

METHODS AND APPARATUSES FOR ENHANCED TYPE I CODEBOOK

TECHNICAL FIELD

[0001] The present disclosure relates to wireless communications, and more specifically to methods and apparatuses for enhanced Type I 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and perform channel state information (CSI) reporting, wherein the CSI reporting includes reporting the PMI.

[0005] In some implementations of the UE described herein, the configuration of (N_1, N_2) is determined by aggregating at least two second antenna arrays with a same second number of CSI-RS ports and a same configuration of (N_1', N_2') , wherein the second number is less than or equal to 32, wherein N_1' is a number of antenna ports per polarization direction in a horizontal direction of the second antenna array, and N_2' is a number of antenna ports per polarization direction in a vertical direction of the second antenna array.

[0006] In some implementations of the UE described herein, in the case that the first number is 48, the configuration of (N_1, N_2) includes (6, 4), (8, 3), (12, 2) or (24, 1); in the case that the first number is 64, the configuration of (N_1, N_2) includes (8, 4), (16, 2), or (32, 1); in the case that the first number is 72, the configuration of (N_1, N_2) includes (6, 6), (12, 3), (18, 2), or (36, 1); in the case that the first number is 96, the configuration of (N_1, N_2) includes (8, 6), (12, 4), (16, 3), (24, 2), or (48, 1); or in the case that the first number is 128, the configuration of (N_1, N_2) includes (8, 8), (16, 4), (32, 2), or (64, 1).

[0007] In some implementations of the UE described herein, in the case that the first number is 48: the second number is 24 and the configuration of (N_1', N_2') includes (4, 3), (6, 2) or (12, 1); or the second number is 16 and the configuration of (N_1', N_2') includes (4, 2) or (8, 1); in the case that the first number is 64: the second number is 16 and the configuration of (N_1', N_2') includes (4, 2) or (8, 1); or the second number is 32 and the configuration of (N_1', N_2') includes (4, 4), (8, 2), or (16, 1); in the case that the first number is 72, the second number is 24 and the configuration of (N_1', N_2') includes (4, 3), (6, 2) or (12, 1); in the case that the first number is 96: the second number is 32 and the configuration of (N_1', N_2') includes (4, 4), (8, 2), or (16, 1); or in the case that the first number is 128: the second number is 32 and the configuration of (N_1', N_2') includes (4, 4), (8, 2), or (16, 1).

[0008] In some implementations of the UE described herein, in the case that $N_2 > 1$, the configuration of (O_1, O_2) includes (4, 4), (4, 2), (2, 4), or (2, 2); or in the case that $N_2 = 1$, the configuration of (O_1, O_2) includes (4, 1) or (2, 1).

[0009] In some implementations of the UE described herein, the configuration information includes the configuration of (O_1, O_2) .

[0010] In some implementations of the UE described herein, for codebook mode 2 of 1-layer CSI reporting using the first number of CSI-RS ports, the codebook includes codeword(s) associated with beam pair(s) determined based on at least one of a horizontal beam offset S_1 or a vertical beam offset S_2 .

[0011] In some implementations of the UE described herein, in the case that $N_2 > 1$: the beam pair(s) includes $(2i_{1,1} + S_1, 2i_{1,2})$, $(2i_{1,1} + S_1 + 1, 2i_{1,2})$, $(2i_{1,1} + S_1, 2i_{1,2} + 1)$, and $(2i_{1,1} + S_1 + 1, 2i_{1,2} + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$; or the beam pair(s) includes $(2i_{1,1}, 2i_{1,2} + S_2)$, $(2i_{1,1} + 1, 2i_{1,2} + S_2)$, $(2i_{1,1}, 2i_{1,2} + S_2 + 1)$, and $(2i_{1,1} + 1, 2i_{1,2} + S_2 + 1)$.

[0012] In some implementations of the UE described herein, in the case that $N_2 > 1$, the codeword(s) includes: $W_{2i_{1,1}+S_1, 2i_{1,2}, 0}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 3}^{(1)}$,

$$\begin{aligned}
& W_{2i_{1,1}+S_1+1,2i_{1,2},0}^{(1)}, W_{2i_{1,1}+S_1+1,2i_{1,2},1}^{(1)}, W_{2i_{1,1}+S_1+1,2i_{1,2},2}^{(1)}, W_{2i_{1,1}+S_1+1,2i_{1,2},3}^{(1)}, \\
& W_{2i_{1,1}+S_1,2i_{1,2}+1,0}^{(1)}, W_{2i_{1,1}+S_1,2i_{1,2}+1,1}^{(1)}, W_{2i_{1,1}+S_1,2i_{1,2}+1,2}^{(1)}, W_{2i_{1,1}+S_1,2i_{1,2}+1,3}^{(1)}, \\
& W_{2i_{1,1}+S_1+1,2i_{1,2}+1,0}^{(1)}, W_{2i_{1,1}+S_1+1,2i_{1,2}+1,1}^{(1)}, W_{2i_{1,1}+S_1+1,2i_{1,2}+1,2}^{(1)}, \text{ and } W_{2i_{1,1}+S_1+1,2i_{1,2}+1,3}^{(1)}; \text{ or} \\
& W_{2i_{1,1},2i_{1,2}+S_2,0}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2,1}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2,2}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2,3}^{(1)}, W_{2i_{1,1}+1,2i_{1,2}+S_2,0}^{(1)}, \\
& W_{2i_{1,1}+1,2i_{1,2}+S_2,1}^{(1)}, W_{2i_{1,1}+1,2i_{1,2}+S_2,2}^{(1)}, W_{2i_{1,1}+1,2i_{1,2}+S_2,3}^{(1)}, \\
& W_{2i_{1,1},2i_{1,2}+S_2+1,0}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2+1,1}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2+1,2}^{(1)}, W_{2i_{1,1},2i_{1,2}+S_2+1,3}^{(1)}, \\
& W_{2i_{1,1}+1,2i_{1,2}+S_2+1,0}^{(1)}, W_{2i_{1,1}+1,2i_{1,2}+S_2+1,1}^{(1)}, W_{2i_{1,1}+1,2i_{1,2}+S_2+1,2}^{(1)}, \text{ and } W_{2i_{1,1}+1,2i_{1,2}+S_2+1,3}^{(1)}.
\end{aligned}$$

[0013] In some implementations of the UE described herein, in the case that $N_2 = 1$, the beam pair(s) includes $(2i_{1,1} + S_1, 0)$, $(2i_{1,1} + S_1 + 1, 0)$, $(2i_{1,1} + S_1 + 2, 0)$, and $(2i_{1,1} + S_1 + 3, 0)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$.

[0014] In some implementations of the UE described herein, in the case that $N_2 = 1$, the codeword(s) includes: $W_{2i_{1,1}+S_1,0,0}^{(1)}$, $W_{2i_{1,1}+S_1,0,1}^{(1)}$, $W_{2i_{1,1}+S_1,0,2}^{(1)}$, $W_{2i_{1,1}+S_1,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,2}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,2}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,2}^{(1)}$, and $W_{2i_{1,1}+S_1+3,0,3}^{(1)}$.

[0015] In some implementations of the UE described herein, S_1 or S_2 is configured to the UE or pre-defined.

[0016] In some implementations of the UE described herein, S_1 is 2 or a value scalable with O_1 , or S_2 is 2 or a value scalable with O_2 .

[0017] In some implementations of the UE described herein, the codebook for 2-layer, 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports is based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , wherein: in the case that $N_1 > N_2 > 1$, the pair of (k_1, k_2) includes $(3O_1, 0)$, $(0, 2O_2)$, (O_1, O_2) , or $(2O_1, O_2)$; in the case that $N_1 = N_2$, the pair of (k_1, k_2) includes $(2O_1, 0)$, $(0, 2O_2)$, $(2O_1, 2O_2)$, or $(3O_1, 0)$; or in the case that $N_1 > 2$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, or $(7O_1, 0)$; wherein $i_{1,3}$ is a codebook

index associated with the codebook, k_1 is a horizontal beam offset for determining beam pair(s) for the codebook, and k_2 is a vertical beam offset for determining the beam pair(s) for the codebook.

[0018] In some implementations of the UE described herein, for 5-layer, 6-layer, 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the codebook includes codeword(s) associated with beam pair(s) determined based on at least one of a horizontal scaling factor or a vertical scaling factor.

[0019] In some implementations of the UE described herein, for 5-layer or 6-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) includes $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or includes $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, and $(i_{1,1} + 2k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook, $i_{1,2}$ is a second codebook index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor; or for 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) includes $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, $(i_{1,1}, i_{1,2} + k_2 O_2)$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or includes $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, $(i_{1,1} + 2k_1 O_1, 0)$, $(i_{1,1} + 3k_1 O_1, 0)$ in case of $N_2 = 1$.

[0020] In some implementations of the UE described herein, in the case that the first number is equal to 48 or 64, the horizontal scaling factor or the vertical scaling factor is selected from $\{1, 2\}$; or in the case that the first number is equal to 72, 96, or 128, the horizontal scaling factor or the vertical scaling factor is selected from $\{1, 2, 3, 4\}$.

[0021] In some implementations of the UE described herein, the PMI includes bit(s) indicating a value of the horizontal scaling factor or the vertical scaling factor.

[0022] In some implementations of the UE described herein, for 2-layer CSI reporting using the first number of CSI-RS ports, the codebook is based on a single beam pair which is determined based on $i_{1,1}$ and $i_{1,2}$, a first co-phasing factor θ_p determined by $i_{1,3}$, and a second co-phasing factor φ_n determined by i_2 , wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, \dots, \frac{N_1 O_1}{2} - 1\}$, $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, \dots, N_2 O_2 - 1\}$, $i_{1,3}$ is a third codebook index

associated with the codebook and is selected from $\{0,1,2,3\}$, and i_2 is a fourth codebook index associated with the codebook and is selected from $\{0,1\}$.

[0023] In some implementations of the UE described herein, the codebook includes codewords

$$\text{determined by } W_{l,m,p,n}^{(2)} = \frac{1}{\sqrt{2P_{\text{CSI-RS}}}} \begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first number,}$$

$$l \text{ is } i_{1,1}, m \text{ is } i_{1,2}, p \text{ is } i_{1,3}, n \text{ is } i_2, \varphi_n = e^{j\pi n/2}, \theta_p = e^{j\pi p/4}, u_m =$$

$$\begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}, \quad \text{and} \quad \tilde{v}_{l,m} =$$

$$\begin{bmatrix} u_m & e^{j\frac{4\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{4\pi l(N_1/2-1)}{O_1 N_1}} u_m \end{bmatrix}^T.$$

[0024] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and perform CSI reporting, wherein the CSI reporting includes reporting the PMI.

[0025] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with

a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and receive CSI reporting, wherein the CSI reporting 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_1, N_2) and the configuration of (O_1, O_2) .

[0026] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and performing CSI reporting, wherein the CSI reporting includes reporting the PMI.

[0027] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and receiving CSI reporting, wherein the CSI reporting 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_1, N_2) and the configuration of (O_1, O_2) .

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] 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.

[0029] Figure 1 illustrates an example of a wireless communications system in accordance with aspects of the present disclosure.

[0030] Figure 2 illustrates a flowchart of an exemplary method performed by a UE in accordance with aspects of the present disclosure.

[0031] Figure 3 illustrates a flowchart of an exemplary method performed by a BS in accordance with aspects of the present disclosure.

[0032] Figure 4 illustrates an example of a UE in accordance with aspects of the present disclosure.

[0033] Figure 5 illustrates an example of a processor in accordance with aspects of the present disclosure.

[0034] Figure 6 illustrates an example of a BS in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0035] 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.

[0036] 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.

[0037] Reference will now be made in detail to some embodiments of the present application, 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 application are also applicable to similar technical problems; and moreover, the terminologies recited in the present application may change, which should not affect the principle of the present application.

[0038] Aspects of the present disclosure are described in the context of a wireless communications system.

[0039] 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 a 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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).

[0045] 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.

[0046] 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).

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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 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.

[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. In existing 5G system, Type I codebook may be designed based on CSI-RS with a maximum port number of 32. To achieve accurate CSI, an enhanced Type I codebook may be designed to support CSI reporting using more than 32 ports. Given this, how to design Type I codebook for more than 32 ports needs to be solved.

[0055] Embodiments of the present disclosure provide solutions for designing enhanced Type I codebook (e.g., Type I single-panel codebook) for more than 32 ports. In some embodiments of the present disclosure, since the legacy Type I codebook has good forward

compatibility, the enhanced Type I codebook for more than 32 ports may be designed based on the legacy Type I codebook design framework. In some embodiments of the present application, the enhanced Type I codebook for more than 32 ports may also be designed to improve robustness and accuracy for beam selection on account of finer beams and more candidate combinations of horizontal beams and vertical beams. More details will be described in the following text in combination with the appended drawings.

[0056] According to some embodiments of the present application, the codebook (e.g., Type I single-panel codebook) for more than 32 ports may be derived based on a configuration of (N_1, N_2) and a configuration of (O_1, O_2) corresponding to or associated with the configuration of (N_1, N_2) for a large scale antenna array with more than 32 antenna ports, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the large scale antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the large scale antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor. For example, the large scale antenna array may be referred to as a first antenna array with a first number of antenna ports, wherein the first number is larger than 32.

[0057] To generate a grid of beams, embodiments of the present disclosure introduce new configurations of (N_1, N_2) and configurations of (O_1, O_2) corresponding to or associated with the configurations of (N_1, N_2) for the first antenna array. In some embodiments, a BS may transmit a configuration of (N_1, N_2) to a UE. The configuration of (O_1, O_2) corresponding to or associated with the configuration of (N_1, N_2) may be specified in specifications, and thus the UE may derive the configuration of (O_1, O_2) based on the configuration of (N_1, N_2) . In some other embodiments, the BS may transmit a configuration of (N_1, N_2) and a corresponding or associated configuration of (O_1, O_2) to the UE.

[0058] In some embodiments of the present disclosure, the first antenna array may be rectangular and generated by aggregating at least two (e.g., 2-4) legacy antenna arrays with no more than 32 antenna ports. For example, the legacy antenna array may be referred to as a second antenna array with a second number of antenna ports, wherein the second number is less than or equal to 32. For example, the second number may be 4, 8, 12, 16, 24, or 32 from legacy antenna port numbers in 5G specification.

[0059] In some examples, the first antenna array (with the first number of CSI-RS ports) or the configuration of (N_1, N_2) may be determined by aggregating at least two second antenna arrays with a same second number of CSI-RS ports and a same configuration of (N_1', N_2') , wherein the second number is less than or equal to 32, wherein N_1' is a number of antenna ports per polarization direction in a horizontal direction of the second antenna array, and N_2' is a number of antenna ports per polarization direction in a vertical direction of the second antenna array.

[0060] In some examples, the first number may be 48, and the configuration of (N_1, N_2) may include (6, 4), (8, 3), (12, 2) or (24, 1).

[0061] As an example, when the configuration of (N_1, N_2) is (6, 4), (8, 3), (12, 2), or (24, 1), the first antenna array may be generated by aggregating 2 second antenna arrays. Each second antenna array may have 24 CSI-RS ports (i.e., the second number may be 24), and the configuration of (N_1', N_2') may include (4, 3), (6, 2), or (12, 1).

[0062] As another example, when the configuration of (N_1, N_2) may include (8, 3), (12, 2), (24, 1), the first antenna array may be generated by aggregating 3 second antenna arrays. Each second antenna array may have 16 CSI-RS ports (i.e., the second number may be 16), and the configuration of (N_1', N_2') may include (4, 2) or (8, 1).

[0063] In some examples, the first number may be 64, and the configuration of (N_1, N_2) may include (8, 4), (16, 2), or (32, 1).

[0064] As an example, the first antenna array may be generated by aggregating 4 second antenna arrays. Each second antenna array may have 16 CSI-RS ports (i.e., the second number may be 16), and the configuration of (N_1', N_2') may include (4, 2) or (8, 1).

[0065] As another example, the first antenna array may be generated by aggregating 2 second antenna arrays. Each second antenna array may have 32 CSI-RS ports (i.e., the second number may be 32), and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1).

[0066] In some examples, the first number may be 72, and the configuration of (N_1, N_2) may include (6, 6), (12, 3), (18, 2), or (36, 1).

[0067] As an example, the first antenna array may be generated by aggregating 3 second antenna arrays. Each second antenna array may have 24 CSI-RS ports (i.e., the second number may be 24), and the configuration of (N_1', N_2') may include (4, 3), (6, 2), or (12, 1).

[0068] In some examples, the first number may be 96, and the configuration of (N_1, N_2) may include (8, 6), (12, 4), (16, 3), (24, 2), or (48, 1).

[0069] As an example, the first antenna array may be generated by aggregating 3 second antenna arrays. Each second antenna array may have 32 CSI-RS ports (i.e., the second number may be 32), and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1).

[0070] In some examples, the first number may be 128, and the configuration of (N_1, N_2) may include (8, 8), (16, 4), (32, 2), or (64, 1).

[0071] As an example, the first antenna array may be generated by aggregating 4 second antenna arrays. Each second antenna array may have 32 CSI-RS ports (i.e., the second number may be 32), and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1).

[0072] In some other examples, the first antenna array (with the first number of CSI-RS ports) or the configuration of (N_1, N_2) may be determined by aggregating at least two antenna arrays with different numbers of CSI-RS ports and different configurations of (N_1', N_2') , wherein the number of CSI-RS ports of each antenna array for aggregating the first antenna array is less than or equal to 32, wherein N_1' is a number of antenna ports per polarization direction in a horizontal direction of a respective antenna array for aggregating the first antenna array, and N_2' is a number of antenna ports per polarization direction in a vertical direction of the respective antenna array for aggregating the first antenna array.

[0073] For example, the first antenna array (with the first number of CSI-RS ports) or the configuration of (N_1, N_2) may be determined by aggregating two antenna arrays, e.g., denoted as antenna array #1 and antenna array #2. Antenna array #1 may have a second number of CSI-RS ports and a configuration of (N_1', N_{21}') , and antenna array #2 may have a third number of CSI-RS ports and a configuration of (N_1', N_{22}') , wherein the second number is different from the third number, N_1' is a number of antenna ports per polarization direction in a horizontal direction of both antenna array #1 and antenna array #2, N_{21}' is a number of antenna ports per

polarization direction in a vertical direction of antenna array #1, and N_{22}' is a number of antenna ports per polarization direction in a vertical direction of antenna array #2. Alternatively, antenna array #1 may have a second number of CSI-RS ports and a configuration of (N_{11}', N_2') , and antenna array #2 may have a third number of CSI-RS ports and a configuration of (N_{12}', N_2') , wherein the second number is different from the third number, N_{11}' is a number of antenna ports per polarization direction in a horizontal direction of antenna array #1, N_{12}' is a number of antenna ports per polarization direction in a horizontal direction of antenna array #2, and N_2' is a number of antenna ports per polarization direction in a vertical direction of both antenna array #1 and antenna array #2.

[0074] In some embodiments of the present disclosure, when $N_2 > 1$, the corresponding or associated configuration of (O_1, O_2) may include (4, 4), (4, 2), (2, 4), or (2, 2); when $N_2 = 1$, the corresponding or associated configuration of (O_1, O_2) may include (4, 1) or (2, 1).

[0075] Exemplary configurations of (N_1, N_2) and corresponding configurations of (O_1, O_2) for an antenna array with more than 32 ports are shown in Table 1.

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

Number of CSI-RS antenna ports, $P_{\text{CSI-RS}}$	(N_1, N_2)	(O_1, O_2)
48	(6,4)	(4,4)
	(8,3)	(4,4)
	(12,2)	(4,4)
	(24,1)	(4,1)
64	(8,4)	(4,4)
	(16,2)	(4,4)
	(32,1)	(4,1)
72	(6, 6)	(4,4)
	(12,3)	(4,4)
	(18,2)	(4,4)
	(36,1)	(4,1)
96	(8,6)	(4,4)
	(12,4)	(4,4)
	(16,3)	(4,4)
	(24, 2)	(4,4)
	(48,1)	(4,1)
128	(8,8)	(4,4)
	(16,4)	(4,4)
	(32,2)	(4,4)
	(64,1)	(4,1)

[0076] In the examples provided in Table 1, the configuration of (O_1, O_2) is (4, 4) when $N_2 > 1$, and the configuration of (O_1, O_2) is (4, 1) when $N_2 = 1$. However, in some other examples of the present disclosure, when $N_2 > 1$, the configuration of (O_1, O_2) may be (4, 2), (2, 4), or (2, 2), and when $N_2 = 1$, the configuration of (O_1, O_2) may be (2, 1).

[0077] In some cases, the configuration of (O_1, O_2) may be specified as a fixed value, e.g., (4, 4) when $N_2 > 1$, or (4, 1) when $N_2 = 1$. In some cases, the configuration of (O_1, O_2) may be configured by a BS (e.g., via radio resource control (RRC) signaling) from candidate values (e.g., (4, 4), (4, 2), (2, 4), or (2, 2) when $N_2 > 1$, or (2, 1), (4, 1) when $N_2 = 1$).

[0078] In some cases, some configurations of (N_1, N_2) in Table 1 (such as (36, 1), (48, 1), or (64, 1)) may be not supported by a practical antenna array on account of a limited size.

[0079] According to some embodiments of the present disclosure, based on (N_1, N_2) and (O_1, O_2) for the first antenna array with more than 32 antenna ports, the codebook (e.g., Type I single-panel codebook) for 1-layer CSI reporting to 8-layer CSI reporting may be derived based on Table 5.2.2.2.1-5, Table 5.2.2.2.1-6, Table 5.2.2.2.1-7, Table 5.2.2.2.1-8, Table 5.2.2.2.1-9, Table 5.2.2.2.1-10, Table 5.2.2.2.1-11, and Table 5.2.2.2.1-12 as specified in 3GPP TS 38.214, respectively.

[0080] According to some embodiments of the present disclosure, for the first antenna array with more than 32 antenna ports, the finer beam may be generated and thus the coverage for each beam becomes smaller. For the enhanced codebook for more than 32 antenna ports, the robustness of beam selection may be improved if more candidate beams from adjacent oversampled beams are included in the codebook. As another aspect, different selected beam pairs may be used for different layers. Herein, a beam pair may represent a two-dimensional beam, which includes a horizontal beam (i.e., a beam in horizontal domain) and a vertical beam (i.e., a beam in vertical domain). Thus, the accuracy of CSI reporting may be improved if more combinations of the selected beam pairs for different layers are supported by the enhanced codebook for more than 32 antenna ports. The following embodiments provide various designs for the enhanced codebook (e.g., Type I single-panel codebook) for more than 32 antenna ports by considering the robustness of beam selection and the accuracy of CSI reporting.

[0081] The precoding matrix W of a codebook (e.g., Type I single-panel codebook) may be expressed as $W_1 * W_2$. W_1 is mainly used to reflect the wideband characteristics of the channel and contains beam selection information. W_2 is mainly used to reflect the narrowband/wideband characteristics of the channel, mainly including co-phasing information in two polarization directions, and sometimes also carries beam selection information.

[0082] According to some embodiments of the present application, the enhanced codebook (e.g., Type I single-panel codebook) for more than 32 antenna ports may include W_2 beam selection enhancement.

[0083] For example, for codebook mode 2 of 1-layer CSI reporting using no more than 32 ports, according to Table 5.2.2.2.1-5 as specified in 3GPP TS 38.214, 4 candidate beam pairs (i.e. $(2i_{1,1}, 2i_{1,2})$, $(2i_{1,1} + 1, 2i_{1,2})$, $(2i_{1,1}, 2i_{1,2} + 1)$, $(2i_{1,1} + 1, 2i_{1,2} + 1)$) may be selected in W_2

when $N_2 > 1$. To improve the robustness of beam selection on account of precise beams by a large antenna array, additional beam pairs can be introduced in W2 to provide larger spatial coverage for selection.

[0084] In some embodiments, for codebook mode 2 of 1-layer CSI reporting using more than 32 CSI-RS ports, a codebook may include codeword(s) associated with beam pair(s) (i.e., additional beam pair(s)) determined based on at least one of a horizontal beam offset S_1 or a vertical beam offset S_2 . As an example, the horizontal beam offset S_1 may be configured to a UE by a BS or may be pre-defined. As an example, the vertical beam offset S_2 may be configured to a UE by a BS or may be pre-defined.

[0085] In some examples, in the case that $N_2 > 1$, the additional beam pair(s) may include $(2i_{1,1} + S_1, 2i_{1,2})$, $(2i_{1,1} + S_1 + 1, 2i_{1,2})$, $(2i_{1,1} + S_1, 2i_{1,2} + 1)$, and $(2i_{1,1} + S_1 + 1, 2i_{1,2} + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, and $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$. Such beam pair(s) may improve beam selection range in horizontal domain.

[0086] For example, in the case that $N_2 > 1$, the codeword(s) in the enhanced codebook may include: $W_{2i_{1,1}+S_1, 2i_{1,2}, 0}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 3}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 1}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 2}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 3}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 0}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 3}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 1}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 2}^{(1)}$, and $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 3}^{(1)}$.

[0087] The following Table 2 illustrates an exemplary codebook for 1-layer CSI reporting using $P_{\text{CSI-RS}}$ (>32) antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$) in the case that $N_2 > 1$. Table 2 may be generated based on Table 5.2.2.2.1-5 as specified in 3GPP TS 38.214. Compared with Table 5.2.2.2.1-5, Table 2 includes additional codewords corresponding to index $i_2 = 16, 17, \dots, 31$, which are associated with beam pairs $(2i_{1,1} + S_1, 2i_{1,2})$, $(2i_{1,1} +$

$S_1 + 1, 2i_{1,2}$), $(2i_{1,1} + S_1, 2i_{1,2} + 1)$, and $(2i_{1,1} + S_1 + 1, 2i_{1,2} + 1)$. The additional codewords may provide more beam pair candidates for selection to improve robustness.

Table 2: Codebook for 1-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 2, $N_2 > 1$, $P_{\text{CSI-RS}} > 32$					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	1	2	3
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	5	6	7
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+1, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	9	10	11
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	13	14	15
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+1, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		16	17	18	19
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+S_1, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		20	21	22	23
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+S_1+1, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		24	25	26	27
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+S_1, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}+S_1, 2i_{1,2}+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		28	29	30	31
$0, 1, \dots, \frac{N_1 O_1}{2}$ - 1	$0, 1, \dots, \frac{N_2 O_2}{2}$ - 1	$W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 3}^{(1)}$
where $W_{l,m,n}^{(1)} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \end{bmatrix}$.					

[0088] In Table 2, $\varphi_n = e^{j\pi n/2}$, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$, and $u_m = \begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] \\ 1 \end{cases}$ $\begin{matrix} N_2 > 1 \\ N_2 = 1 \end{matrix}$.

[0089] As an example, S_1 may be equal to 2, which means a continuous extension of the existing beam pairs. In such example, the additional groups of beam pairs are adjacent or continuous groups of beam pairs of the existing groups of beam pairs.

[0090] As another example, S_1 may be a value scalable with the horizontal oversampling factor O_1 (e.g., S_1 may be equal to O_1). In such example, the spatial range for beam selection is further increased since the additional groups of beam pairs and the existing groups of beam pairs are spaced with a beam width of non-oversampled spatial beams.

[0091] Alternatively or additionally, in the case that $N_2 > 1$, the additional beam pair(s) may include $(2i_{1,1}, 2i_{1,2} + S_2)$, $(2i_{1,1} + 1, 2i_{1,2} + S_2)$, $(2i_{1,1}, 2i_{1,2} + S_2 + 1)$, and $(2i_{1,1} + 1, 2i_{1,2} + S_2 + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, and $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$. Such beam pair(s) may improve beam selection range in vertical domain.

[0092] For example, in the case that $N_2 > 1$, the codeword(s) in the enhanced codebook may include: $W_{2i_{1,1}, 2i_{1,2} + S_2, 0}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2, 1}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2, 2}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2, 3}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2, 0}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2, 1}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2, 2}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2, 3}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2 + 1, 0}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2 + 1, 1}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2 + 1, 2}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2} + S_2 + 1, 3}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2 + 1, 0}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2 + 1, 1}^{(1)}$, $W_{2i_{1,1} + 1, 2i_{1,2} + S_2 + 1, 2}^{(1)}$, and $W_{2i_{1,1} + 1, 2i_{1,2} + S_2 + 1, 3}^{(1)}$.

[0093] The following Table 3 illustrates an exemplary codebook for 1-layer CSI reporting using $P_{\text{CSI-RS}}$ (> 32) antenna ports (e.g., using antenna ports 3000 to 2999 + $P_{\text{CSI-RS}}$) in the case that $N_2 > 1$. Table 3 may be generated based on Table 5.2.2.2.1-5 as specified in 3GPP TS 38.214. Compared with Table 5.2.2.2.1-5, Table 3 includes additional codewords corresponding to index $i_2 = 16, 17, \dots, 31$, which are associated with beam pairs $(2i_{1,1}, 2i_{1,2} + S_2)$, $(2i_{1,1} + 1, 2i_{1,2} + S_2)$, $(2i_{1,1}, 2i_{1,2} + S_2 + 1)$, and $(2i_{1,1} + 1, 2i_{1,2} + S_2 + 1)$. The additional codewords may provide more beam pair candidates for selection to improve robustness.

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

$\text{codebookMode} = 2, N_2 > 1, P_{\text{CSI-RS}} > 32$					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	1	2	3
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	5	6	7
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}+1, 2i_{1,2}, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	9	10	11
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	13	14	15
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		16	17	18	19
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}, 2i_{1,2}+S_2, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		20	21	22	23
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		24	25	26	27
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}, 2i_{1,2}+S_2+1, 0}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2+1, 1}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2+1, 2}^{(1)}$	$W_{2i_{1,1}, 2i_{1,2}+S_2+1, 3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		28	29	30	31
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	$0, 1, \dots, \frac{N_2 O_2}{2} - 1$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 0}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 1}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 2}^{(1)}$	$W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 3}^{(1)}$
where $W_{l,m,n}^{(1)} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} [\mathbf{v}_{l,m} \mathbf{\varphi}_n \mathbf{v}_{l,m}^H]$.					

[0094] In Table 3, $\varphi_n = e^{j\pi n/2}$, $\mathbf{v}_{l,m} = [u_m \ e^{j\frac{2\pi l}{O_1 N_1}} u_m \ \dots \ e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m]^T$, and $u_m =$

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

[0095] As an example, S_2 may be equal to 2, which means a continuous extension of the existing beam pairs. In such example, the additional groups of beam pairs are adjacent or continuous groups of beam pairs of the existing groups of beam pairs.

[0096] As another example, S_2 may be a value scalable with the vertical oversampling factor O_2 (e.g., S_2 may be equal to O_2). In such example, the spatial range for beam selection is further increased since the additional groups of beam pairs and the existing groups of beam pairs are spaced with a beam width of non-oversampled spatial beams.

[0097] Following the above principle for the case of $N_2 > 1$, a similar design may also be made for the case of $N_2 = 1$. In some examples, for codebook mode 2 of 1-layer CSI reporting using more than 32 CSI-RS ports, in the case that $N_2 = 1$, the additional beam pair(s) may include $(2i_{1,1} + S_1, 0)$, $(2i_{1,1} + S_1 + 1, 0)$, $(2i_{1,1} + S_1 + 2, 0)$, and $(2i_{1,1} + S_1 + 3, 0)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$. All the definitions for S_1 in the case that $N_2 > 1$ may also apply here.

[0098] For example, in the case that $N_2 = 1$, the codeword(s) in the enhanced codebook may include: $W_{2i_{1,1}+S_1,0,0}^{(1)}$, $W_{2i_{1,1}+S_1,0,1}^{(1)}$, $W_{2i_{1,1}+S_1,0,2}^{(1)}$, $W_{2i_{1,1}+S_1,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,2}^{(1)}$, $W_{2i_{1,1}+S_1+1,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,2}^{(1)}$, $W_{2i_{1,1}+S_1+2,0,3}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,0}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,1}^{(1)}$, $W_{2i_{1,1}+S_1+3,0,2}^{(1)}$, and $W_{2i_{1,1}+S_1+3,0,3}^{(1)}$.

[0099] The following Table 4 illustrates an exemplary codebook for 1-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$) in the case that $N_2 = 1$. Table 4 may be generated based on Table 5.2.2.2.1-5 as specified in 3GPP TS 38.214. Compared with Table 5.2.2.2.1-5, Table 4 includes additional codewords corresponding to index $i_2 = 16, 17, \dots, 31$, which are associated with beam pairs $(2i_{1,1} + S_1, 0)$, $(2i_{1,1} + S_1 + 1, 0)$, $(2i_{1,1} + S_1 + 2, 0)$, and $(2i_{1,1} + S_1 + 3, 0)$. The additional codewords may provide more beam pair candidates for selection to improve robustness.

Table 4: Codebook for 1-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

$codebookMode = 2, N_2 = 1, P_{\text{CSI-RS}} > 32$					
$i_{1,1}$	$i_{1,2}$	i_2			
		0	1	2	3
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1},0,0}^{(1)}$	$W_{2i_{1,1},0,1}^{(1)}$	$W_{2i_{1,1},0,2}^{(1)}$	$W_{2i_{1,1},0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		4	5	6	7
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+1,0,0}^{(1)}$	$W_{2i_{1,1}+1,0,1}^{(1)}$	$W_{2i_{1,1}+1,0,2}^{(1)}$	$W_{2i_{1,1}+1,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		8	9	10	11
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+2,0,0}^{(1)}$	$W_{2i_{1,1}+2,0,1}^{(1)}$	$W_{2i_{1,1}+2,0,2}^{(1)}$	$W_{2i_{1,1}+2,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		12	13	14	15
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+3,0,0}^{(1)}$	$W_{2i_{1,1}+3,0,1}^{(1)}$	$W_{2i_{1,1}+3,0,2}^{(1)}$	$W_{2i_{1,1}+3,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		16	17	18	19
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+S_1,0,1}^{(1)}$	$W_{2i_{1,1}+S_1,0,1}^{(1)}$	$W_{2i_{1,1}+S_1,0,2}^{(1)}$	$W_{2i_{1,1}+S_1,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		20	21	22	23
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+S_1+1,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+1,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+1,0,2}^{(1)}$	$W_{2i_{1,1}+S_1+1,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		24	25	26	27
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+S_1+2,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+2,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+2,0,2}^{(1)}$	$W_{2i_{1,1}+S_1+2,0,3}^{(1)}$
$i_{1,1}$	$i_{1,2}$	i_2			
		28	29	30	31
$0, 1, \dots, \frac{N_1 O_1}{2} - 1$	0	$W_{2i_{1,1}+S_1+3,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+3,0,1}^{(1)}$	$W_{2i_{1,1}+S_1+3,0,2}^{(1)}$	$W_{2i_{1,1}+S_1+3,0,3}^{(1)}$
where $W_{l,m,n}^{(1)} = \frac{1}{\sqrt{P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \end{bmatrix}$.					

[0100] In Table 4, $\varphi_n = e^{j\pi n/2}$, $v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1} u_m} & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m} \end{bmatrix}^T$, $u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$.

[0101] Each of Table 2, Table 3 and Table 4 includes additional codewords associated with beam pairs determined based on either the horizontal beam offset S_1 or the vertical beam offset

S_2 . It is contemplated that the enhanced codebook may also include additional codewords associated with beam pairs determined based on both S_1 and S_2 in some other embodiments.

[0102] In some examples, if $N_2 > 1$, the horizontal beam offset S_1 may be fixed as 2 or O_1 , and/or the vertical beam offset S_2 may be fixed as 2 or O_2 . In some examples, if $N_2 = 1$, the horizontal beam offset S_1 may be fixed as 2 or O_1 and the vertical beam offset S_2 is 0. In some examples, the horizontal beam offset S_1 or the vertical beam offset S_2 may be configured by a BS (e.g., via RRC signaling).

[0103] According to some embodiments of the present application, the enhanced codebook (e.g., Type I single-panel codebook) for more than 32 antenna ports may include W1 beam selection enhancement.

[0104] In some cases, for 2-layer, 3-layer, or 4-layer CSI reporting using no more than 32 ports, according to Table 5.2.2.2.1-6, Table 5.2.2.2.1-7, and Table 5.2.2.2.1-8 as specified in 3GPP TS 38.214, a pair of offsets (k_1, k_2) may be used for selecting a second beam in horizontal domain and vertical domain, respectively. The values of (k_1, k_2) may be determined by a mapping table from $i_{1,3}$ to (k_1, k_2) . For example, the mapping table may be Table 5.2.2.2.1-3 as specified in 3GPP TS 38.214 which illustrates mapping of $i_{1,3}$ to k_1 and k_2 for 2-layer CSI reporting, or may be Table 5.2.2.2.1-4 as specified in 3GPP TS 38.214 which illustrates mapping of $i_{1,3}$ to k_1 and k_2 for 3-layer and 4-layer CSI reporting when $P_{\text{CSI-RS}} < 16$, wherein $P_{\text{CSI-RS}}$ is the number of antenna ports.

[0105] To improve robustness and CSI reporting accuracy for CSI reporting using more than 32 ports, additional candidate pairs of (k_1, k_2) may be introduced to achieve a larger range for beam selection not only in horizontal domain but also in vertical domain.

[0106] In some embodiments, the codebook for 2-layer, 3-layer or 4-layer CSI reporting using more than 32 CSI-RS ports may be based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , wherein $i_{1,3}$ is a codebook index associated with the codebook, k_1 is a horizontal beam offset for determining beam pair(s) for the codebook, and k_2 is a vertical beam offset for determining the beam pair(s) for the codebook. Specifically, k_1 is an offset for two selected beams in horizontal domain in one codeword. In other words, k_1 is used to select a second beam in horizontal domain in one codeword. k_2 is an offset for two selected beams in vertical domain

in one codeword. In other words, k_2 is used to select a second beam in horizontal domain in one codeword.

[0107] As an example, in the case that $N_1 > N_2 > 1$, the mapping table may include additional pairs of (k_1, k_2) such as $(3O_1, 0)$, $(0, 2O_2)$, (O_1, O_2) , or $(2O_1, O_2)$. As another example, in the case that $N_1 = N_2$, the mapping table may include additional pairs of (k_1, k_2) such as $(2O_1, 0)$, $(0, 2O_2)$, $(2O_1, 2O_2)$, or $(3O_1, 0)$. As another example, in the case that $N_1 > 2$ and $N_2 = 1$, the mapping table may include additional pairs of (k_1, k_2) such as $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, or $(7O_1, 0)$. In such examples, $(2O_1, 0)$, $(3O_1, 0)$, $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$ or $(7O_1, 0)$ may be introduced for a larger range of the second selected beam in horizontal domain; $(0, 2O_2)$ may be introduced for a larger range of the second selected beam in vertical domain; (O_1, O_2) , $(2O_1, O_2)$ or $(2O_1, 2O_2)$ may be introduced for a larger range of the second selected beam in a combination of horizontal domain and vertical domain.

[0108] The following Table 5 illustrates an exemplary mapping table from $i_{1,3}$ to a pair of (k_1, k_2) for 2-layer, 3-layer or 4-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports. Table 5 may be generated based on Table 5.2.2.2.1-3 as specified in 3GPP TS 38.214. Compared with Table 5.2.2.2.1-3, Table 5 includes additional pairs of (k_1, k_2) respectively mapping to $i_{1,3} = 4, 5, 6$, and 7 for three cases (i.e., $\{N_1 > N_2 > 1\}$, $\{N_1 = N_2\}$, and $\{N_1 > 2, N_2 = 1\}$).

Table 5: Mapping of $i_{1,3}$ to k_1 and k_2 for 2-layer, 3-layer, or 4-layer CSI reporting when $P_{\text{CSI-RS}} > 32$

$i_{1,3}$	$N_1 > N_2 > 1$		$N_1 = N_2$		$N_1 = 2, N_2 = 1$		$N_1 > 2, N_2 = 1$	
	k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
0	0	0	0	0	0	0	0	0
1	O_1	0	O_1	0	O_1	0	O_1	0
2	0	O_2	0	O_2			$2O_1$	0
3	$2O_1$	0	O_1	O_2			$3O_1$	0
4	$3O_1$	0	$2O_1$	0			$4O_1$	0
5	0	$2O_2$	0	$2O_2$			$5O_1$	0
6	O_1	O_2	$2O_1$	$2O_2$			$6O_1$	0
7	$2O_1$	O_2	$3O_1$	0			$7O_1$	0

[0109] In some examples, the aforementioned mapping table from $i_{1,3}$ to a pair of (k_1, k_2) (e.g., Table 5) may be used together with Table 5.2.2.2.1-6, Table 5.2.2.2.1-7, or Table 5.2.2.2.1-

8 as specified in 3GPP TS 38.214 to determine the codebook for 2-layer, 3-layer or 4-layer CSI reporting using more than 32 CSI-RS ports.

[0110] In some cases, for 5-layer or 6-layer CSI reporting using no more than 32 ports, according to Table 5.2.2.2.1-9 and Table 5.2.2.2.1-10 as specified in 3GPP TS 38.214, the beam pairs $(i_{1,1}, i_{1,2})$, $(i_{1,1} + O_1, i_{1,2})$, and $(i_{1,1} + O_1, i_{1,2} + O_2)$ may be selected when $N_2 > 1$, and the beam pairs $(i_{1,1}, 0)$, $(i_{1,1} + O_1, 0)$, and $(i_{1,1} + 2O_1, 0)$ may be selected when $N_2 = 1$; for 7-layer or 8-layer CSI reporting using no more than 32 ports, according to Table 5.2.2.2.1-11 and Table 5.2.2.2.1-12 as specified in 3GPP TS 38.214, the beam pairs $(i_{1,1}, i_{1,2})$, $(i_{1,1} + O_1, i_{1,2})$, $(i_{1,1}, i_{1,2} + O_2)$, and $(i_{1,1} + O_1, i_{1,2} + O_2)$ may be selected when $N_2 > 1$, and the beam pairs $(i_{1,1}, 0)$, $(i_{1,1} + O_1, 0)$, $(i_{1,1} + 2O_1, 0)$, and $(i_{1,1} + 3O_1, 0)$ may be selected when $N_2 = 1$. To improve robustness, scalable beam spacing may be introduced between beam pairs.

[0111] In some embodiments, for 5-layer, 6-layer, 7-layer or 8-layer CSI reporting using more than 32 CSI-RS ports, the codebook may include codeword(s) associated with beam pair(s) determined based on at least one of a horizontal scaling factor or a vertical scaling factor.

[0112] In some examples, for 5-layer or 6-layer CSI reporting using more than 32 CSI-RS ports, the beam pair(s) may include $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$, or include $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, and $(i_{1,1} + 2k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook, $i_{1,2}$ is a second codebook index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor.

[0113] The following Table 6 illustrates an exemplary codebook for 5-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999 + $P_{\text{CSI-RS}}$). Table 6 may be generated by extension based on Table 5.2.2.2.1-9 as specified in 3GPP TS 38.214.

Table 6: Codebook for 5-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1-2, $P_{\text{CSI-RS}} > 32$				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_2 > 1$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$W_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + k_1 O_1, i_{1,2}, i_{1,2} + k_2 O_2, i_2}^{(5)}$
$N_1 > 2, N_2 = 1$	$0, \dots, N_1 O_1 - 1$	0	0,1	$W_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + 2k_1 O_1, 0, 0, 0, i_2}^{(5)}$
where $W_{l,l',l'',m,m',m'',n}^{(5)} = \frac{1}{\sqrt{5P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & v_{l',m'} & -v_{l',m'} & v_{l'',m''} \end{bmatrix}$, (k_1, k_2) is determined based on $i_{1,4}$				

[0114] In Table 6, $\varphi_n = e^{j\pi n/2}$, $v_{l,m} = \left[u_m \ e^{j\frac{2\pi l}{O_1 N_1}} u_m \ \dots \ e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \right]^T$, $u_m = \begin{cases} [1 \ e^{j\frac{2\pi m}{O_2 N_2}} \ \dots \ e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, and $i_{1,4}$ is a codebook index. In some examples, a UE may report a value of $i_{1,4}$ indicating at least one of a value of k_1 or a value of k_2 to a BS. For example, the PMI reported by the UE may include bit(s) (e.g., a value of $i_{1,4}$) indicating at least one of a value of k_1 or a value of k_2 selected by the UE.

[0115] The following Table 7 illustrates an exemplary codebook for 6-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$). Table 7 may be generated by extension based on Table 5.2.2.2.1-10 as specified in 3GPP TS 38.214.

Table 7: Codebook for 6-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

codebookMode = 1-2, $P_{\text{CSI-RS}} > 32$				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_2 > 1$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$W_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + k_1 O_1, i_{1,2}, i_{1,2} + k_2 O_2, i_2}^{(6)}$
$N_1 > 2, N_2 = 1$	$0, \dots, N_1 O_1 - 1$	0	0,1	$W_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + 2k_1 O_1, 0, 0, 0, i_2}^{(6)}$
where $W_{l,l',l'',m,m',m'',n}^{(6)} = \frac{1}{\sqrt{6P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} \end{bmatrix}$, (k_1, k_2) is determined based on $i_{1,4}$				

[0116] In Table 7, the definition for each parameter is the same as that in Table 6.

[0117] In some examples, for 7-layer or 8-layer CSI reporting using more than 32 CSI-RS ports, the beam pair(s) may include $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, $(i_{1,1}, i_{1,2} + k_2 O_2)$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or include $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, $(i_{1,1} + 2k_1 O_1, 0)$, $(i_{1,1} + 3k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook,

$i_{1,2}$ is a second codebook index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor.

[0118] The following Table 8 illustrates an exemplary codebook for 7-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$). Table 8 may be generated by extension based on Table 5.2.2.2.1-11 as specified in 3GPP TS 38.214.

Table 8: Codebook for 7-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

<i>codebookMode</i> = 1-2, $P_{\text{CSI-RS}} > 32$				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_1 = 4, N_2 = 1$	$0, \dots, \frac{N_1 O_1}{2} - 1$	0	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1} + 2k_1 \mathbf{O}_1, i_{1,1} + 3k_1 \mathbf{O}_1, 0, 0, 0, 0, i_2}^{(7)}$
$N_1 > 4, N_2 = 1$	$0, \dots, N_1 O_1 - 1$	0	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1} + 2k_1 \mathbf{O}_1, i_{1,1} + 3k_1 \mathbf{O}_1, 0, 0, 0, 0, i_2}^{(7)}$
$N_1 = 2, N_2 = 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,2}, i_{1,2} + k_2 \mathbf{O}_2, i_{1,2} + k_2 \mathbf{O}_2, i_2}^{(7)}$
$N_1 > 2, N_2 = 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, \frac{N_2 O_2}{2} - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,2}, i_{1,2} + k_2 \mathbf{O}_2, i_{1,2} + k_2 \mathbf{O}_2, i_2}^{(7)}$
$N_1 > 2, N_2 > 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,2}, i_{1,2} + k_2 \mathbf{O}_2, i_{1,2} + k_2 \mathbf{O}_2, i_2}^{(7)}$
where $\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,1}, i_{1,1} + k_1 \mathbf{O}_1, i_{1,2}, i_{1,2} + k_2 \mathbf{O}_2, i_{1,2} + k_2 \mathbf{O}_2, i_2}^{(7)}$ $= \frac{1}{\sqrt{7P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l'',m''} & v_{l',m''} & v_{l'',m''} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} & v_{l'',m''} & -v_{l'',m''} \end{bmatrix}$, $(\mathbf{k}_1, \mathbf{k}_2)$ is determined based on $i_{1,4}$				

[0119] In Table 8, $\varphi_n = e^{j\pi n/2}$, $v_{l,m} = \left[u_m \ e^{j\frac{2\pi l}{O_1 N_1} u_m} \dots e^{j\frac{2\pi l(N_1-1)}{O_1 N_1} u_m} \right]^T$, $u_m = \begin{cases} \left[1 \ e^{j\frac{2\pi m}{O_2 N_2}} \dots e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \right] & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}$, and $i_{1,4}$ is a codebook index. In some examples, a UE may report a value of $i_{1,4}$ indicating at least one of a value of k_1 or a value of k_2 to a BS. For example, the PMI reported by the UE to the BS may include bit(s) (e.g., a value of $i_{1,4}$) indicating at least one of a value of k_1 or a value of k_2 selected by the UE.

[0120] The following Table 9 illustrates an exemplary codebook for 8-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$). Table 9 may be generated by extension based on Table 5.2.2.2.1-12 as specified in 3GPP TS 38.214.

Table 9: Codebook for 8-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

$codebookMode = 1-2, P_{\text{CSI-RS}} > 32$				
	$i_{1,1}$	$i_{1,2}$	i_2	
$N_1 = 4, N_2 = 1$	$0, \dots, \frac{N_1 O_1}{2} - 1$	0	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + 2k_1 O_1, i_{1,1} + 3k_1 O_1, 0, 0, 0, 0, i_2}^{(8)}$
$N_1 > 4, N_2 = 1$	$0, \dots, N_1 O_1 - 1$	0	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1} + 2k_1 O_1, i_{1,1} + 3k_1 O_1, 0, 0, 0, 0, i_2}^{(8)}$
$N_1 = 2, N_2 = 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1}, i_{1,1} + k_1 O_1, i_{1,2}, i_{1,2} + k_2 O_2, i_{1,2} + k_2 O_2, i_2}^{(8)}$
$N_1 > 2, N_2 = 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, \frac{N_2 O_2}{2} - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1}, i_{1,1} + k_1 O_1, i_{1,2}, i_{1,2} + k_2 O_2, i_{1,2} + k_2 O_2, i_2}^{(8)}$
$N_1 > 2, N_2 > 2$	$0, \dots, N_1 O_1 - 1$	$0, \dots, N_2 O_2 - 1$	0,1	$\mathbf{W}_{i_{1,1}, i_{1,1} + k_1 O_1, i_{1,1}, i_{1,1} + k_1 O_1, i_{1,2}, i_{1,2} + k_2 O_2, i_{1,2} + k_2 O_2, i_2}^{(8)}$
where $\mathbf{W}_{l,l',l'',m,m',m'',n}^{(8)} = \frac{1}{\sqrt{8P_{\text{CSI-RS}}}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} & v_{l',m'} & v_{l'',m''} & v_{l'',m''} & v_{l'',m''} & v_{l'',m''} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l',m'} & v_{l'',m''} & -v_{l'',m''} & v_{l'',m''} & -v_{l'',m''} \end{bmatrix}$, (k_1, k_2) is determined based on $i_{1,4}$				

[0121] In Table 9, the definition for each parameter is the same as that in Table 8.

[0122] The horizontal scaling factor or the vertical scaling factor may be a positive integer. As an example, in the case of 48 or 64 ports, the horizontal scaling factor or the vertical scaling factor may be selected from {1,2}. As an example, in the case of 72, 96, or 128 ports, the horizontal scaling factor or the vertical scaling factor may be selected from {1,2,3,4}.

[0123] In some embodiments, a UE may report a selected value of the horizontal scaling factor to a BS. Alternatively or additionally, a UE may report a selected value of the vertical scaling factor to a BS. For example, the PMI reported by the UE may include bit(s) (e.g., a value of $i_{1,4}$) indicating at least one of a value of k_1 or a value of k_2 selected by the UE.

[0124] In some embodiments, the horizontal scaling factor or the vertical scaling factor may have the same value. Then, the horizontal scaling factor k_1 and the vertical scaling factor k_2 may be unified as a scaling factor k , which is used as both the horizontal scaling factor and the vertical scaling factor. In some examples, the UE may report a selected value of the scaling factor k to a BS. For example, the PMI reported by the UE may include bit(s) (e.g., a value of $i_{1,4}$) indicating a value of the scaling factor k .

[0125] In some cases, for 3-layer CSI reporting using no more than 32 ports, according to Table 5.2.2.2.1-7 as specified in 3GPP TS 38.214, only one beam pair is selected when $P_{\text{CSI-RS}} \geq$

16. A first co-phasing factor θ_p is used for different subgroups of antenna ports and a second co-phasing factor φ_n is used for different polarization directions. For this structure of codebook, there is no performance loss for multiple beam selections because only one beam pair is selected. Thus, the robustness is better with flexible selection of $i_{1,1}$, $i_{1,2}$ and θ_p . The aforementioned single selected beam based Type I single-panel codebook may be well suitable for the large antenna array, which may be generated by aggregating multiple antenna arrays with a same configuration of (N_1', N_2') as stated above. Given this, the codebook for 3-layer CSI reporting using no more than 32 ports can be reused for 2-layer CSI reporting using more than 32 antenna ports to achieve better robustness.

[0126] For example, for 2-layer CSI reporting using more than 32 antenna ports, the codebook may be based on a single beam pair which is determined based on $i_{1,1}$ and $i_{1,2}$, a first co-phasing factor θ_p determined by $i_{1,3}$, and a second co-phasing factor φ_n determined by i_2 , wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, \dots, \frac{N_1 O_1}{2} - 1\}$, $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, \dots, N_2 O_2 - 1\}$, $i_{1,3}$ is a third codebook index associated with the codebook and is selected from $\{0, 1, 2, 3\}$, and i_2 is a fourth codebook index associated with the codebook and is selected from $\{0, 1\}$.

[0127] The following Table 10 illustrates an exemplary codebook for 2-layer CSI reporting using $P_{\text{CSI-RS}} (>32)$ antenna ports (e.g., using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$). Table 10 may be generated based on Table 5.2.2.2.1-7 as specified in 3GPP TS 38.214.

Table 10: Codebook for 2-layer CSI reporting using antenna ports 3000 to 2999+ $P_{\text{CSI-RS}}$

$codebookMode = 1-2, P_{\text{CSI-RS}} > 32$				
$i_{1,1}$	$i_{1,2}$	$i_{1,3}$	i_2	
$0, \dots, \frac{N_1 O_1}{2} - 1$	$0, \dots, N_2 O_2 - 1$	$0, 1, 2, 3$	$0, 1$	$W_{i_{1,1}, i_{1,2}, i_{1,3}, i_2}^{(2)}$
where $W_{l,m,p,n}^{(2)} = \frac{1}{\sqrt{2P_{\text{CSI-RS}}}}$ $\begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}$				

[0128] In Table 10, $\varphi_n = e^{j\pi n/2}$, $\theta_p = e^{j\pi p/4}$, $u_m =$

$$\begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] & N_2 > 1 \\ & & & & N_2 = 1 \end{cases}, \quad \text{and} \quad \tilde{v}_{l,m} =$$

$$\left[u_m \quad e^{j\frac{4\pi l}{O_1 N_1}} u_m \quad \dots \quad e^{j\frac{4\pi l(N_1/2-1)}{O_1 N_1}} u_m \right]^T.$$

[0129] In the above example, the value of $i_{1,3}$ may be indicated by 2 bits in the PMI reported by the UE. In some other examples, to improve performance, $i_{1,3}$ may have more candidate values and may be indicated by more bits in the PMI.

[0130] 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.

[0131] As shown in Figure 2, in step 202, the UE may receive configuration information (e.g., via RRC signaling) for a first antenna array with a first number of CSI-RS ports, wherein the first number is more than 32.

[0132] The configuration information may include a configuration of (N_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor. In some embodiments, the configuration information may also include the configuration of (O_1, O_2) .

[0133] In step 204, the UE may determine a PMI based on a codebook (e.g., Type I single-panel codebook) for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (N_1, N_2) and the configuration of (O_1, O_2) . For example, the codebook may be one of the aforementioned enhanced codebooks for more than 32 ports associated with the configuration of (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 $i_{1,3}$, or a

value of i_2 determined by the UE. The definitions for $i_{1,1}$, $i_{1,2}$, $i_{1,3}$, and i_2 provided in the aforementioned embodiments may apply here.

[0134] In step 206, the UE may perform CSI reporting, wherein the CSI reporting includes reporting the PMI.

[0135] According to some embodiments of the present disclosure, in the case that the first number is 48, the configuration of (N_1, N_2) includes (6, 4), (8, 3), (12, 2) or (24, 1); in the case that the first number is 64, the configuration of (N_1, N_2) includes (8, 4), (16, 2), or (32, 1); in the case that the first number is 72, the configuration of (N_1, N_2) includes (6, 6), (12, 3), (18, 2), or (36, 1); in the case that the first number is 96, the configuration of (N_1, N_2) includes (8, 6), (12, 4), (16, 3), (24, 2), or (48, 1); or in the case that the first number is 128, the configuration of (N_1, N_2) includes (8, 8), (16, 4), (32, 2), or (64, 1).

[0136] According to some embodiments of the present disclosure, the configuration of (N_1, N_2) may be determined by aggregating at least two second antenna arrays with a same second number of CSI-RS ports and a same configuration of (N_1', N_2') , wherein the second number is less than or equal to 32, wherein N_1' is a number of antenna ports per polarization direction in a horizontal direction of the second antenna array, and N_2' is a number of antenna ports per polarization direction in a vertical direction of the second antenna array. In some examples, the UE may receive the configuration of (N_1', N_2') from a BS via RRC signaling. In other words, the configuration of (N_1', N_2') may be configured by the BS to the UE via RRC signaling.

[0137] In some embodiments of the present application, in the case that the first number is 48: the second number may be 24 and the configuration of (N_1', N_2') may include (4, 3), (6, 2) or (12, 1); or the second number may be 16 and the configuration of (N_1', N_2') may include (4, 2) or (8, 1); in the case that the first number is 64: the second number may be 16 and the configuration of (N_1', N_2') may include (4, 2) or (8, 1); or the second number may be 32 and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1); in the case that the first number is 72, the second number may be 24 and the configuration of (N_1', N_2') may include (4, 3), (6, 2) or (12, 1); in the case that the first number is 96: the second number may be 32 and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1); or in the case that the first

number is 128: the second number may be 32 and the configuration of (N_1', N_2') may include (4, 4), (8, 2), or (16, 1).

[0138] According to some embodiments of the present disclosure, in the case that $N_2 > 1$, the configuration of (O_1, O_2) may include (4, 4), (4, 2), (2, 4), or (2, 2); in the case that $N_2 = 1$, the configuration of (O_1, O_2) may include (4, 1) or (2, 1).

[0139] According to some embodiments of the present disclosure, for codebook mode 2 of 1-layer CSI reporting using the first number of CSI-RS ports, the codebook may include codeword(s) associated with beam pair(s) determined based on at least one of a horizontal beam offset S_1 or a vertical beam offset S_2 .

[0140] In some embodiments, in the case that $N_2 > 1$: the beam pair(s) may include $(2i_{1,1} + S_1, 2i_{1,2})$, $(2i_{1,1} + S_1 + 1, 2i_{1,2})$, $(2i_{1,1} + S_1, 2i_{1,2} + 1)$, and $(2i_{1,1} + S_1 + 1, 2i_{1,2} + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, and $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$. As an example, in the case that $N_2 > 1$, the codeword(s) may include:

$$\begin{aligned} & W_{2i_{1,1}+S_1, 2i_{1,2}, 0}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}, 1}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}, 2}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}, 3}^{(1)}, W_{2i_{1,1}+S_1+1, 2i_{1,2}, 0}^{(1)}, \\ & W_{2i_{1,1}+S_1+1, 2i_{1,2}, 1}^{(1)}, W_{2i_{1,1}+S_1+1, 2i_{1,2}, 2}^{(1)}, W_{2i_{1,1}+S_1+1, 2i_{1,2}, 3}^{(1)}, \\ & W_{2i_{1,1}+S_1, 2i_{1,2}+1, 0}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}+1, 1}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}+1, 2}^{(1)}, W_{2i_{1,1}+S_1, 2i_{1,2}+1, 3}^{(1)}, \\ & W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 0}^{(1)}, W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 1}^{(1)}, W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 2}^{(1)}, \text{ and } W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 3}^{(1)}. \end{aligned}$$

[0141] In some embodiments, in the case that $N_2 > 1$: the beam pair(s) may include $(2i_{1,1}, 2i_{1,2} + S_2)$, $(2i_{1,1} + 1, 2i_{1,2} + S_2)$, $(2i_{1,1}, 2i_{1,2} + S_2 + 1)$, and $(2i_{1,1} + 1, 2i_{1,2} + S_2 + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, and $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$. As an example, in the case that $N_2 > 1$, the codeword(s) may

$$\begin{aligned} & \text{include: } W_{2i_{1,1}, 2i_{1,2}+S_2, 0}^{(1)}, W_{2i_{1,1}, 2i_{1,2}+S_2, 1}^{(1)}, W_{2i_{1,1}, 2i_{1,2}+S_2, 2}^{(1)}, W_{2i_{1,1}, 2i_{1,2}+S_2, 3}^{(1)}, W_{2i_{1,1}+1, 2i_{1,2}+S_2, 0}^{(1)}, \\ & W_{2i_{1,1}+1, 2i_{1,2}+S_2, 1}^{(1)}, W_{2i_{1,1}+1, 2i_{1,2}+S_2, 2}^{(1)}, W_{2i_{1,1}+1, 2i_{1,2}+S_2, 3}^{(1)}, \end{aligned}$$

$W_{2i_{1,1}, 2i_{1,2}+S_2+1,0}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1,1}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1,2}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1,3}^{(1)}$,
 $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1,0}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1,1}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1,2}^{(1)}$, and $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1,3}^{(1)}$.

[0142] In some embodiments, in the case that $N_2 = 1$, the beam pair(s) may include $(2i_{1,1} + S_1, 0)$, $(2i_{1,1} + S_1 + 1, 0)$, $(2i_{1,1} + S_1 + 2, 0)$, and $(2i_{1,1} + S_1 + 3, 0)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$. As an example, in the case that $N_2 = 1$, the codeword(s) may include: $W_{2i_{1,1}+S_1, 0,0}^{(1)}$, $W_{2i_{1,1}+S_1, 0,1}^{(1)}$, $W_{2i_{1,1}+S_1, 0,2}^{(1)}$, $W_{2i_{1,1}+S_1, 0,3}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0,0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0,1}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0,2}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0,3}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0,0}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0,1}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0,2}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0,3}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0,0}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0,1}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0,2}^{(1)}$, and $W_{2i_{1,1}+S_1+3, 0,3}^{(1)}$.

[0143] In some embodiments, the horizontal beam offset S_1 or the vertical beam offset S_2 may be configured to the UE by a BS or pre-defined.

[0144] In some embodiments, the horizontal beam offset S_1 may be 2 or a value scalable with O_1 .

[0145] In some embodiments, the vertical beam offset S_2 may be 2 or a value scalable with O_2 .

[0146] According to some embodiments of the present disclosure, the codebook for 2-layer, 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports may be based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) . In the case that $N_1 > N_2 > 1$, the pair of (k_1, k_2) may include $(3O_1, 0)$, $(0, 2O_2)$, (O_1, O_2) , or $(2O_1, O_2)$; in the case that $N_1 = N_2$, the pair of (k_1, k_2) may include $(2O_1, 0)$, $(0, 2O_2)$, $(2O_1, 2O_2)$, or $(3O_1, 0)$; or in the case that $N_1 > 2$ and $N_2 = 1$, the pair of (k_1, k_2) may include $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, or $(7O_1, 0)$; wherein $i_{1,3}$ is a codebook index associated with the codebook, k_1 is a horizontal beam offset for determining beam pair(s) for the codebook, and k_2 is a vertical beam offset for determining the beam pair(s) for the codebook.

[0147] According to some embodiments of the present disclosure, for 5-layer, 6-layer, 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the codebook may include

codeword(s) associated with beam pair(s) determined based on at least one of a horizontal scaling factor or a vertical scaling factor.

[0148] In some embodiments, for 5-layer or 6-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) may include $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or include $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, and $(i_{1,1} + 2k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook, $i_{1,2}$ is a second codebook index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor.

[0149] In some embodiments, for 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) may include $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, $(i_{1,1}, i_{1,2} + k_2 O_2)$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or include $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, $(i_{1,1} + 2k_1 O_1, 0)$, $(i_{1,1} + 3k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook, $i_{1,2}$ is a second codebook index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor.

[0150] In some embodiments, in the case that the first number is equal to 48 or 64, the horizontal scaling factor or the vertical scaling factor is selected from $\{1, 2\}$; in the case that the first number is equal to 72, 96, or 128, the horizontal scaling factor or the vertical scaling factor is selected from $\{1, 2, 3, 4\}$.

[0151] In some embodiments, the PMI may include bit(s) indicating at least one of a value of the horizontal scaling factor or a value of the vertical scaling factor.

[0152] According to some embodiments of the present disclosure, for 2-layer CSI reporting using the first number of CSI-RS ports, the codebook may be based on a single beam pair which is determined based on $i_{1,1}$ and $i_{1,2}$, a first co-phasing factor θ_p determined by $i_{1,3}$, and a second co-phasing factor φ_n determined by i_2 , wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, \dots, \frac{N_1 O_1}{2} - 1\}$, $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, \dots, N_2 O_2 - 1\}$, $i_{1,3}$ is a third codebook index associated with the codebook and is selected from $\{0, 1, 2, 3\}$, and i_2 is a fourth codebook index associated with the codebook and is selected from $\{0, 1\}$.

[0153] In some embodiments, the codebook may include codewords determined by $W_{l,m,p,n}^{(2)} =$

$$\frac{1}{\sqrt{2P_{\text{CSI-RS}}}} \begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix}, \text{ wherein } P_{\text{CSI-RS}} \text{ is the first number, } l \text{ is } i_{1,1}, m \text{ is } i_{1,2}, p \text{ is } i_{1,3},$$

$$n \text{ is } i_2, \varphi_n = e^{j\pi n/2}, \theta_p = e^{j\pi p/4}, u_m = \begin{cases} [1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}}] \\ & 1 \end{cases} \quad \begin{matrix} N_2 > 1 \\ N_2 = 1 \end{matrix}, \text{ and}$$

$$\tilde{v}_{l,m} = \begin{bmatrix} u_m & e^{j\frac{4\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{4\pi l(N_1/2-1)}{O_1 N_1}} u_m \end{bmatrix}^T.$$

[0154] 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.

[0155] As shown in Figure 3, in step 302, the BS may transmit configuration information for a first antenna array with a first number of CSI-RS ports, wherein the first number is more than 32.

[0156] The configuration information may include a configuration of (N_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor. In some embodiments, the configuration information may also include the configuration of (O_1, O_2) .

[0157] In step 304, the BS may receive CSI reporting, wherein the CSI reporting includes a PMI associated with a codebook (e.g., Type I single-panel codebook) for the first number of CSI-RS ports, wherein the codebook is associated with the configuration of (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 $i_{1,3}$, or a value of i_2 determined by the UE. The definitions for $i_{1,1}$, $i_{1,2}$, $i_{1,3}$, and i_2 provided in the aforementioned embodiments may apply

here. In some embodiments, the PMI may also include bit(s) indicating at least one of a value of the horizontal scaling factor or a value of the vertical scaling factor.

[0158] All the definitions and operations related to the configuration of (N_1, N_2) , the configuration of (O_1, O_2) , configuration of (N_1', N_2') , the codebook for the first number of CSI-RS ports, the beam pair(s), the horizontal beam offset, the vertical beam offset, the mapping table, the horizontal scaling factor, and the vertical scaling factor described with respect to FIG. 2 may also apply here. Thus, details are omitted for simplicity.

[0159] 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.

[0160] 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.

[0161] 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.

[0162] 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.

[0163] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and perform CSI reporting, wherein the CSI reporting includes reporting the PMI.

[0164] 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.

[0165] 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.

[0166] 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.

[0167] 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.

[0168] 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 a 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).

[0169] 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).

[0170] 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.

[0171] 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.

[0172] 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).

[0173] 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.

[0174] 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.

[0175] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and perform CSI reporting, wherein the CSI reporting includes reporting the PMI.

[0176] Figure 11 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.

[0177] 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.

[0178] 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.

[0179] 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.

[0180] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and receive CSI reporting, wherein the CSI reporting 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_1, N_2) and the configuration of (O_1, O_2) .

[0181] 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.

[0182] 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.

[0183] A receiver chain 600 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.

[0184] 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.

[0185] 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and
 - perform channel state information (CSI) reporting, wherein the CSI reporting includes reporting the PMI.
2. The UE of Claim 1, wherein the configuration of (N_1, N_2) is determined by aggregating at least two second antenna arrays with a same second number of CSI-RS ports and a same configuration of (N_1', N_2') , wherein the second number is less than or equal to 32, wherein N_1' is a number of antenna ports per polarization direction in a horizontal direction of the second antenna array, and N_2' is a number of antenna ports per polarization direction in a vertical direction of the second antenna array.

3. The UE of Claim 1, wherein:
 - in the case that the first number is 48, the configuration of (N_1, N_2) includes (6, 4), (8, 3), (12, 2) or (24, 1);
 - in the case that the first number is 64, the configuration of (N_1, N_2) includes (8, 4), (16, 2), or (32, 1);
 - in the case that the first number is 72, the configuration of (N_1, N_2) includes (6, 6), (12, 3), (18, 2), or (36, 1);
 - in the case that the first number is 96, the configuration of (N_1, N_2) includes (8, 6), (12, 4), (16, 3), (24, 2), or (48, 1); or
 - in the case that the first number is 128, the configuration of (N_1, N_2) includes (8, 8), (16, 4), (32, 2), or (64, 1).
4. The UE of Claim 1, wherein:
 - in the case that $N_2 > 1$, the configuration of (O_1, O_2) includes (4, 4), (4, 2), (2, 4), or (2, 2); or
 - in the case that $N_2 = 1$, the configuration of (O_1, O_2) includes (4, 1) or (2, 1).
5. The UE of Claim 1, wherein the configuration information includes the configuration of (O_1, O_2) .
6. The UE of Claim 1, wherein for codebook mode 2 of 1-layer CSI reporting using the first number of CSI-RS ports, the codebook includes codeword(s) associated with beam pair(s) determined based on at least one of a horizontal beam offset S_1 or a vertical beam offset S_2 .
7. The UE of Claim 6, wherein:
 - in the case that $N_2 > 1$:
 - the beam pair(s) includes $(2i_{1,1} + S_1, 2i_{1,2})$, $(2i_{1,1} + S_1 + 1, 2i_{1,2})$, $(2i_{1,1} + S_1, 2i_{1,2} + 1)$, and $(2i_{1,1} + S_1 + 1, 2i_{1,2} + 1)$, wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from

$\{0, 1, \dots, \frac{N_1 O_1}{2} - 1\}$, and $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, 1, \dots, \frac{N_2 O_2}{2} - 1\}$; or

the beam pair(s) includes $(2i_{1,1}, 2i_{1,2} + S_2)$, $(2i_{1,1} + 1, 2i_{1,2} + S_2)$, $(2i_{1,1}, 2i_{1,2} + S_2 + 1)$, and $(2i_{1,1} + 1, 2i_{1,2} + S_2 + 1)$; or

in the case that $N_2 = 1$, the beam pair(s) includes $(2i_{1,1} + S_1, 0)$, $(2i_{1,1} + S_1 + 1, 0)$, $(2i_{1,1} + S_1 + 2, 0)$, and $(2i_{1,1} + S_1 + 3, 0)$.

8. The UE of Claim 7, wherein:

in the case that $N_2 > 1$, the codeword(s) includes:

$W_{2i_{1,1}+S_1, 2i_{1,2}, 0}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}, 3}^{(1)}$,
 $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 1}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 2}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}, 3}^{(1)}$,
 $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 0}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 2i_{1,2}+1, 3}^{(1)}$,
 $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 1}^{(1)}$, $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 2}^{(1)}$, and
 $W_{2i_{1,1}+S_1+1, 2i_{1,2}+1, 3}^{(1)}$; or
 $W_{2i_{1,1}, 2i_{1,2}+S_2, 0}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2, 1}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2, 2}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2, 3}^{(1)}$,
 $W_{2i_{1,1}+1, 2i_{1,2}+S_2, 0}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2, 1}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2, 2}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2, 3}^{(1)}$,
 $W_{2i_{1,1}, 2i_{1,2}+S_2+1, 0}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1, 1}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1, 2}^{(1)}$, $W_{2i_{1,1}, 2i_{1,2}+S_2+1, 3}^{(1)}$,
 $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 0}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 1}^{(1)}$, $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 2}^{(1)}$, and
 $W_{2i_{1,1}+1, 2i_{1,2}+S_2+1, 3}^{(1)}$; or

in the case that $N_2 = 1$, the codeword(s) includes: $W_{2i_{1,1}+S_1, 0, 0}^{(1)}$,

$W_{2i_{1,1}+S_1, 0, 1}^{(1)}$, $W_{2i_{1,1}+S_1, 0, 2}^{(1)}$, $W_{2i_{1,1}+S_1, 0, 3}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0, 0}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0, 1}^{(1)}$,
 $W_{2i_{1,1}+S_1+1, 0, 2}^{(1)}$, $W_{2i_{1,1}+S_1+1, 0, 3}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0, 0}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0, 1}^{(1)}$, $W_{2i_{1,1}+S_1+2, 0, 2}^{(1)}$,
 $W_{2i_{1,1}+S_1+2, 0, 3}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0, 0}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0, 1}^{(1)}$, $W_{2i_{1,1}+S_1+3, 0, 2}^{(1)}$, and
 $W_{2i_{1,1}+S_1+3, 0, 3}^{(1)}$.

9. The UE of Claim 6, wherein S_1 or S_2 is configured to the UE or pre-defined.
10. The UE of Claim 6, wherein S_1 is 2 or a value scalable with O_1 , or S_2 is 2 or a value scalable with O_2 .
11. The UE of Claim 1, wherein the codebook for 2-layer, 3-layer or 4-layer CSI reporting using the first number of CSI-RS ports is based on a mapping table from $i_{1,3}$ to a pair of (k_1, k_2) , and wherein:
- in the case that $N_1 > N_2 > 1$, the pair of (k_1, k_2) includes $(3O_1, 0)$, $(0, 2O_2)$, (O_1, O_2) , or $(2O_1, O_2)$;
 - in the case that $N_1 = N_2$, the pair of (k_1, k_2) includes $(2O_1, 0)$, $(0, 2O_2)$, $(2O_1, 2O_2)$, or $(3O_1, 0)$; or
 - in the case that $N_1 > 2$ and $N_2 = 1$, the pair of (k_1, k_2) includes $(4O_1, 0)$, $(5O_1, 0)$, $(6O_1, 0)$, or $(7O_1, 0)$;
- wherein $i_{1,3}$ is a codebook index associated with the codebook, k_1 is a horizontal beam offset for determining beam pair(s) for the codebook, and k_2 is a vertical beam offset for determining the beam pair(s) for the codebook.
12. The UE of Claim 1, wherein for 5-layer, 6-layer, 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the codebook includes codeword(s) associated with beam pair(s) determined based on at least one of a horizontal scaling factor or a vertical scaling factor.
13. The UE of Claim 12, wherein:
- for 5-layer or 6-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) includes $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or includes $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, and $(i_{1,1} + 2k_1 O_1, 0)$ in case of $N_2 = 1$, wherein $i_{1,1}$ is a first codebook index associated with the codebook, $i_{1,2}$ is a second codebook

index associated with the codebook, k_1 is the horizontal scaling factor, and k_2 is the vertical scaling factor; or

for 7-layer or 8-layer CSI reporting using the first number of CSI-RS ports, the beam pair(s) includes $(i_{1,1}, i_{1,2})$, $(i_{1,1} + k_1 O_1, i_{1,2})$, $(i_{1,1}, i_{1,2} + k_2 O_2)$, and $(i_{1,1} + k_1 O_1, i_{1,2} + k_2 O_2)$ in case of $N_2 > 1$ or includes $(i_{1,1}, 0)$, $(i_{1,1} + k_1 O_1, 0)$, $(i_{1,1} + 2k_1 O_1)$, $(i_{1,1} + 3k_1 O_1, 0)$ in case of $N_2 = 1$.

14. The UE of Claim 12, wherein:

in the case that the first number is equal to 48 or 64, the horizontal scaling factor or the vertical scaling factor is selected from $\{1,2\}$; or

in the case that the first number is equal to 72, 96, or 128, the horizontal scaling factor or the vertical scaling factor is selected from $\{1,2,3,4\}$.

15. The UE of Claim 12, wherein the PMI includes bit(s) indicating a value of the horizontal scaling factor or the vertical scaling factor.

16. The UE of Claim 1, wherein for 2-layer CSI reporting using the first number of CSI-RS ports, the codebook is based on a single beam pair which is determined based on $i_{1,1}$ and $i_{1,2}$, a first co-phasing factor θ_p determined by $i_{1,3}$, and a second co-phasing factor φ_n determined by i_2 , and

wherein $i_{1,1}$ is a first codebook index associated with the codebook and is selected from $\{0, \dots, \frac{N_1 O_1}{2} - 1\}$, $i_{1,2}$ is a second codebook index associated with the codebook and is selected from $\{0, \dots, N_2 O_2 - 1\}$, $i_{1,3}$ is a third codebook index associated with the codebook and is selected from $\{0,1,2,3\}$, and i_2 is a fourth codebook index associated with the codebook and is selected from $\{0,1\}$.

17. The method of claim 16, wherein the codebook includes codewords

$$\text{determined by } W_{l,m,p,n}^{(2)} = \frac{1}{\sqrt{2P_{\text{CSI-RS}}}} \begin{bmatrix} \tilde{v}_{l,m} & \tilde{v}_{l,m} \\ \theta_p \tilde{v}_{l,m} & -\theta_p \tilde{v}_{l,m} \\ \varphi_n \tilde{v}_{l,m} & \varphi_n \tilde{v}_{l,m} \\ \varphi_n \theta_p \tilde{v}_{l,m} & -\varphi_n \theta_p \tilde{v}_{l,m} \end{bmatrix},$$

wherein $P_{\text{CSI-RS}}$ is the first number, l is $i_{1,1}$, m is $i_{1,2}$, p is $i_{1,3}$, n is i_2 , $\varphi_n = e^{j\pi n/2}$,

$$\theta_p = e^{j\pi p/4}, u_m = \begin{cases} \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix} & N_2 > 1 \\ 1 & N_2 = 1 \end{cases}, \text{ and } \tilde{v}_{l,m} =$$

$$\begin{bmatrix} u_m & e^{j\frac{4\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{4\pi l(N_1/2-1)}{O_1 N_1}} u_m \end{bmatrix}^T.$$

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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and

perform channel state information (CSI) reporting, wherein the CSI reporting includes reporting 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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first antenna array, O_1 is a horizontal oversampling factor, and O_2 is a vertical oversampling factor; and

receive channel state information (CSI) reporting, wherein the CSI reporting 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_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 a first 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_1, N_2) for the first antenna array, wherein the configuration of (N_1, N_2) is associated with a configuration of (O_1, O_2) for the first antenna array, wherein N_1 is a number of antenna ports per polarization direction in a horizontal direction of the first antenna array, N_2 is a number of antenna ports per polarization direction in a vertical direction of the first 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_1, N_2) and the configuration of (O_1, O_2) ; and

performing channel state information (CSI) reporting, wherein the CSI reporting includes reporting the PMI.