding to the second wideband cophasing factor.

[0021] In some implementations of the UE described herein, the third codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,1}$ or $W_{l,m,p,n}^{2,3,1}$, wherein $W_{l,m,p,n}^{1,3,1} =$

$$\frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first number,}$$

$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m =$

$$\begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] \\ & & & 1 \end{cases} \quad \begin{matrix} N_2 > 1 \\ N_2 = 1 \end{matrix}, \varphi_n = e^{j\pi n/2}, \varphi_{p_1} \text{ is the first wideband cophasing factor, and } \varphi_{p_2} \text{ is the second wideband cophasing factor.}$$

[0022] In some implementations of the UE described herein, the at least one processor is further configured to cause the UE to receive a configuration for N_g CSI-RS resources, each CSI-RS resource is associated with a corresponding panel of the antenna array, and for CSI reporting, the first number of CSI-RS ports are ordered first according to an order from a lowest port index to a highest port index within a CSI-RS resource, and then according to an order from a lowest CSI-RS resource index to a highest CSI-RS resource index of the N_g CSI-RS resources.

[0023] Some implementations of the methods and apparatuses described herein may include a processor for wireless communication. The processor may include: at least one controller coupled with at least one memory and configured to cause the processor to: receive configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; determine a PMI based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and transmit a CSI report, wherein the CSI report includes the PMI.

[0024] Some implementations of the methods and apparatuses described herein may include a BS for wireless communication. The BS may include: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the BS to: transmit configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with

a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and receive a CSI report, wherein the CSI report includes a PMI associated with a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) .

[0025] Some implementations of the methods and apparatuses described herein may include a method performed by a UE. The method may include: receiving configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; determining a PMI based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and transmitting a CSI report, wherein the CSI report includes the PMI.

[0026] Some implementations of the methods and apparatuses described herein may include a method performed by a BS. The method may include: transmitting configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical

oversampling factor; and receiving a CSI report, wherein the CSI report includes a PMI associated with a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) .

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] In order to describe the manner in which advantages and features of the application can be obtained, a description of the application is rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings. These drawings depict only example embodiments of the application and are not therefore to be considered limiting of its scope.

[0028] Figure 1 illustrates an example of a wireless communications system in accordance with aspects of the present disclosure.

[0029] Figure 2 illustrates a flowchart of an exemplary method performed by a UE in accordance with aspects of the present disclosure.

[0030] Figure 3 illustrates a flowchart of an exemplary method performed by a BS in accordance with aspects of the present disclosure.

[0031] Figure 4 illustrates an example of a UE in accordance with aspects of the present disclosure.

[0032] Figure 5 illustrates an example of a processor in accordance with aspects of the present disclosure.

[0033] Figure 6 illustrates an example of a BS in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0034] The detailed description of the appended drawings is intended as a description of preferred embodiments of the present application and is not intended to represent the only form in which the present application may be practiced. It should be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the spirit and scope of the present application.

[0035] While operations are depicted in the drawings in a particular order, persons skilled in the art will readily recognize that such operations need not be performed in the particular order as shown or in a sequential order, or that all illustrated operations need be performed, to achieve desirable results; sometimes one or more operations can be skipped. Further, the drawings can schematically depict one or more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing can be advantageous.

[0036] Reference will now be made in detail to some embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings. To facilitate understanding, embodiments are provided under specific network architecture and new service scenarios, such as 3rd generation partnership project (3GPP) long-term evolution (LTE) and LTE advanced, 3GPP 5G new radio (NR), 5G-Advanced, 6G, and so on. It is contemplated that along with developments of network architectures and new service scenarios, all embodiments in the present disclosure are also applicable to similar technical problems; and moreover, the terminologies recited in the present disclosure may change, which should not affect the principle of the present disclosure.

[0037] Aspects of the present disclosure are described in the context of a wireless communications system.

[0038] Figure 1 illustrates an example of a wireless communications system 100 in accordance with aspects of the present disclosure. The wireless communications system 100 may include one or more network equipments (NEs) (e.g., BSs) 102, one or more UEs 104, and a core network (CN) 106. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a 4G network, such as an LTE network or an LTE-Advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be an NR network, such as a 5G network, a 5G-Advanced (5G-A) network, or a 5G ultrawideband (5G-UWB) network. In other implementations, the wireless communications system 100 may be a combination of a 4G network and a 5G network, or other suitable radio access technology including Institute of

Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G, for example, 6G. Additionally, the wireless communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

[0039] The one or more NEs 102 may be dispersed throughout a geographic region to form the wireless communications system 100. One or more of the NEs 102 described herein may be or include or may be referred to as a network node, a base station, a network element, a network function, a network entity, a radio access network (RAN), a NodeB, an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. An NE 102 and a UE 104 may communicate via a communication link, which may be a wireless or wired connection. For example, an NE 102 and a UE 104 may perform wireless communication (e.g., receive signaling, transmit signaling) over a Uu interface.

[0040] An NE 102 may provide a geographic coverage area for which the NE 102 may support services for one or more UEs 104 within the geographic coverage area. For example, an NE 102 and a UE 104 may support wireless communication of signals related to services (e.g., voice, video, packet data, messaging, broadcast, etc.) according to one or multiple radio access technologies. In some implementations, an NE 102 may be moveable, for example, a satellite associated with a non-terrestrial network (NTN). In some implementations, different geographic coverage areas associated with the same or different radio access technologies may overlap, but the different geographic coverage areas may be associated with different NEs 102.

[0041] The one or more UEs 104 may be dispersed throughout a geographic region of the wireless communications system 100. A UE 104 may include or may be referred to as a remote unit, a mobile device, a wireless device, a remote device, a subscriber device, a transmitter device, a receiver device, or some other suitable terminology. In some implementations, the UE 104 may be referred to as a unit, a station, a terminal, or a client, among other examples. Additionally, or alternatively, the UE 104 may be referred to as an Internet-of-Things (IoT) device, an Internet-of-Everything (IoE) device, or machine-type communication (MTC) device, among other examples.

[0042] A UE 104 may be able to support wireless communication directly with other UEs 104 over a communication link. For example, a UE 104 may support wireless communication directly with another UE 104 over a device-to-device (D2D) communication link. In some implementations, such as vehicle-to-vehicle (V2V) deployments, vehicle-to-everything (V2X) deployments, or cellular-V2X deployments, the communication link may be referred to as a sidelink. For example, a UE 104 may support wireless communication directly with another UE 104 over a PC5 interface.

[0043] An NE 102 may support communications with the CN 106, or with another NE 102, or both. For example, an NE 102 may interface with other NE 102 or the CN 106 through one or more backhaul links (e.g., S1, N2, N2, or network interface). In some implementations, the NEs 102 may communicate with each other directly. In some other implementations, the NEs 102 may communicate with each other indirectly (e.g., via the CN 106). In some implementations, one or more NEs 102 may include subcomponents, such as an access network entity, which may be an example of an access node controller (ANC). An ANC may communicate with the one or more UEs 104 through one or more other access network transmission entities, which may be referred to as radio heads, smart radio heads, or transmission-reception points (TRPs).

[0044] The CN 106 may support user authentication, access authorization, tracking, connectivity, and other access, routing, or mobility functions. The CN 106 may be an evolved packet core (EPC), or a 5G core (5GC), which may include a control plane entity that manages access and mobility (e.g., a mobility management entity (MME), an access and mobility management function (AMF)) and a user plane entity that routes packets or interconnects to external networks (e.g., a serving gateway (S-GW), a Packet Data Network (PDN) gateway (P-GW), or a user plane function (UPF)). In some implementations, the control plane entity may manage non-access stratum (NAS) functions, such as mobility, authentication, and bearer management (e.g., data bearers, signal bearers, etc.) for the one or more UEs 104 served by the one or more NEs 102 associated with the CN 106.

[0045] The CN 106 may communicate with a packet data network over one or more backhaul links (e.g., via an S1, N2, N2, or another network interface). The packet data network may include an application server. In some implementations, one or more UEs 104 may

communicate with the application server. A UE 104 may establish a session (e.g., a protocol data unit (PDU) session, or the like) with the CN 106 via an NE 102. The CN 106 may route traffic (e.g., control information, data, and the like) between the UE 104 and the application server using the established session (e.g., the established PDU session). The PDU session may be an example of a logical connection between the UE 104 and the CN 106 (e.g., one or more network functions of the CN 106).

[0046] In the wireless communications system 100, the NEs 102 and the UEs 104 may use resources of the wireless communications system 100 (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers)) to perform various operations (e.g., wireless communications). In some implementations, the NEs 102 and the UEs 104 may support different resource structures. For example, the NEs 102 and the UEs 104 may support different frame structures. In some implementations, such as in 4G, the NEs 102 and the UEs 104 may support a single frame structure. In some other implementations, such as in 5G and among other suitable radio access technologies, the NEs 102 and the UEs 104 may support various frame structures (e.g., multiple frame structures). The NEs 102 and the UEs 104 may support various frame structures based on one or more numerologies.

[0047] One or more numerologies may be supported in the wireless communications system 100, and a numerology may include a subcarrier spacing and a cyclic prefix. A first numerology (e.g., $\mu=0$) may be associated with a first subcarrier spacing (e.g., 15 kHz) and a normal cyclic prefix. In some implementations, the first numerology (e.g., $\mu=0$) associated with the first subcarrier spacing (e.g., 15 kHz) may utilize one slot per subframe. A second numerology (e.g., $\mu=1$) may be associated with a second subcarrier spacing (e.g., 30 kHz) and a normal cyclic prefix. A third numerology (e.g., $\mu=2$) may be associated with a third subcarrier spacing (e.g., 60 kHz) and a normal cyclic prefix or an extended cyclic prefix. A fourth numerology (e.g., $\mu=3$) may be associated with a fourth subcarrier spacing (e.g., 120 kHz) and a normal cyclic prefix. A fifth numerology (e.g., $\mu=4$) may be associated with a fifth subcarrier spacing (e.g., 240 kHz) and a normal cyclic prefix.

[0048] A time interval of a resource (e.g., a communication resource) may be organized according to frames (also referred to as radio frames). Each frame may have a duration, for example, a 10 millisecond (ms) duration. In some implementations, each frame may include

multiple subframes. For example, each frame may include 10 subframes, and each subframe may have a duration, for example, a 1 ms duration. In some implementations, each frame may have the same duration. In some implementations, each subframe of a frame may have the same duration.

[0049] Additionally or alternatively, a time interval of a resource (e.g., a communication resource) may be organized according to slots. For example, a subframe may include a number (e.g., quantity) of slots. The number of slots in each subframe may also depend on the one or more numerologies supported in the wireless communications system 100. For instance, the first, second, third, fourth, and fifth numerologies (e.g., $\mu=0$, $\mu=1$, $\mu=2$, $\mu=3$, $\mu=4$) associated with respective subcarrier spacings of 15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz may utilize a single slot per subframe, two slots per subframe, four slots per subframe, eight slots per subframe, and 16 slots per subframe, respectively. Each slot may include a number (e.g., quantity) of symbols (e.g., orthogonal frequency division multiplexing (OFDM) symbols). In some implementations, the number (e.g., quantity) of slots for a subframe may depend on a numerology. For a normal cyclic prefix, a slot may include 14 symbols. For an extended cyclic prefix (e.g., applicable for 60 kHz subcarrier spacing), a slot may include 12 symbols. The relationship between the number of symbols per slot, the number of slots per subframe, and the number of slots per frame for a normal cyclic prefix and an extended cyclic prefix may depend on a numerology. It should be understood that reference to a first numerology (e.g., $\mu=0$) associated with a first subcarrier spacing (e.g., 15 kHz) may be used interchangeably between subframes and slots.

[0050] In the wireless communications system 100, an electromagnetic (EM) spectrum may be split, based on frequency or wavelength, into various classes, frequency bands, frequency channels, etc. By way of example, the wireless communications system 100 may support one or multiple operating frequency bands, such as frequency range designations FR1 (410 MHz – 7.125 GHz), FR2 (24.25 GHz – 52.6 GHz), FR3 (7.125 GHz – 24.25 GHz), FR4 (52.6 GHz – 114.25 GHz), FR4a or FR4-1 (52.6 GHz – 71 GHz), and FR5 (114.25 GHz – 300 GHz). In some implementations, the NEs 102 and the UEs 104 may perform wireless communications over one or more of the operating frequency bands. In some implementations, FR1 may be used by the NEs 102 and the UEs 104, among other equipment or devices for cellular communications

traffic (e.g., control information, data). In some implementations, FR2 may be used by the NEs 102 and the UEs 104, among other equipment or devices for short-range, high data rate capabilities.

[0051] FR1 may be associated with one or multiple numerologies (e.g., at least three numerologies). For example, FR1 may be associated with a first numerology (e.g., $\mu=0$), which includes 15 kHz subcarrier spacing; a second numerology (e.g., $\mu=1$), which includes 30 kHz subcarrier spacing; and a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing. FR2 may be associated with one or multiple numerologies (e.g., at least 2 numerologies). For example, FR2 may be associated with a third numerology (e.g., $\mu=2$), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g., $\mu=3$), which includes 120 kHz subcarrier spacing.

[0052] With the development of communication technology, enhancements on downlink multiple input multiple output (MIMO) that facilitate the use of large antenna array, for both FR1 and FR2, are proposed to fulfil the demand for evolution of NR deployments, especially for 7GHz frequency band(s). In the existing 5G system, the CSI-RS port is designed based on a maximum port number of 32. However, for the large antenna array, a larger number of CSI-RS ports (e.g., more than 32 ports) may be used to further increase beamforming gain, thereby improving the cell coverage and cell average/edge throughput, especially for the case that the CSI-RS ports are implemented with full digital ports. Herein, the terms "port," "CSI-RS port," "antenna port" and "CSI-RS antenna port" may be used interchangeably.

[0053] Multiple panels may be used for a large antenna array, which can reduce realization complexity since there is no strict requirement on spacing and time/frequency transmission difference between multiple panels.

[0054] Type I codebook may be used for single-user multiple-input multiple-output (SU-MIMO) scenarios. A Type I codebook may include PMI values and codewords (i.e., precoding matrices) corresponding to the PMI values. For a BS with a hardware structure of multiple panels, a Type I multi-panel codebook may be used for CSI reporting.

[0055] In the existing 5G system, a Type I multi-panel codebook is designed based on CSI-RS with 8, 16, or 32 ports. To support CSI reporting using more than 32 ports, an enhanced

Type I multi-panel codebook for more than 32 ports needs to be designed, which may involve various issues such as:

- how to define the configuration for a large antenna array with multiple panels;
- how to determine selected beams for 3-layer or 4-layer CSI reporting using more than 32 ports; or
- how to design a codebook for three panels.

[0056] Embodiments of the present disclosure provide solutions for designing enhanced Type I multi-panel codebook for more than 32 ports, which can solve at least one of the above issues. More details will be described in the following text in combination with the appended drawings.

[0057] In the existing 5G system, for an antenna array with 8, 16, or 32 CSI-RS ports, a number of panels (e.g., denoted as N_g) of the antenna array, a number of antenna ports (e.g., denoted as N_1) per polarization direction per panel in a horizontal direction of the antenna array, and a number of antenna ports (e.g., denoted as N_2) per polarization direction per panel in a vertical direction of the antenna array may be configured by higher layer parameters (e.g., $ng-n1-n2$ as specified in 3GPP standard documents), wherein N_g may be one of 2 and 4, and (N_1, N_2) may be one of (2, 1), (4, 1), (2, 2), (8, 1), and (4, 2). (N_1, N_2) may define an array size of a panel.

[0058] To support multi-panel codebook for an antenna array with more than 32 CSI-RS ports, new configurations of (N_g, N_1, N_2) may be defined. According to some embodiments of the present application, the new configurations of (N_g, N_1, N_2) may be extensions of the aforementioned existing configurations of (N_g, N_1, N_2) .

[0059] In some embodiments of the present application, for the antenna array with more than 32 CSI-RS ports, the legacy panel number, e.g., 2 or 4, may be reused, while an array size per panel of the antenna array may be increased. Generally, it is assumed that $N_1 \geq N_2$, so as to achieve a good horizontal beamforming granularity and beamforming gain as much as possible.

[0060] In an embodiment, the array size per panel of the antenna array may reuse the existing array sizes supported by Type I single-panel (SP) codebook and those supported by existing Type I multi-panel (MP) codebook as much as possible.

[0061] As an example, in the case of an antenna array with 64 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (2, 16, 1), (2, 8, 2), (2, 4, 4), (4, 8, 1), or (4, 4, 2), wherein (16, 1), (8, 2), and (4, 4) are newly introduced array sizes for a panel of multiple panels.

[0062] As another example, in the case of an antenna array with 128 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (2, 32, 1), (2, 16, 2), (2, 8, 4), (4, 16, 1), (4, 8, 2), or (4, 4, 4), wherein (16, 1), (8, 2), (4, 4), (32, 1), (16, 2), and (8, 4) are newly introduced array sizes for a panel of multiple panels.

[0063] In the above examples, array sizes of (8, 1) and (4, 2) are supported by legacy Type I MP codebook for no more than 32 CSI-RS ports, array sizes of (16, 1), (8, 2), and (4, 4) are supported by legacy Type I SP codebook for no more than 32 CSI-RS ports, and array sizes of (32, 1), (16, 2), and (8, 4) may be supported by enhanced Type I SP codebook for more than 32 CSI-RS ports. With these larger array sizes, a larger horizontal and/or vertical beamforming gain may be obtained. In addition, these larger array sizes may also be compatible with the legacy multi-panel codebook structure and will not cause large effort for the specification work.

[0064] In addition to 64 CSI-RS ports and 128 CSI-RS ports, 48 and/or 96 CSI-RS ports may also be supported for the antenna array with more than 32 CSI-RS ports because they can provide a middle port number between 32 and 64 ports and between 64 and 128 ports, respectively, for an antenna array with a middle size.

[0065] As an example, in the case of an antenna array with 48 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (2, 12, 1), (2, 6, 2), (2, 4, 3), (4, 6, 1), or (4, 3, 2), wherein (12, 1), (6, 2), (4, 3), (6, 1), and (3, 2) are newly introduced array sizes for a panel of multiple panels.

[0066] As another example, in the case of an antenna array with 96 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (2, 24, 1), (2, 12, 2), (2, 8, 3), (2, 6, 4), (4, 12, 1), (4,

6, 2), or (4, 4, 3), wherein (24, 1), (12, 2), (8, 3), (6, 4), (12, 1), (6, 2) and (4, 3) are newly introduced array sizes for a panel of multiple panels.

[0067] In the above examples, array sizes of (12, 1), (6, 2), (4, 3), (6, 1), and (3, 2) are supported by legacy Type I SP codebook for no more than 32 CSI-RS ports, and array sizes of (24, 1), (12, 2), (8, 3), and (6, 4) may be supported by enhanced Type I SP codebook for more than 32 CSI-RS ports. With these larger array sizes, a larger horizontal and/or vertical beamforming gain may be obtained. In addition, these larger array sizes may also be compatible with the legacy multi-panel codebook structure and will not cause large effort for the specification work.

[0068] In some other embodiments of the present application, an addition panel number, e.g., 3, may be used for an antenna array with more than 32 CSI-RS ports. 3 panels in addition to 2 and 4 panels used for the antenna array may provide more flexible antenna array configuration. In such embodiments, an array size per panel of the antenna array may be an existing array size or an increased array size. Generally, it is also assumed that $N_1 \geq N_2$, so as to achieve a good horizontal beamforming granularity and beamforming gain as much as possible.

[0069] As an example, in the case of an antenna array with 48 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (3, 8, 1) or (3, 4, 2).

[0070] As another example, in the case of an antenna array with 96 CSI-RS ports, the configuration of (N_g, N_1, N_2) may include (3, 16, 1), (3, 8, 2), or (3, 4, 4), wherein (16, 1), (8, 2), and (4, 4) are newly introduced array sizes for a panel of multiple panels.

[0071] In the above examples, array sizes of (8, 1) and (4, 2) are supported by legacy Type I MP codebook for no more than 32 CSI-RS ports, and array sizes of (16, 1), (8, 2), and (4, 4) are supported by legacy Type I SP codebook for no more than 32 CSI-RS ports.

[0072] With supporting new codebook for 3 panels, it is more friendly to BS's implementation in case of 48 or 96 CSI-RS ports. Moreover, it can also provide good performance on account of a larger horizontal and vertical beamforming gain obtained from the larger array sizes and a combination gain obtained from multiple panels.

[0073] The configuration of (N_g, N_1, N_2) may be associated with a configuration of (O_1, O_2) for the antenna array, wherein O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor. In some embodiments, the candidate values for (O_1, O_2) may include (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) and (4, 4).

[0074] In some embodiments, the association between configurations of (N_g, N_1, N_2) and configurations of (O_1, O_2) may be predefined in a configuration association table. In such embodiments, a BS may transmit configuration information including a configuration of (N_g, N_1, N_2) to a UE, e.g., via radio resource control (RRC) signaling. The BS and the UE may determine a configuration of (O_1, O_2) associated with the configuration of (N_g, N_1, N_2) based on the configuration association table.

[0075] An example of the configuration association table may be the following Table 1, which include exemplary configurations of (N_g, N_1, N_2) and associated configurations of (O_1, O_2) for an antenna array with more than 32 ports in addition to the legacy configurations of (N_g, N_1, N_2) and associated configurations of (O_1, O_2) for an antenna array with no more than 32 ports.

Table 1: Supported configurations of (N_g, N_1, N_2) and (O_1, O_2)

Number of CSI-RS antenna ports, $P_{\text{CSI-RS}}$	(N_g, N_1, N_2)	(O_1, O_2)
8	(2,2,1)	(4,1)
16	(2,4,1)	(4,1)
	(4,2,1)	(4,1)
	(2,2,2)	(4,4)
	(2,8,1)	(4,1)
32	(4,4,1)	(4,1)
	(2,4,2)	(4,4)
	(4,2,2)	(4,4)
	(2,16,1)	(4,1)
64	(2,8,2)	(4,4)
	(2,4,4)	(4,4)
	(4,8,1)	(4,1)
	(4,4,2)	(4,4)
	(2,32,1)	(4,1)
128	(2,16,2)	(4,4)
	(2,8,4)	(4,4)
	(4,16,1)	(4,1)
	(4,8,2)	(4,4)
	(4,4,4)	(4,4)
	(2,12,1)	(4,1)
48	(2,6,2)	(4,4)
	(2,4,3)	(4,4)
	(3,8,1)	(4,1)
	(3,4,2)	(4,4)
	(4,6,1)	(4,1)
	(4,3,2)	(4,4)
	(2,24,1)	(4,1)
	(2,12,2)	(4,4)
96	(2,8,3)	(4,4)
	(2,6,4)	(4,4)
	(3,16,1)	(4,1)
	(3,8,2)	(4,4)
	(3,4,4)	(4,4)
	(4,12,1)	(4,1)
	(4,6,2)	(4,4)
	(4,4,3)	(4,4)
	(2,24,1)	(4,1)
	(2,12,2)	(4,4)

[0076] It should be understood that it is not necessary to include all the exemplary configurations of (N_g, N_1, N_2) listed in Table 1 in the configuration association table. Also, it

should be understood that the configuration association table may include other configurations of (N_g, N_1, N_2) which are not listed in Table 1.

[0077] In the examples provided in Table 1, the associated configuration of (O_1, O_2) is (4, 4) when $N_2 > 1$, and the associated configuration of (O_1, O_2) is (4, 1) when $N_2 = 1$. It is contemplated that other configurations of (O_1, O_2) may be applied. For example, in some other examples of the present disclosure, when $N_2 > 1$, the associated configuration of (O_1, O_2) may be (4, 2), (4, 1), (2, 2), (2, 1) or (1, 1), and when $N_2 = 1$, the associated configuration of (O_1, O_2) may be (2, 1) or (1, 1).

[0078] In some other embodiments, the configuration of (N_g, N_1, N_2) and its associated configuration of (O_1, O_2) may be jointly configured in the same configuration information, or separately configured in different configuration information.

[0079] In some examples, a configuration association table between configurations of (N_g, N_1, N_2) and configurations of (O_1, O_2) may be designed such that at least one configuration of (N_g, N_1, N_2) may correspond to two or more candidate configurations of (O_1, O_2) . The candidate configurations of (O_1, O_2) in the configuration association table may be selected from all the supported configurations of (O_1, O_2) . For example, for the case of $N_2 > 1$, all the supported configurations of (O_1, O_2) may include (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) and (4, 4), and for the case of $N_2 = 1$, all the supported configurations of (O_1, O_2) may include (4, 1), (2, 1) and (1, 1).

[0080] In such examples, a BS may transmit configuration information including a configuration of (N_g, N_1, N_2) to a UE, e.g., via RRC signaling. In the case that the configuration of (N_g, N_1, N_2) corresponds to two or more candidate configurations of (O_1, O_2) according to the configuration association table, as an example, the BS may jointly configure a configuration of (O_1, O_2) associated with the configuration of (N_g, N_1, N_2) in the configuration information (e.g., the configuration information may include the configuration of (O_1, O_2) , or include an index associated with the configuration of (O_1, O_2) in the case that each of the two or more candidate configurations of (O_1, O_2) has an associated index), wherein the configuration of (O_1, O_2) is selected from the two or more candidate configurations of (O_1, O_2) . As another

example, the BS may separately configure a configuration of (O_1, O_2) associated with the configuration of (N_g, N_1, N_2) in another configuration information (e.g., the BS may transmit another configuration information including the configuration of (O_1, O_2) or including an index associated with the configuration of (O_1, O_2) in the case that each of the two or more candidate configurations of (O_1, O_2) has an associated index), wherein the configuration of (O_1, O_2) is selected from the two or more candidate configurations of (O_1, O_2) .

[0081] An example of the configuration association table may be the following Table 2.

Table 2: Candidate configurations of (N_g, N_1, N_2) and (O_1, O_2)

Number of CSI-RS antenna ports, $P_{\text{CSI-RS}}$	(N_g, N_1, N_2)	(O_1, O_2)
8	(2,2,1)	(4,1)
		(2,1)
16	(2,4,1)	(4,1)
		(2,1)
	(4,2,1)	(4,1)
		(1,1)
	(2,2,2)	(4,4)
		(4,2)
32	(2,8,1)	(4,1)
		(1,1)
	(4,4,1)	(4,1)
		(2,1)
	(2,4,2)	(4,4)
		(4,2)
	(4,2,2)	(4,4)
		(2,2)
64	(2,16,1)	(4,1)
		(2,1)
	(2,8,2)	(4,4)
		(2,2)
	(2,4,4)	(4,4)
		(4,2)
	(4,8,1)	(4,1)
		(2,1)
	(4,4,2)	(4,4)
		(2,2)
128	(2,32,1)	(4,1)
		(2,1)
	(2,16,2)	(4,4)
		(4, 2)

	(2,8,4)	(4,4)
		(4,2)
		(4,1)
		(2,1)
		(4,4)
		(4,2)
	(4,16,1)	(4,4)
		(4,2)
		(4,1)
		(2,1)
		(4,4)
		(4,2)
	(4,8,2)	(4,4)
		(4,2)
		(4,4)
		(4,2)
		(4,4)
		(4,2)
	(4,4,4)	(4,4)
		(4,2)
48	(2,12,1)	(4,1)
		(2,1)
	(2,6,2)	(4,4)
		(4,2)
	(2,4,3)	(4,4)
		(4,2)
	(3,8,1)	(4,1)
		(2,1)
	(3,4,2)	(4,4)
		(4, 2)
	(4,6,1)	(4,1)
		(2,1)
96	(4,3,2)	(4,4)
		(4,2)
	(2,24,1)	(4,1)
		(2,1)
	(2,12,2)	(4,4)
		(4,2)
	(2,8,3)	(4,4)
		(4,2)
	(2,6,4)	(4,4)
		(4,2)
	(3,16,1)	(4,1)
		(2,1)
	(3,8,2)	(4,4)
		(2,2)
	(3,4,4)	(4,4)
		(4,2)
	(4,12,1)	(4,1)
		(2,1)
	(4,6,2)	(4,4)
		(2,2)
	(4,4,3)	(4,4)
		(4,2)

[0082] It should be understood that it is not necessary to include all the exemplary configurations of (N_g, N_1, N_2) listed in Table 2 in the configuration association table. Also, it

should be understood that the configuration association table may include other configurations of (N_g, N_1, N_2) which are not listed in Table 2. Although Table 2 shows that each configuration of (N_g, N_1, N_2) corresponds to the same number (e.g., two) of candidate configurations of (O_1, O_2) , it should be understood that the number of candidate configurations of (O_1, O_2) for each configuration of (N_g, N_1, N_2) may be different. The candidate configurations of (O_1, O_2) listed in Table 2 are only for illustrative purpose, and other configurations of (O_1, O_2) from all the supported configurations of (O_1, O_2) may be applied. In some cases, the candidate configuration(s) of (O_1, O_2) corresponding to each configuration of (N_g, N_1, N_2) may have an associated index. For example, for (2,2,1), the associated indexes of (4,1) and (2,1) may be 0 and 1, respectively.

[0083] In some other examples, there is no configuration association table, and a BS may transmit configuration information including a configuration of (N_g, N_1, N_2) to a UE, e.g., via RRC signaling. As an example, the BS may jointly configure a configuration of (O_1, O_2) associated with the configuration of (N_g, N_1, N_2) in the configuration information (e.g., the configuration information may include the configuration of (O_1, O_2) , or include an index associated with the configuration of (O_1, O_2) in the case that each of the supported configurations of (O_1, O_2) has an associated index), wherein the configuration of (O_1, O_2) is selected from all the supported configurations of (O_1, O_2) . As another example, the BS may separately configure a configuration of (O_1, O_2) associated with the configuration of (N_g, N_1, N_2) in another configuration information (e.g., the BS may transmit another configuration information including the configuration of (O_1, O_2) or including an index associated with the configuration of (O_1, O_2) in the case that each of the supported configurations of (O_1, O_2) has an associated index), wherein the configuration of (O_1, O_2) is selected from all the supported configurations of (O_1, O_2) . For example, for the case of $N_2 > 1$, all the supported configurations of (O_1, O_2) may include (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) and (4, 4), which may have indexes of 0, 1, 2, 3, 4 and 5, respectively, and for the case of $N_2 = 1$, all the supported configurations of (O_1, O_2) may include (4, 1), (2, 1) and (1, 1), which may have indexes of 0, 1, and 2, respectively.

[0084] According to some embodiments of the present application, to support CSI reporting using more than 32 CSI-RS ports, multiple CSI-RS resources may be used for channel measurement. For example, for an antenna array with more than 32 CSI-RS ports which is configured with N_g panels, a BS may transmit a configuration for N_g CSI-RS resources to a UE, wherein each CSI-RS resource is associated with a corresponding panel of the antenna array. In such embodiments, for CSI reporting, CSI-RS ports are ordered first according to an order from a lowest port index to a highest port index within a CSI-RS resource, and then according to an order from a lowest CSI-RS resource index to a highest CSI-RS resource index of the N_g CSI-RS resources.

[0085] For example, assuming that each CSI-RS resource has P CSI-RS ports, the CSI-RS ports are ordered as: (CSI-RS resource index 0 associated with panel 0, port index 0), (CSI-RS resource index 0 associated with panel 0, port index 1), ..., (CSI-RS resource index 0 associated with panel 0, port index $P-1$), (CSI-RS resource index 1 associated with panel 1, port index 0), (CSI-RS resource index 1 associated with panel 1, port index 1), ..., (CSI-RS resource index 1 associated with panel 1, port index $P-1$), ..., (CSI-RS resource index $N_g - 1$ associated with panel $N_g - 1$, port index 0), (CSI-RS resource index $N_g - 1$ associated with panel $N_g - 1$, port index 1), ..., (CSI-RS resource index $N_g - 1$ associated with panel $N_g - 1$, port index $P-1$).

[0086] For an antenna array with no more than 32 antenna ports, based on configurations of (N_g, N_1, N_2) and (O_1, O_2) for the antenna array, the Type I MP codebook for 1-layer CSI reporting to 4-layer CSI reporting may be derived based on the following Table 3, Table 4, Table 5, and Table 6, respectively, wherein Table 3, Table 4, Table 5, and Table 6 are the same as Table 5.2.2.2.2-3, Table 5.2.2.2.2-4, Table 5.2.2.2.2-5, and Table 5.2.2.2.2-6 as specified in 3GPP TS 38.214, respectively. A UE may determine a PMI based on the derived Type I MP codebook. The PMI may include bit(s) indicating at least one of: a value of $i_{1,1}$, a value of $i_{1,2}$, a value of $i_{1,3}$, a value of $i_{1,4}$, or a value of i_2 determined by the UE. $i_{1,1}$, $i_{1,2}$, $i_{1,3}$, $i_{1,4}$, and i_2 are indexes associated with the derived Type I MP codebook, and may be selected from the value ranges defined in the following Table 3, Table 4, Table 5, and Table 6, respectively.

Table 3: Codebook for 1-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1, $N_g \in \{2, 4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, \dots, N_g - 1$	i_2	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	$0, 1, 2, 3$	$0, 1, 2, 3$	$W_{i_{1,1}, i_{1,2}, i_{1,4}, i_2}^{(1)}$
where $W_{l,m,p,n}^{(1)} = W_{l,m,p,n}^{1,N_g,1}$				

codebookMode = 2, $N_g = 2$					
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, 2$	$i_{2,0}$	$i_{2,q}, q = 1, 2$	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	$0, 1, 2, 3$	$0, 1, 2, 3$	$0, 1$	$W_{i_{1,1}, i_{1,2}, i_{1,4}, i_2}^{(1)}$
where $W_{l,m,p,n}^{(1)} = W_{l,m,p,n}^{1,N_g,2}$					

Table 4: Codebook for 2-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1, $N_g \in \{2, 4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, \dots, N_g - 1$	i_2	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	$0, 1, 2, 3$	$0, 1$	$W_{i_{1,1}, i_{1,2}, i_{1,4}, i_2}^{(2)}$
where $W_{l,l',m,m',p,n}^{(2)} = \frac{1}{\sqrt{2}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,1} & W_{l',m',p,n}^{1,N_g,1} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.				

codebookMode = 2, $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, 2$	$i_{2,q}, q = 0, 1, 2$	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	$0, 1, 2, 3$	$0, 1$	$W_{i_{1,1}, i_{1,2}, i_{1,4}, i_2}^{(2)}$
where $W_{l,l',m,m',p,n}^{(2)} = \frac{1}{\sqrt{2}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,2} & W_{l',m',p,n}^{1,N_g,2} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.1-3.				

Table 5: Codebook for 3-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1, $N_g \in \{2, 4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, \dots, N_g - 1$	i_2	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0, 1, 2, 3	0, 1	$W_{i_{1,1}i_{1,2}+k_1i_{1,2}+k_2i_{1,4}i_2}^{(3)}$
where $W_{l,l',m,m',p,n}^{(3)} = \frac{1}{\sqrt{3}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,1} & W_{l',m',p,n}^{1,N_g,1} & W_{l,m,p,n}^{2,N_g,1} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

codebookMode = 2, $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, 2$	$i_{2,q}, q = 0, 1, 2$	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0, 1, 2, 3	0, 1	$W_{i_{1,1}i_{1,2}+k_1i_{1,2}+k_2i_{1,4}i_2}^{(3)}$
where $W_{l,l',m,m',p,n}^{(3)} = \frac{1}{\sqrt{3}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,2} & W_{l',m',p,n}^{1,N_g,2} & W_{l,m,p,n}^{2,N_g,2} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

Table 6: Codebook for 4-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1, $N_g \in \{2, 4\}$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, \dots, N_g - 1$	i_2	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0, 1, 2, 3	0, 1	$W_{i_{1,1}i_{1,2}+k_1i_{1,2}+k_2i_{1,4}i_2}^{(4)}$
where $W_{l,l',m,m',p,n}^{(4)} = \frac{1}{\sqrt{4}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,1} & W_{l',m',p,n}^{1,N_g,1} & W_{l,m,p,n}^{2,N_g,1} & W_{l',m',p,n}^{2,N_g,1} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

codebookMode = 2, $N_g = 2$				
$i_{1,1}$	$i_{1,2}$	$i_{1,4,q}, q = 1, 2$	$i_{2,q}, q = 0, 1, 2$	
$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0, 1, 2, 3	0, 1	$W_{i_{1,1}i_{1,2}+k_1i_{1,2}+k_2i_{1,4}i_2}^{(4)}$
where $W_{l,l',m,m',p,n}^{(4)} = \frac{1}{\sqrt{4}} \begin{bmatrix} W_{l,m,p,n}^{1,N_g,2} & W_{l',m',p,n}^{1,N_g,2} & W_{l,m,p,n}^{2,N_g,2} & W_{l',m',p,n}^{2,N_g,2} \end{bmatrix}$ and the mapping from $i_{1,3}$ to k_1 and k_2 is given in Table 5.2.2.2.2-2.				

[0087] Type I MP codebook for CSI reporting using more than 32 ports may reuse Table 3, Table 4, Table 5, and Table 6, except for some modifications.

[0088] According to Table 5 and Table 6, it can be seen that a legacy Type I MP codebook for 3-layer or 4-layer CSI reporting using no more than 32 ports may be associated with two

orthogonal beams. A first beam of the two orthogonal beams may be determined by $i_{1,1}$ and $i_{1,2}$, wherein $i_{1,1}$ is selected from $\{0, 1, \dots, N_1 O_1 - 1\}$, and $i_{1,2}$ is selected from $\{0, 1, \dots, N_2 O_2 - 1\}$. A second beam of the two orthogonal beams may be determined based on a horizontal beam offset value (e.g., denoted as k_1) and a vertical beam offset value (e.g., denoted as k_2) with respect to the first beam of the two orthogonal beams.

[0089] The pair of (k_1, k_2) may be determined by $i_{1,3}$. The following Table 7 illustrates mapping from $i_{1,3}$ to a pair of (k_1, k_2) . Table 7 is the same as Table 5.2.2.2.2-2 as specified in 3GPP TS 38.214.

Table 7: Mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer CSI reporting

$i_{1,3}$	$N_1 = 2, N_2 = 1$		$N_1 = 4, N_2 = 1$		$N_1 = 8, N_2 = 1$		$N_1 = 2, N_2 = 2$		$N_1 = 4, N_2 = 2$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	O_1	0	O_1	0	O_1	0	O_1	0	O_1	0
1			$2O_1$	0	$2O_1$	0	0	O_2	0	O_2
2			$3O_1$	0	$3O_1$	0	O_1	O_2	O_1	O_2
3					$4O_1$	0			$2O_1$	0

[0090] Table 7 illustrates possible values of (k_1, k_2) for existing array sizes of a panel of an antenna array with no more than 32 ports. However, as stated above, for an antenna array with more than 32 ports, additional array sizes (e.g., additional values of (N_1, N_2)) for a panel may be introduced. For example, these values of (N_1, N_2) may be supported by legacy SP codebook, such as (16, 1), (8, 2), (4, 4), (12, 1), (6, 2), (4, 3), (6, 1), or (3, 2), or may be supported by enhanced SP codebook, such as (32, 1), (16, 2), (8, 4), (24, 1), (12, 2), (8, 3), (6, 4), or (3, 1). For these newly introduced values of (N_1, N_2) , the corresponding values of (k_1, k_2) are not defined in Table 7. Then, how to define the corresponding values of (k_1, k_2) for newly introduced values of (N_1, N_2) needs to be solved.

[0091] According to some embodiments of the present application, values of (k_1, k_2) may be designed based on the principle that the adjacent beams are selected with most probability. In an embodiment, to achieve tradeoff between feedback overhead and candidate beams for selection, no more than 4 candidate pairs of (k_1, k_2) may be used for a panel with a large array size, and thus a UE may report a 2-bit indication indicating $i_{1,3}$ to a BS.

[0092] In some examples, in the case that $N_1 \geq N_2 \geq 2$ except $N_1 = 2$ and $N_2 = 2$, the 2-bit indication may be used to indicate both the horizontal and vertical beam offsets. As an example, in the case that $N_1 \geq N_2 \geq 2$ except $N_1 = 2$ and $N_2 = 2$, the candidate pairs of (k_1, k_2) may include $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$.

[0093] In some examples, in the case that $N_1 \geq 6$ and $N_2 = 1$, there is no beam in vertical domain and the 2-bit indication may be used to indicate the horizontal beam offset. As an example, in the case that $N_1 \geq 6$ and $N_2 = 1$, the candidate pairs of (k_1, k_2) may include $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$.

[0094] In some examples, for the case that $N_1 = 3$ and $N_2 = 1$, it is enough to achieve the similar beam selecting range as $N_1 = 4$ and $N_2 = 1$. Thus, the candidate pairs of (k_1, k_2) may include $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$ for the case that $N_1 = 3$ and $N_2 = 1$.

[0095] The following Table 8 illustrates an exemplary mapping table from $i_{1,3}$ to a pair of (k_1, k_2) for 3-layer or 4-layer CSI reporting using more than 32 antenna ports. Table 8 may be generated based on Table 7. Compared with Table 7, Table 8 includes the aforementioned candidate pairs of (k_1, k_2) for additional array sizes (e.g., additional values of (N_1, N_2)) for a panel. It is contemplated that other mapping relationship may be applied without departing from the spirit of the present disclosure.

Table 8: Mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer

$i_{1,3}$	$N_1 = 2, N_2 = 1$		$N_1 = 4, N_2 = 1$ or $N_1 = 3, N_2 = 1$		$N_1 \geq 6, N_2 = 1$		$N_1 = 2, N_2 = 2$		$N_1 \geq N_2 \geq 2$ except $N_1 = 2, N_2 = 2$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	O_1	0	O_1	0	O_1	0	O_1	0	O_1	0
1			$2O_1$	0	$2O_1$	0	0	O_2	0	O_2
2			$3O_1$	0	$3O_1$	0	O_1	O_2	O_1	O_2
3					$4O_1$	0			$2O_1$	0

[0096] According to some embodiments of the present application, more possible pairs of (k_1, k_2) may be introduced for panels with a large array size and a UE may report an indication with two or more bits for indicating $i_{1,3}$ to a BS. With the increasing number of horizontal and vertical beam offsets (i.e., candidate pairs of (k_1, k_2)), the impact on the finer beam caused by

a larger array size of a panel may be reduced and the spatial range for beams may be increased as much as possible.

[0097] In some embodiments, when $N_2 = 1$, there is no need for the beam indication in the vertical domain and the indication with two or more bits may be used to indicate only the horizontal beam offset.

[0098] As an example, in the case that $N_1 > 8$ and $N_2 = 1$ (e.g., (N_1, N_2) is $(16, 1)$, $(12, 1)$, $(24, 1)$, or $(32, 1)$), the candidate pairs of (k_1, k_2) may include $(0_1, 0)$, $(20_1, 0)$, $(30_1, 0)$, $(40_1, 0)$, $(50_1, 0)$, $(60_1, 0)$, $(70_1, 0)$, or $(80_1, 0)$. In such example, three bits may be enough to indicate the eight candidate pairs of (k_1, k_2) . The UE may transmit a 3-bit indication for indicating $i_{1,3}$ (which is mapped to one candidate pair of (k_1, k_2) of the eight candidate pairs of (k_1, k_2)).

[0099] As another example, for the case that $N_1 = 3$ and $N_2 = 1$, it is enough to achieve the similar beam selecting range as $N_1 = 4$ and $N_2 = 1$. Thus, the candidate pairs of (k_1, k_2) may include $(0_1, 0)$, $(20_1, 0)$, or $(30_1, 0)$ for the case that $N_1 = 3$ and $N_2 = 1$. In such example, two bits may be enough to indicate the three candidate pairs of (k_1, k_2) . The UE may transmit a 2-bit indication for indicating $i_{1,3}$ (which is mapped to one candidate pair of (k_1, k_2) of the three candidate pairs of (k_1, k_2)).

[0100] As another example, for the case that $N_1 = 6$ and $N_2 = 1$, it is enough to achieve the similar beam selecting range as $N_1 = 8$ and $N_2 = 1$. Thus, the candidate pairs of (k_1, k_2) may include $(0_1, 0)$, $(20_1, 0)$, $(30_1, 0)$, or $(40_1, 0)$ for the case that $N_1 = 6$ and $N_2 = 1$. In such example, two bits may be enough to indicate the four candidate pairs of (k_1, k_2) . The UE may transmit a 2-bit indication for indicating $i_{1,3}$ (which is mapped to one candidate pair of (k_1, k_2) of the four candidate pairs of (k_1, k_2)).

[0101] In some embodiments, when $N_2 > 1$, the indication with two or more bits may be used to indicate both the horizontal and vertical beam offsets for a panel with a larger array size, e.g., including $(8, 2)$, $(4, 4)$, $(6, 2)$, $(4, 3)$, $(16, 2)$, $(8, 4)$, $(12, 2)$, $(8, 3)$, or $(6, 4)$.

[0102] As an example, in the case that $N_1 \geq 4$ and $N_2 \geq 2$ except $N_1 = 4$ and $N_2 = 2$, the candidate pairs of (k_1, k_2) may include $(0_1, 0)$, $(0, 0_2)$, $(0_1, 0_2)$, $(20_1, 0)$, $(20_1, 0_2)$, $(20_1, 20_2)$,

$(0, 2O_2)$, or $(O_1, 2O_2)$, which can provide a full indication for beam selection in spatial range within two non-oversampling beams in horizontal domain and vertical domain. In such example, three bits may be enough to indicate the eight candidate pairs of (k_1, k_2) . The UE may transmit a 3-bit indication for indicating $i_{1,3}$ (which is mapped to one candidate pair of (k_1, k_2) of the eight candidate pairs of (k_1, k_2)).

[0103] As another example, for the case that $N_1 = 3$ and $N_2 = 2$, it is enough to achieve the similar beam selecting range as $N_1 = 4$ and $N_2 = 2$. Thus, the candidate pairs of (k_1, k_2) may include $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$ for the case that $N_1 = 3$ and $N_2 = 2$. In such example, two bits may be enough to indicate the four candidate pairs of (k_1, k_2) . The UE may transmit a 2-bit indication for indicating $i_{1,3}$ (which is mapped to one candidate pair of (k_1, k_2) of the four candidate pairs of (k_1, k_2)).

[0104] The following Table 9 illustrates an exemplary mapping table from $i_{1,3}$ to a pair of (k_1, k_2) for 3-layer or 4-layer CSI reporting using more than 32 antenna ports. Table 9 may be generated based on Table 7. Compared with Table 7, Table 9 includes the aforementioned candidate pairs of (k_1, k_2) for additional array sizes (e.g., additional values of (N_1, N_2)) for a panel. It is contemplated that other mapping relationship may be applied without departing from the spirit of the present disclosure.

Table 9: Mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer CSI reporting

$i_{1,3}$	$N_1 = 2, N_2 = 1$		$N_1 = 4, N_2 = 1$ or $N_1 = 3, N_2 = 1$		$N_1 = 6, N_2 = 1$ or $N_1 = 8, N_2 = 1$		$N_1 > 8, N_2 = 1$		$N_1 = 2, N_2 = 2$		$N_1 = 4, N_2 = 2$ Or $N_1 = 3, N_2 = 2$		$N_1 \geq 4, N_2 \geq 2$ except $N_1 = 4, N_2 = 2$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	0_1	0	0_1	0	0_1	0	0_1	0	0_1	0	0_1	0	0_1	0
1			20_1	0	20_1	0	20_1	0	0	0_2	0	0_2	0	0_2
2			30_1	0	30_1	0	30_1	0	0_1	0_2	0_1	0_2	0_1	0_2
3					40_1	0	40_1	0			20_1	0	20_1	0
5							50_1	0					20_1	0_2
6							60_1	0					20_1	20_2
7							70_1	0					0	20_2
8							80_1	0					0_1	20_2

[0105] Although it is described that a 2-bit indication may be used for indicating $i_{1,3}$ for some array sizes shown in Table 9, it is contemplated that a 3-bit indication may be used for indicating $i_{1,3}$ for all the array sizes shown in Table 9.

[0106] In some examples, the aforementioned mapping table from $i_{1,3}$ to a pair of (k_1, k_2) (e.g., Tables 8 and 9) may be used together with Table 5 and Table 6 to determine the multi-panel codebook for 3-layer or 4-layer CSI reporting using more than 32 CSI-RS ports.

[0107] According to Tables 3-6, it can be seen that for a legacy Type I MP codebook, only $N_g = 2$ or 4 is supported and codebook structure is designed based on two or four panels. For example, for codebook mode 1, the codebook structure is designed based on two or four panels, whereas for codebook mode 2, the codebook structure is designed based only on two panels. However, as stated above, for CSI-RS reporting with more than 32 CSI-RS ports, three panels may be used. Then, how to design a Type I MP codebook for three panels needs to be solved.

[0108] Given this, the following embodiments provide four solutions for designing the Type I MP codebook for three panels, wherein solutions 1-3 are related to design of Type I MP codebook for three panels for codebook mode 2 for CSI reporting using more than 32 CSI-RS ports, whereas solution 4 is related to design of Type I MP codebook for three panels for codebook mode 1 for CSI reporting using more than 32 CSI-RS ports.

[0109] **Solution 1**

[0110] In solution 1, wideband cophasing factors between panels and between polarizations and subband cophasing factors between panels and between polarizations are introduced. Compared with the codebook for two panels, the codebook for three panels introduces additional two wideband cophasing factors respectively corresponding to two polarization directions for the third panel and two subband cophasing factors respectively corresponding to two polarization directions for the third panel.

[0111] In solution 1, the codebook for three panels for codebook mode 2 for CSI reporting using more than 32 CSI-RS ports may be determined based on a first wideband cophasing factor (e.g., denoted as a_{p_1}) and a second wideband cophasing factor (e.g., denoted as a_{p_2}) respectively corresponding to two polarization directions for a second panel, a third wideband cophasing factor (e.g., denoted as a_{p_3}) and a fourth wideband cophasing factor (e.g., denoted as a_{p_4}) respectively corresponding to two polarization directions for a third panel, a first subband cophasing factor (e.g., denoted as b_{n_1}) and a second subband cophasing factor (e.g., denoted as b_{n_2}) respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor (e.g., denoted as b_{n_3}) and a fourth subband cophasing factor (e.g., denoted as b_{n_4}) respectively corresponding to two polarization directions for the third panel.

[0112] In some embodiments of the present application, the PMI reported by the UE may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the third wideband cophasing factor, the fourth wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, and the fourth subband cophasing factor. As an example, the PMI may indicate p_1 for a_{p_1} , p_2 for a_{p_2} , p_3 for a_{p_3} , p_4 for a_{p_4} , n_1 for b_{n_1} , n_2 for b_{n_2} , n_3 for b_{n_3} , and n_4 for b_{n_4} . For example, p_1 for a_{p_1} , p_2 for a_{p_2} , p_3 for a_{p_3} , and p_4 for a_{p_4} may be reported by $i_{1,4}$, and n_1 for b_{n_1} , n_2 for b_{n_2} , n_3 for b_{n_3} , and n_4 for b_{n_4} may be reported by i_2 .

[0113] The values of p_1 , p_2 , p_3 , p_4 , n_1 , n_2 , n_3 , n_4 , a_{p_1} , a_{p_2} , a_{p_3} , a_{p_4} , b_{n_1} , b_{n_2} , b_{n_3} , and b_{n_4} may be determined based on the definitions and formulas similar to those specified in TS 38.214.

[0114] As an example, each of p_1, p_2, p_3 and p_4 may be selected from $\{0, 1, 2, 3\}$. Based on the formula $a_p = e^{j\pi/4} e^{j\pi p/2}$, each of $a_{p_1}, a_{p_2}, a_{p_3}$ and a_{p_4} may be selected from $\{e^{j\pi/4}, e^{j3\pi/4}, e^{j5\pi/4}, e^{j7\pi/4}\}$.

[0115] As an example, each of n_1, n_2, n_3 and n_4 may be selected from $\{0, 1\}$. Based on the formula $b_n = e^{-j\pi/4} e^{j\pi n/2}$, each of $b_{n_1}, b_{n_2}, b_{n_3}$ and b_{n_4} may be selected from $\{e^{-j\pi/4}, e^{j\pi/4}\}$.

[0116] In some examples, the codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ a_{p_4} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ -a_{p_4} b_{n_4} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the number of CSI-RS ports of the antenna array, $v_{l,m} =$

$$\begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T, \quad u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases},$$

$\varphi_{n_0} = e^{j\pi n_0/2}$. For φ_{n_0} , as specified in TS 38.214, n_0 is from $\{0, 1, 2, 3\}$ for 1-layer CSI reporting and from $\{0, 1\}$ for 2-layer, 3-layer, and 4-layer CSI reporting, and thus φ_{n_0} is from $\{1, j, -1, -j\}$ for 1-layer CSI reporting and from $\{1, j\}$ for 2-layer, 3-layer, and 4-layer CSI reporting.

[0117] After obtaining the quantities (i.e., $W_{l,m,p,n}^{1,3,2}$ and $W_{l,m,p,n}^{2,3,2}$) of the codebook, a BS and a UE may use Tables 3-6 to generate codebook with three panels for 1-layer, 2-layer, 3-layer, and 4-layer CSI-reporting, respectively.

[0118] Solution 1 may achieve the best performance since it obtains the largest combination gain by the cophasing factors from subband level and polarization level. However, solution 1 needs relatively large overhead for reporting $a_{p_3}, a_{p_4}, b_{n_3}$, and b_{n_4} .

[0119] Solution 2

[0120] Solution 2 makes some optimization based on solution 1. For example, solution 2 uses a same wideband cophasing factor between different polarization directions in one panel.

Thus, for wideband cophasing, a UE only reports two wideband cophasing factors (e.g., a_{p_1} and a_{p_2}) for the second and third panels and a polarization cophasing factor (e.g., φ_{n_0}) between different polarization directions in one panel. The definition for φ_{n_0} in solution 1 may also apply here. In this way, solution 2 can reduce feedback overhead for a_{p_3} and a_{p_4} but without causing much performance loss since the difference of wideband cophasing factors between different polarization directions (if existing) can be implicitly absorbed by the subband cophasing factors for the different polarization directions.

[0121] In solution 2, the codebook for three panels for codebook mode 2 for CSI reporting using more than 32 CSI-RS ports may be determined based on a first wideband cophasing factor (e.g., denoted as a_{p_1}) for both polarization directions for a second panel and a second wideband cophasing factor (e.g., denoted as a_{p_2}) for both polarization directions for a third panel, a first subband cophasing factor (e.g., denoted as b_{n_1}) and a second subband cophasing factor (e.g., denoted as b_{n_2}) respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor (e.g., denoted as b_{n_3}) and a fourth subband cophasing factor (e.g., denoted as b_{n_4}) respectively corresponding to two polarization directions for the third panel.

[0122] In some embodiments of the present application, the PMI reported by the UE may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, and the fourth subband cophasing factor. As an example, the PMI may indicate p_1 for a_{p_1} , p_2 for a_{p_2} , n_1 for b_{n_1} , n_2 for b_{n_2} , n_3 for b_{n_3} , and n_4 for b_{n_4} . For example, p_1 for a_{p_1} and p_2 for a_{p_2} may be reported by $i_{1,4}$, and n_1 for b_{n_1} , n_2 for b_{n_2} , n_3 for b_{n_3} , and n_4 for b_{n_4} may be reported by i_2 .

[0123] The values of p_1 , p_2 , n_1 , n_2 , n_3 , n_4 , a_{p_1} , a_{p_2} , b_{n_1} , b_{n_2} , b_{n_3} , and b_{n_4} may be determined based on the definitions and formulas similar to those specified in TS 38.214.

[0124] As an example, each of p_1 and p_2 may be selected from $\{0, 1, 2, 3\}$. Based on the formula $a_p = e^{j\pi/4} e^{j\pi p/2}$, each of a_{p_1} and a_{p_2} may be selected from $\{e^{j\pi/4}, e^{j3\pi/4}, e^{j5\pi/4}, e^{j7\pi/4}\}$.

[0125] As an example, each of n_1, n_2, n_3 and n_4 may be selected from $\{0, 1\}$. Based on the formula $b_n = e^{-j\pi/4} e^{j\pi n/2}$, each of $b_{n_1}, b_{n_2}, b_{n_3}$ and b_{n_4} may be selected from $\{e^{-\frac{j\pi}{4}}, e^{\frac{j\pi}{4}}\}$.

[0126] In some examples, the codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the number of CSI-RS ports of the antenna array, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m = \begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$.

[0127] After obtaining the quantities (i.e. $W_{l,m,p,n}^{1,3,2}$ and $W_{l,m,p,n}^{2,3,2}$) of the codebook, a BS and a UE may use Tables 3-6 to generate codebook with three panels for 1-layer, 2-layer, 3-layer, and 4-layer CSI-reporting, respectively.

[0128] Solution 3

[0129] Solution 3 makes some optimization based on solution 1. For example, solution 3 uses a same wideband cophasing factors and a same subband cophasing factors between different polarization directions in one panel. Thus, a UE only reports two wideband cophasing factors (e.g., a_{p_1} and a_{p_2}) and two subband cophasing factors (e.g., b_{n_1} and b_{n_2}) for the second and third panels and a polarization cophasing factor (e.g., φ_{n_0}) between different polarization directions in one panel. The definition for φ_{n_0} in solution 1 may also apply here. In this way, solution 3 can reduce feedback overhead for a_{p_3} , a_{p_4} , b_{n_3} , and b_{n_4} but causes some performance loss.

[0130] In solution 3, the codebook for three panels for codebook mode 2 for CSI reporting using more than 32 CSI-RS ports may be determined based on a first wideband cophasing factor

(e.g., denoted as a_{p_1}) for both polarization directions for a second panel, a second wideband cophasing factor (e.g., denoted as a_{p_2}) for both polarization directions for a third panel, a first subband cophasing factor (e.g., denoted as b_{n_1}) for both polarization directions for the second panel, and a second subband cophasing factor (e.g., denoted as b_{n_2}) for both polarization directions for the third panel.

[0131] In some embodiments of the present application, the PMI reported by the UE may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, and the second subband cophasing factor. As an example, the PMI may indicate p_1 for a_{p_1} , p_2 for a_{p_2} , n_1 for b_{n_1} , and n_2 for b_{n_2} . For example, p_1 for a_{p_1} and p_2 for a_{p_2} may be reported by $i_{1,4}$, and n_1 for b_{n_1} and n_2 for b_{n_2} may be reported by i_2 .

[0132] The values of p_1 , p_2 , n_1 , n_2 , a_{p_1} , a_{p_2} , b_{n_1} , and b_{n_2} may be determined based on the definitions and formulas similar to those specified in TS 38.214.

[0133] As an example, each of p_1 and p_2 may be selected from $\{0, 1, 2, 3\}$. Based on the formula $a_p = e^{j\pi/4} e^{j\pi p/2}$, each of a_{p_1} and a_{p_2} may be selected from $\{e^{j\pi/4}, e^{j3\pi/4}, e^{j5\pi/4}, e^{j7\pi/4}\}$.

[0134] As an example, each of n_1 and n_2 may be selected from $\{0, 1\}$. Based on the formula $b_n = e^{-j\pi/4} e^{j\pi n/2}$, each of b_{n_1} and b_{n_2} may be selected from $\{e^{-j\pi/4}, e^{j\pi/4}\}$.

[0135] In some examples, the codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the number of CSI-RS ports of the antenna array, $v_{l,m} =$

$$\begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T, \quad u_m =$$

$$\begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & & & & N_2 = 1, \varphi_{n_0} = e^{j\pi n_0/2}. \end{cases}$$

[0136] After obtaining the quantities (i.e. $W_{l,m,p,n}^{1,3,2}$ and $W_{l,m,p,n}^{2,3,2}$) of the codebook, a BS and a UE may use Tables 3-6 to generate codebook with three panels for 1-layer, 2-layer, 3-layer, and 4-layer CSI-reporting, respectively.

[0137] **Solution 4**

[0138] In solution 4, compared with the codebook for two panels, an additional wideband cophasing factor for the third panel is introduced.

[0139] In solution 4, the codebook for three panels for codebook mode 1 for CSI reporting using more than CSI-RS ports may be determined based on a first wideband cophasing factor (e.g., denoted as φ_{p_1}) for a second panel and a second wideband cophasing factor (e.g., denoted as φ_{p_2}) for a third panel.

[0140] In some embodiments of the present application, the PMI reported by the UE may indicate an index (e.g., denoted as p_1) corresponding to the first wideband cophasing factor and an index (e.g., denoted as p_2) corresponding to the second wideband cophasing factor. As an example, p_1 and p_2 may be reported by $i_{1,4}$.

[0141] The values of p_1 , p_2 , φ_{p_1} , and φ_{p_2} may be determined based on the definitions and formulas similar to those specified in TS 38.214. As an example, each of p_1 and p_2 may be selected from $\{0, 1, 2, 3\}$. Based on the formula $\varphi_p = e^{j\pi p/2}$, each of φ_{p_1} and φ_{p_2} may be selected from $\{1, j, -1, -j\}$.

[0142] In some examples, the codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,1}$ or $W_{l,m,p,n}^{2,3,1}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the number of CSI-RS ports of the antenna array, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_n = e^{j\pi n/2}$. For φ_n , as specified in TS 38.214, n is from $\{0, 1, 2, 3\}$ for 1-layer CSI reporting and from $\{0, 1\}$ for 2-layer, 3-layer, and 4-layer CSI reporting, and thus φ_n is from $\{1, j, -1, -j\}$ for 1-layer CSI reporting and from $\{1, j\}$ for 2-layer, 3-layer, and 4-layer CSI reporting.

[0143] After obtaining the quantities (i.e. $W_{l,m,p,n}^{1,3,1}$ and $W_{l,m,p,n}^{2,3,1}$) of the codebook, a BS and a UE may use Tables 3-6 to generate codebook with three panels for 1-layer, 2-layer, 3-layer, and 4-layer CSI-reporting, respectively.

[0144] Figure 2 illustrates a flowchart of an exemplary method in accordance with aspects of the present disclosure. The operations of the method illustrated in Figure 2 may be performed by a UE (e.g., UE 104 in Figure 1) as described herein or other apparatus with the like functions. In some implementations, the UE may execute a set of instructions to control functional elements of the UE to perform the described operations or functions.

[0145] As shown in Figure 2, in step 202, the UE may receive, from a BS (e.g., BS 102 in Figure 1), configuration information (e.g., via RRC signaling) for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32.

[0146] The configuration information may include a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical

direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor.

[0147] In step 204, the UE may determine a PMI based on a codebook (e.g., Type I MP codebook) for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) . For example, the codebook may be any of the aforementioned codebooks for more than 32 ports associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) . In some embodiments, the PMI may include bit(s) indicating at least one of: a value of $i_{1,1}$, a value of $i_{1,2}$, a value of $i_{1,3}$, a value of $i_{1,4}$, or a value of i_2 determined by the UE. The definitions for $i_{1,1}$, $i_{1,2}$, $i_{1,3}$, $i_{1,4}$, and i_2 provided in the aforementioned embodiments may apply here.

[0148] In step 206, the UE may transmit a CSI report, wherein the CSI report includes the PMI.

[0149] According to some embodiments of the present disclosure, in the case that the first number is 48, the configuration of (N_g, N_1, N_2) may include (2, 12, 1), (2, 6, 2), (2, 4, 3), (3, 8, 1), (3, 4, 2), (4, 6, 1), or (4, 3, 2); in the case that the first number is 64, the configuration of (N_g, N_1, N_2) may include (2, 16, 1), (2, 8, 2), (2, 4, 4), (4, 8, 1), or (4, 4, 2); in the case that the first number is 96, the configuration of (N_g, N_1, N_2) may include (2, 24, 1), (2, 12, 2), (2, 8, 3), (2, 6, 4), (3, 16, 1), (3, 8, 2), (3, 4, 4), (4, 12, 1), (4, 6, 2), or (4, 4, 3); or in the case that the first number is 128, the configuration of (N_g, N_1, N_2) may include (2, 32, 1), (2, 16, 2), (2, 8, 4), (4, 16, 1), (4, 8, 2), or (4, 4, 4).

[0150] According to some embodiments of the present disclosure, the configuration of (O_1, O_2) may be jointly configured with the configuration of (N_g, N_1, N_2) in the configuration information or separately configured in another configuration information. In some embodiments, the configuration of (O_1, O_2) may include (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) or (4, 4).

[0151] According to some embodiments of the present disclosure, the codebook may include a first codebook for 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports, each codeword in the first codebook is associated with two orthogonal beams, and one

beam of the two orthogonal beams is determined based on a horizontal beam offset value and a vertical beam offset value with respect to the other beam of the two orthogonal beams, wherein the first codebook is based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , $i_{1,3}$ is a codebook index of the first codebook, k_1 is the horizontal beam offset value, and k_2 is the vertical beam offset value.

[0152] In some embodiments, the PMI may include a 2-bit indication for indicating $i_{1,3}$, and the mapping table may indicate that: in the case that $N_1 = 3$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$; in the case that $N_1 \geq 6$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$; or in the case that $N_1 \geq N_2 \geq 2$ except $N_1 = 2$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$.

[0153] In some embodiments of the present disclosure, the PMI may include a 2-bit or 3-bit indication for indicating $i_{1,3}$, and the mapping table may indicate that: in the case that $N_1 = 3$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$; in the case that $N_1 = 6$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$; in the case that $N_1 > 8$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, $(7O_1, 0)$, or $(8O_1, 0)$; in the case that $N_1 = 3$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$; or in the case that $N_1 \geq 4$ and $N_2 \geq 2$ except $N_1 = 4$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , $(2O_1, 0)$, $(2O_1, O_2)$, $(2O_1, 2O_2)$, $(0, 2O_2)$, or $(O_1, 2O_2)$.

[0154] According to some embodiments of the present disclosure, the codebook may include a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor and a second wideband cophasing factor respectively corresponding to two polarization directions for a second panel, a third wideband cophasing factor and a fourth wideband cophasing factor respectively corresponding to two polarization directions for a third panel, a first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

[0155] In some embodiments, the PMI may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the third wideband cophasing factor, the fourth wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, and the fourth subband cophasing factor.

[0156] In some embodiments, the second codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ a_{p_4} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ -a_{p_4} b_{n_4} v_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}}$$

is the first number, $v_{l,m} = [u_m \ e^{j\frac{2\pi l}{O_1 N_1} u_m} \dots e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m}]^T$, $u_m = \begin{cases} [1 \ e^{j\frac{2\pi m}{O_2 N_2}} \dots e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband cophasing factor, a_{p_2} is the second wideband cophasing factor, a_{p_3} is the third wideband cophasing factor, a_{p_4} is the fourth wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

[0157] According to some embodiments of the present disclosure, the codebook may include a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

[0158] In some embodiments, the PMI may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband

cophasing factor, the second subband cophasing factor, the third subband cophasing factor, the fourth subband cophasing factor.

[0159] In some embodiments, the second codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1} u_m} & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m} \end{bmatrix}^T$, $u_m = \begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband cophasing factor, a_{p_2} is the second wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

[0160] According to some embodiments of the present disclosure, the codebook may include a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor for both polarization directions for the second panel, and a second subband cophasing factor for both polarization directions for the third panel.

[0161] In some embodiments, the PMI may indicate a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, and the second subband cophasing factor.

[0162] In some embodiments, the second codebook may include codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_2} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = [u_m \ e^{j\frac{2\pi l}{O_1 N_1} u_m} \dots e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m}]^T$, $u_m = \begin{cases} [1 \ e^{j\frac{2\pi m}{O_2 N_2}} \dots e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband cophasing factor, a_{p_2} is the second wideband cophasing factor, b_{n_1} is the first subband cophasing factor, and b_{n_2} is the second subband cophasing factor

[0163] According to some embodiments of the present disclosure, the codebook may include a third codebook for three panels for codebook mode 1 for CSI reporting using the first number of CSI-RS ports, and the third codebook is determined based on a first wideband cophasing factor for a second panel and a second wideband cophasing factor for a third panel.

[0164] In some embodiments, the PMI may indicate an index corresponding to the first wideband cophasing factor and an index corresponding to the second wideband cophasing factor.

[0165] In some embodiments, the third codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,1}$ or $W_{l,m,p,n}^{2,3,1}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = [u_m \ e^{j\frac{2\pi l}{O_1 N_1} u_m} \dots e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m}]^T$, $u_m = \begin{cases} [1 \ e^{j\frac{2\pi m}{O_2 N_2}} \dots e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_n = e^{j\pi n/2}$, φ_{p_1} is the first wideband cophasing factor, and φ_{p_2} is the second wideband cophasing factor.

[0166] According to some embodiments of the present disclosure, the UE may receive, from the BS, a configuration for N_g CSI-RS resources, wherein each CSI-RS resource is associated with a corresponding panel of the antenna array. For CSI reporting, the first number of CSI-RS ports are ordered first according to an order from a lowest port index to a highest port index within a CSI-RS resource, and then according to an order from a lowest CSI-RS resource index to a highest CSI-RS resource index of the N_g CSI-RS resources.

[0167] Figure 3 illustrates a flowchart of an exemplary method in accordance with aspects of the present disclosure. The operations of the method illustrated in Figure 3 may be performed by a BS (e.g., NE 102 in Figure 1) as described herein or other apparatus with the like functions. In some implementations, the BS may execute a set of instructions to control functional elements of the BS to perform the described operations or functions.

[0168] As shown in Figure 3, in step 302, the BS may transmit, to a UE (e.g., UE 104 in Figure 1), configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32.

[0169] The configuration information may include a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor.

[0170] In step 304, the BS may receive a CSI report, wherein the CSI report includes a PMI associated with a codebook (e.g., Type I MP codebook) for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) . In some embodiments, the PMI may include bit(s) indicating at least one of: a value of $i_{1,1}$, a value of $i_{1,2}$, a value of $i_{1,3}$, a value of $i_{1,4}$, or a value of i_2 determined by the UE. The definitions for $i_{1,1}$, $i_{1,2}$, $i_{1,3}$, $i_{1,4}$, and i_2 provided in the aforementioned embodiments may apply here.

[0171] According to some embodiments of the present disclosure, the BS may transmit, to the UE, a configuration for N_g CSI-RS resources, wherein each CSI-RS resource is associated with a corresponding panel of the antenna array. For CSI reporting, the first number of CSI-RS ports are ordered first according to an order from a lowest port index to a highest port index within a CSI-RS resource, and then according to an order from a lowest CSI-RS resource index to a highest CSI-RS resource index of the N_g CSI-RS resources.

[0172] All the definitions and operations related to the configuration of (N_g, N_1, N_2) , the configuration of (O_1, O_2) , the codebook for the first number of CSI-RS ports, the two orthogonal beams, the horizontal beam offset, the vertical beam offset, and the mapping table described with respect to Figure 2 may also apply here. Thus, details are omitted for simplicity.

[0173] Figure 4 illustrates an example of a UE 400 in accordance with aspects of the present disclosure. The UE 400 may include at least one processor 402 and at least one memory 404. Additionally, the UE 400 may also include one or more of at least one controller 406 or at least one transceiver 408. The processor 402, the memory 404, the controller 406, or the transceiver 408, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described herein. These components may be coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces.

[0174] The processor 402, the memory 404, the controller 406, or the transceiver 408, or various combinations or components thereof may be implemented in hardware (e.g., circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), or other programmable logic device, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure.

[0175] The processor 402 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, or any combination thereof). In some implementations, the processor 402 may be configured to operate the memory 404. In some other implementations, the memory 404 may be integrated into the processor 402. The

processor 402 may be configured to execute computer-readable instructions stored in the memory 404 to cause the UE 400 to perform various functions of the present disclosure.

[0176] The memory 404 may include volatile or non-volatile memory. The memory 404 may store computer-readable, computer-executable code including instructions when executed by the processor 402 cause the UE 400 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 404 or another type of memory. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer.

[0177] In some implementations, the processor 402 and the memory 404 coupled with the processor 402 may be configured to cause the UE 400 to perform one or more of the functions described herein (e.g., executing, by the processor 402, instructions stored in the memory 404). For example, the processor 402 may support wireless communication at the UE 400 in accordance with examples as disclosed herein. The UE 400 may be configured to support a means for performing the operations of the methods described in the embodiments of the present disclosure. In an embodiment, the processor 402 may be configured to cause the UE 400 to: receive configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; determine a PMI based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and transmit a CSI report, wherein the CSI report includes the PMI.

[0178] The controller 406 may manage input and output signals for the UE 400. The controller 406 may also manage peripherals not integrated into the UE 400. In some implementations, the controller 406 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 406 may be implemented as part of the processor 402.

[0179] In some implementations, the UE 400 may include at least one transceiver 408. In some other implementations, the UE 400 may have more than one transceiver 408. The transceiver 408 may represent a wireless transceiver. The transceiver 408 may include one or more receiver chains 410, one or more transmitter chains 412, or a combination thereof.

[0180] A receiver chain 410 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 410 may include one or more antennas for receive the signal over the air or wireless medium. The receiver chain 410 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 410 may include at least one demodulator configured to demodulate the receive signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receiver chain 410 may include at least one decoder for decoding the demodulated signal to receive the transmitted data.

[0181] A transmitter chain 412 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 412 may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmitter chain 412 may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmitter chain 412 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0182] Figure 5 illustrates an example of a processor 500 in accordance with aspects of the present disclosure. The processor 500 may be an example of a processor configured to perform

various operations in accordance with examples as described herein. The processor 500 may include at least one controller 502 configured to perform various operations in accordance with examples as described herein. The processor 500 may optionally include at least one memory 504, which may be, for example, a layer 1 (L1), layer 2 (L2), or layer 3 (L3) cache. Additionally, or alternatively, the processor 500 may optionally include one or more arithmetic-logic units (ALUs) 506. One or more of these components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0183] The processor 500 may be a processor chipset and include a protocol stack (e.g., a software stack) executed by the processor chipset to perform various operations (e.g., receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) in accordance with examples as described herein. The processor chipset may include one or more cores, one or more caches (e.g., memory local to or included in the processor chipset (e.g., the processor 500) or other memory (e.g., random access memory (RAM), read-only memory (ROM), dynamic RAM (DRAM), synchronous dynamic RAM (SDRAM), static RAM (SRAM), ferroelectric RAM (FeRAM), magnetic RAM (MRAM), resistive RAM (RRAM), flash memory, phase change memory (PCM), and others).

[0184] The controller 502 may be configured to manage and coordinate various operations (e.g., signaling, receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) of the processor 500 to cause the processor 500 to support various operations in accordance with examples as described herein. For example, the controller 502 may operate as a control unit of the processor 500, generating control signals that manage the operation of various components of the processor 500. These control signals include enabling or disabling functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

[0185] The controller 502 may be configured to fetch (e.g., obtain, retrieve, receive) instructions from the memory 504 and determine subsequent instruction(s) to be executed to cause the processor 500 to support various operations in accordance with examples as described herein. The controller 502 may be configured to track memory address of instructions associated with the memory 504. The controller 502 may be configured to decode instructions

to determine the operation to be performed and the operands involved. For example, the controller 502 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 500 to cause the processor 500 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 502 may be configured to manage flow of data within the processor 500. The controller 502 may be configured to control transfer of data between registers, ALUs, and other functional units of the processor 500.

[0186] The memory 504 may include one or more caches (e.g., memory local to or included in the processor 500 or other memory, such RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc.). In some implementations, the memory 504 may reside within or on a processor chipset (e.g., local to the processor 500). In some other implementations, the memory 504 may reside external to the processor chipset (e.g., remote to the processor 500).

[0187] The memory 504 may store computer-readable, computer-executable code including instructions that, when executed by the processor 500, cause the processor 500 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. The controller 502 and/or the processor 500 may be configured to execute computer-readable instructions stored in the memory 504 to cause the processor 500 to perform various functions. For example, the processor 500 and/or the controller 502 may be coupled with or to the memory 504, the processor 500, the controller 502, and the memory 504 may be configured to perform various functions described herein. In some examples, the processor 500 may include multiple processors and the memory 504 may include multiple memories. One or more of the multiple processors may be coupled with one or more of the multiple memories, which may, individually or collectively, be configured to perform various functions herein.

[0188] The one or more ALUs 506 may be configured to support various operations in accordance with examples as described herein. In some implementations, the one or more ALUs 506 may reside within or on a processor chipset (e.g., the processor 500). In some other implementations, the one or more ALUs 506 may reside external to the processor chipset (e.g., the processor 500). One or more ALUs 506 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 506

may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 506 be configured with a variety of logical and arithmetic circuits, including adders, subtractors, shifters, and logic gates, to process and manipulate the data according to the operation. Additionally, or alternatively, the one or more ALUs 506 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 506 to handle conditional operations, comparisons, and bitwise operations.

[0189] The processor 500 may support wireless communication in accordance with examples as disclosed herein. The processor 500 may be configured to or operable to support a means for performing the operations of the methods described in the embodiments of the present disclosure. In an embodiment, the controller 502 may cause the processor 500 to: receive configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; determine a PMI based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and transmit a CSI report, wherein the CSI report includes the PMI.

[0190] Figure 6 illustrates an example of a BS 600 in accordance with aspects of the present disclosure. The BS 600 may include at least one processor 602 and at least one memory 604. Additionally, the BS 600 may also include one or more of at least one controller 606 or at least one transceiver 608. The processor 602, the memory 604, the controller 606, or the transceiver 608, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described herein. These components may be coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces.

[0191] The processor 602, the memory 604, the controller 606, or the transceiver 608, or various combinations or components thereof may be implemented in hardware (e.g., circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), or other programmable logic device, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure.

[0192] The processor 602 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, or any combination thereof). In some implementations, the processor 602 may be configured to operate the memory 604. In some other implementations, the memory 604 may be integrated into the processor 602. The processor 602 may be configured to execute computer-readable instructions stored in the memory 604 to cause the BS 600 to perform various functions of the present disclosure.

[0193] The memory 604 may include volatile or non-volatile memory. The memory 604 may store computer-readable, computer-executable code including instructions when executed by the processor 602 cause the BS 600 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 604 or another type of memory. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer.

[0194] In some implementations, the processor 602 and the memory 604 coupled with the processor 602 may be configured to cause the BS 600 to perform one or more of the functions described herein (e.g., executing, by the processor 602, instructions stored in the memory 604). For example, the processor 602 may support wireless communication at the BS 600 in accordance with examples as disclosed herein. The BS 600 may be configured to support a means for performing the operations of the methods described in the embodiments of the present disclosure. In an embodiment, the processor 602 may be configured to cause the BS 600 to: transmit configuration information for an antenna array with a first number of CSI-RS ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is

associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and receive a CSI report, wherein the CSI report includes a PMI associated with a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) .

[0195] The controller 606 may manage input and output signals for the BS 600. The controller 606 may also manage peripherals not integrated into the BS 600. In some implementations, the controller 606 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 606 may be implemented as part of the processor 602.

[0196] In some implementations, the BS 600 may include at least one transceiver 608. In some other implementations, the BS 600 may have more than one transceiver 608. The transceiver 608 may represent a wireless transceiver. The transceiver 608 may include one or more receiver chains 610, one or more transmitter chains 612, or a combination thereof.

[0197] A receiver chain 610 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 610 may include one or more antennas for receive the signal over the air or wireless medium. The receiver chain 610 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 610 may include at least one demodulator configured to demodulate the receive signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receiver chain 610 may include at least one decoder for decoding the demodulated signal to receive the transmitted data.

[0198] A transmitter chain 612 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 612 may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital

modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmitter chain 612 may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmitter chain 612 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0199] The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

CLAIMS

What is claimed is:

1. A user equipment (UE) for wireless communication, comprising:
 - at least one memory; and
 - at least one processor coupled with the at least one memory and configured to cause the UE to:
 - receive configuration information for an antenna array with a first number of channel state information reference signal (CSI-RS) ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor;
 - determine a precoding matrix indicator (PMI) based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and
 - transmit a channel state information (CSI) report, wherein the CSI report includes the PMI.
2. The UE of Claim 1, wherein:
 - in the case that the first number is 48, the configuration of (N_g, N_1, N_2) includes $(2, 12, 1)$, $(2, 6, 2)$, $(2, 4, 3)$, $(3, 8, 1)$, $(3, 4, 2)$, $(4, 6, 1)$, or $(4, 3, 2)$;

in the case that the first number is 64, the configuration of (N_g, N_1, N_2) includes (2, 16, 1), (2, 8, 2), (2, 4, 4), (4, 8, 1), or (4, 4, 2);

in the case that the first number is 96, the configuration of (N_g, N_1, N_2) includes (2, 24, 1), (2, 12, 2), (2, 8, 3), (2, 6, 4), (3, 16, 1), (3, 8, 2), (3, 4, 4), (4, 12, 1), (4, 6, 2), or (4, 4, 3); or

in the case that the first number is 128, the configuration of (N_g, N_1, N_2) includes (2, 32, 1), (2, 16, 2), (2, 8, 4), (4, 16, 1), (4, 8, 2), or (4, 4, 4).

3. The UE of Claim 1, wherein the configuration of (O_1, O_2) is jointly configured with the configuration of (N_g, N_1, N_2) in the configuration information or separately configured in another configuration information, and wherein the configuration of (O_1, O_2) includes (1, 1), (2, 1), (2, 2), (4, 1), (4, 2) or (4, 4).

4. The UE of Claim 1, wherein the codebook includes a first codebook for 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports, each codeword in the first codebook is associated with two orthogonal beams, and one beam of the two orthogonal beams is determined based on a horizontal beam offset value and a vertical beam offset value with respect to the other beam of the two orthogonal beams, wherein the first codebook is based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , $i_{1,3}$ is a codebook index of the first codebook, k_1 is the horizontal beam offset value, and k_2 is the vertical beam offset value.

5. The UE of Claim 4, wherein the PMI includes a 2-bit indication for indicating $i_{1,3}$, and the mapping table indicates that:

in the case that $N_1 = 3$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, or $(3O_1, 0)$;

in the case that $N_1 \geq 6$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(2O_1, 0)$, $(3O_1, 0)$, or $(4O_1, 0)$; or

in the case that $N_1 \geq N_2 \geq 2$ except $N_1 = 2$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(O_1, 0)$, $(0, O_2)$, (O_1, O_2) , or $(2O_1, 0)$.

6. The UE of Claim 4, wherein the PMI includes a 3-bit indication for indicating $i_{1,3}$, and the mapping table indicates that:

in the case that $N_1 > 8$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(0_1, 0)$, $(20_1, 0)$, $(30_1, 0)$, $(40_1, 0)$, $(50_1, 0)$, $(60_1, 0)$, $(70_1, 0)$, or $(80_1, 0)$;
or

in the case that $N_1 \geq 4$ and $N_2 \geq 2$ except $N_1 = 4$ and $N_2 = 2$, the pair of (k_1, k_2) includes $(0_1, 0)$, $(0, 0_2)$, $(0_1, 0_2)$, $(20_1, 0)$, $(20_1, 0_2)$, $(20_1, 20_2)$, $(0, 20_2)$, or $(0_1, 20_2)$.

7. The UE of claim 1, wherein the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor and a second wideband cophasing factor respectively corresponding to two polarization directions for a second panel, a third wideband cophasing factor and a fourth wideband cophasing factor respectively corresponding to two polarization directions for a third panel, a first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

8. The UE of claim 7, wherein the PMI indicates a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the third wideband cophasing factor, the fourth wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, and the fourth subband cophasing factor.

9. The UE of claim 7, wherein the second codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ a_{p_4} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_2} b_{n_2} v_{l,m} \\ a_{p_3} b_{n_3} v_{l,m} \\ -a_{p_4} b_{n_4} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, $u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband

cophasing factor, a_{p_2} is the second wideband cophasing factor, a_{p_3} is the third wideband cophasing factor, a_{p_4} is the fourth wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

10. The UE of claim 1, wherein the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor and a second subband cophasing factor respectively corresponding to two polarization directions for the second panel, and a third subband cophasing factor and a fourth subband cophasing factor respectively corresponding to two polarization directions for the third panel.

11. The UE of claim 10, wherein the PMI indicates a corresponding index for each of the first wideband cophasing factor, the second wideband cophasing factor, the first subband cophasing factor, the second subband cophasing factor, the third subband cophasing factor, the fourth subband cophasing factor.

12. The UE of claim 10, wherein the second codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,2}$ or $W_{l,m,p,n}^{2,3,2}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,2} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_{n_0} v_{l,m} \\ a_{p_1} b_{n_1} v_{l,m} \\ -a_{p_1} \varphi_{n_0} b_{n_2} v_{l,m} \\ a_{p_2} b_{n_3} v_{l,m} \\ -a_{p_2} \varphi_{n_0} b_{n_4} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1} u_m} & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m} \end{bmatrix}^T$, $u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_{n_0} = e^{j\pi n_0/2}$, a_{p_1} is the first wideband

cophasing factor, a_{p_2} is the second wideband cophasing factor, b_{n_1} is the first subband cophasing factor, b_{n_2} is the second subband cophasing factor, b_{n_3} is the third subband cophasing factor, and b_{n_4} is the fourth subband cophasing factor.

13. The UE of claim 1, wherein the codebook includes a second codebook for three panels for codebook mode 2 for CSI reporting using the first number of CSI-RS ports, and the second codebook is determined based on a first wideband cophasing factor for both polarization directions for a second panel, a second wideband cophasing factor for both polarization directions for a third panel, a first subband cophasing factor for both polarization directions for the second panel, and a second subband cophasing factor for both polarization directions for the third panel.

14. The UE of claim 1, wherein the codebook includes a third codebook for three panels for codebook mode 1 for CSI reporting using the first number of CSI-RS ports, and the third codebook is determined based on a first wideband cophasing factor for a second panel and a second wideband cophasing factor for a third panel.

15. The UE of claim 14, wherein the PMI indicates an index corresponding to the first wideband cophasing factor and an index corresponding to the second wideband cophasing factor.

16. The UE of claim 14, wherein the third codebook includes codewords determined by at least one of $W_{l,m,p,n}^{1,3,1}$ or $W_{l,m,p,n}^{2,3,1}$,

$$\text{wherein } W_{l,m,p,n}^{1,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ \varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ \varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix} \text{ and } W_{l,m,p,n}^{2,3,1} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ -\varphi_n v_{l,m} \\ \varphi_{p_1} v_{l,m} \\ -\varphi_n \varphi_{p_1} v_{l,m} \\ \varphi_{p_2} v_{l,m} \\ -\varphi_n \varphi_{p_2} v_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1} u_m} & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m} \end{bmatrix}^T$, $u_m = \begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, $\varphi_n = e^{j\pi n/2}$, φ_{p_1} is the first wideband cophasing factor, and φ_{p_2} is the second wideband cophasing factor.

17. The UE of Claim 1, wherein the at least one processor is further configured to cause the UE to receive a configuration for N_g CSI-RS resources, each CSI-RS resource is associated with a corresponding panel of the antenna array, and wherein for CSI reporting, the first number of CSI-RS ports are ordered first according to an order from a lowest port index to a highest port index within a CSI-RS resource, and then according to an order from a lowest CSI-RS resource index to a highest CSI-RS resource index of the N_g CSI-RS resources.

18. A processor for wireless communication, comprising:

at least one controller coupled with at least one memory and configured to cause the processor to:

receive configuration information for an antenna array with a first number of channel state information reference signal (CSI-RS) ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor;

determine a precoding matrix indicator (PMI) based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and

transmit a channel state information (CSI) report, wherein the CSI report includes the PMI.

19. A base station (BS) for wireless communication, comprising:

at least one memory; and

at least one processor coupled with the at least one memory and configured to cause the BS to:

transmit configuration information for an antenna array with a first number of channel state information reference signal (CSI-RS) ports, wherein the first number is more than 32, wherein the configuration information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and

receive a CSI report, wherein the CSI report includes a precoding matrix indicator (PMI) associated with a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) .

20. A method performed by a user equipment (UE), the method comprising:

receiving configuration information for an antenna array with a first number of channel state information reference signal (CSI-RS) ports, wherein the first number is more than 32, wherein the configuration

information includes a configuration of (N_g, N_1, N_2) for the antenna array, wherein the configuration of (N_g, N_1, N_2) is associated with a configuration of (O_1, O_2) for the antenna array, wherein N_g is a number of panels of the antenna array, N_1 is a number of antenna ports per polarization direction per panel in a horizontal direction of the antenna array, N_2 is a number of antenna ports per polarization direction per panel in a vertical direction of the antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor;

determining a precoding matrix indicator (PMI) based on a codebook for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_g, N_1, N_2) and the configuration of (O_1, O_2) ; and

transmitting a channel state information (CSI) report, wherein the CSI report includes the PMI.