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(71) Applicant: **LENOVO (BEIJING) LIMITED** [CN/CN]; 6 Shangdi West Road, Haidian District, Beijing 100085 (CN).

(72) Inventors: **ZHU, Chenxi**; 11452 Mallard Creek Trail, Fairfax, Virginia 22033 (US). **LIU, Bingchao**; Room 501, Unit 8, Building No.3, Lantianyuan Community, Huoying Street, Changping District, Beijing 102200 (CN). **ZHANG, Yi**; Room #601, Unit 1, Building 37, Yard No. 9, Hua Yan Bei Li, Minzuyuan West Road, Chaoyang District, Beijing 100029 (CN).

(74) Agent: **LEE AND LI - LEAVEN IPR AGENCY LTD.**; Suite 1202, Tower A, Hehua Mingcheng Building, No. 7 Jianguomen South Avenue, Dongcheng District, Beijing 100005 (CN).

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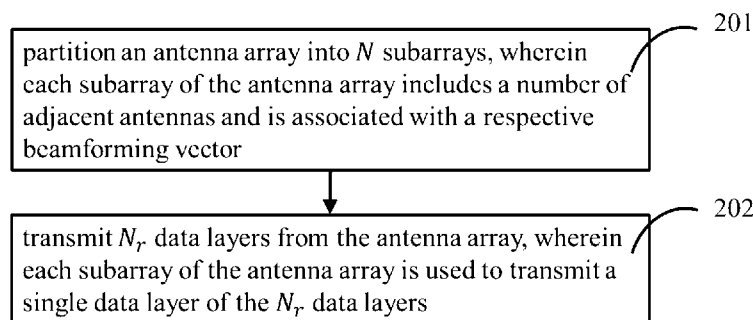


Figure 2

(57) Abstract: Various aspects of the present disclosure relate to methods and apparatuses for transmission with extremely large antenna arrays. According to an embodiment of the present disclosure, a base station (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: partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.



METHODS AND APPARATUSES FOR TRANSMISSION WITH EXTREMELY LARGE ANTENNA ARRAYS

TECHNICAL FIELD

[0001] The present disclosure relates to wireless communications, and more specifically to methods and apparatuses for transmission with extremely large antenna arrays (ELAA).

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 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: partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

[0005] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to divide the N subarrays into N_r subarray groups, and each subarray group of the N_r subarray groups is used to transmit a respective data layer of the N_r data layers.

[0006] In some implementations of the BS described herein, N_r is 1, and a single data layer is transmitted from the N subarrays using the respective beamforming vectors associated with the N subarrays.

[0007] In some implementations of the BS described herein, $N_r > 1$, each subarray group of the N_r subarray groups consists of at least K subarray(s), and is used to transmit the respective data layer of the N_r data layers using the respective beamforming vectors associated with the at least K subarray(s) in the subarray group, and $K = \left\lfloor \frac{N}{N_r} \right\rfloor$.

[0008] In some implementations of the BS described herein, the at least K subarray(s) of the subarray group are adjacent subarrays.

[0009] In some implementations of the BS described herein, the at least K subarray(s) of the subarray group are interleaved subarrays.

[0010] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to transmit downlink control information (DCI) scheduling

transmission of the N_r data layers, the DCI indicates N_r transmission configuration indication (TCI) state groups, and each TCI state group of the N_r TCI state groups is associated with a respective data layer of the N_r data layers.

[0011] In some implementations of the BS described herein, each TCI state group of the N_r TCI state groups includes one or more TCI states, and each TCI state of the one or more TCI states is associated with a respective subarray used to transmit the respective data layer associated with the TCI state group.

[0012] In some implementations of the BS described herein, the one or more TCI states included in each TCI state group of the N_r TCI state groups are transmitted in the DCI.

[0013] In some implementations of the BS described herein, each TCI state group of the N_r TCI state groups is associated with a group index, and the group index associated with each TCI state group of the N_r TCI state groups is transmitted in the DCI.

[0014] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to transmit a radio resource control (RRC) or medium access control (MAC) control element (CE) configuration message including the one or more TCI states included in each TCI state group of the N_r TCI state groups.

[0015] In some implementations of the BS described herein, the respective beamforming vector associated with each subarray of the N subarrays is a discrete-time Fourier transform (DFT) beamforming vector for steering a beam associated with the subarray towards a receiver of a UE.

[0016] In some implementations of the BS described herein, the at least one processor is configured to cause the BS to apply a hybrid beamforming precoder to the antenna array for transmission of the N_r data layers, and the hybrid beamforming precoder includes an analogue beamforming part and a digital precoder.

[0017] In some implementations of the BS described herein, the analogue beamforming part is applied to each subarray of the N subarrays to apply the respective beamforming vector to the subarray.

[0018] In some implementations of the BS described herein, for each subarray of the antenna array, the digital precoder determines a data layer of the N_r data layers to be transmitted from the subarray.

[0019] 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 DCI scheduling transmission of N_r data layers from an antenna array of a BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state; and receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

[0020] In some implementations of the UE described herein, the N TCI states are divided into N_r TCI state groups, each TCI state group of the N_r TCI state groups is associated with a respective data layer of the N_r data layers, and each TCI state of the N TCI states is included in a single TCI state group of the N_r TCI state groups.

[0021] In some implementations of the UE described herein, each TCI state group of the N_r TCI state groups includes one or more TCI states, and the one or more TCI states included in each TCI state group of the N_r TCI state groups are included in the DCI.

[0022] In some implementations of the UE described herein, each TCI state group of the N_r TCI state groups is associated with a group index, and the group index associated with each TCI state group of the N_r TCI state groups is included in the DCI.

[0023] In some implementations of the UE described herein, each TCI state group of the N_r TCI state groups includes one or more TCI states, and the at least one processor is further configured to cause the UE to receive an RRC or MAC CE configuration message including the one or more TCI states included in each TCI state group of the N_r TCI state groups.

[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: partition an antenna

array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

[0025] Some implementations of the methods and apparatuses described herein may include a method performed by a BS. The method may include: partitioning an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmitting N_r data layers from the antenna array, wherein $N \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

[0026] 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 DCI scheduling transmission of N_r data layers from an antenna array of a BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state; and receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

[0027] Some implementations of the methods and apparatuses described herein may include a method performed by a UE. The method may include: receiving DCI scheduling transmission of N_r data layers from an antenna array of a BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state; and receiving the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

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 BS in accordance with aspects of the present disclosure.

[0031] Figure 3 illustrates an example of transmission with an antenna array partitioned into subarrays with aspects of the present disclosure.

[0032] Figure 4 illustrates an example of transmission of multiple data layers with an antenna array partitioned into subarrays in accordance with aspects of the present disclosure.

[0033] Figure 5 illustrates another example of transmission of multiple data layers with an antenna array partitioned into subarrays in accordance with aspects of the present disclosure.

[0034] Figure 6 illustrates a flowchart of an exemplary method performed by a UE in accordance with aspects of the present disclosure.

[0035] Figure 7 illustrates an example of a BS in accordance with aspects of the present disclosure.

[0036] Figure 8 illustrates an example of a processor in accordance with aspects of the present disclosure.

[0037] Figure 9 illustrates an example of a UE in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0038] 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.

[0039] 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.

[0040] Reference will now be made in detail to some embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings. To facilitate understanding, embodiments are provided under specific network architecture and service scenarios, such as 3rd generation partnership project (3GPP) long-term evolution (LTE) and LTE advanced, 3GPP 5G new radio (NR), 5G-Advanced, 6G, and so on. It is contemplated that along with developments of network architectures and new service scenarios, all embodiments in the present disclosure are also applicable to similar technical problems; and moreover, the terminologies recited in the present disclosure may change, which should not affect the principle of the present disclosure.

[0041] Aspects of the present disclosure are described in the context of a wireless communications system.

[0042] Figure 1 illustrates an example of a wireless communications system 100 in accordance with aspects of the present disclosure. The wireless communications system 100 may include one or more network equipments (NEs) (e.g., BSs) 102, one or more UEs 104, and a core network (CN) 106. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a 4G network, such as an LTE network or an LTE-Advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be an NR network, such as a 5G network, a 5G-Advanced (5G-A) network, or a 5G ultrawideband (5G-UWB) network. In other implementations, the wireless communications system 100 may be a combination of a

4G network and a 5G network, or other suitable radio access technology including Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G, for example, 6G. Additionally, the wireless communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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).

[0048] 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.

[0049] 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).

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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.

[0055] 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.

[0056] Multiple-input multiple-output (MIMO) has been a fundamental part of the 4G or 5G system, and may continue to be an important part of 6G networks. Massive MIMO (also known as large-scale antenna systems and very large MIMO) is a MIMO technology where an NE may be equipped with a large number of antenna elements (for example, 50 antenna elements), which are used to perform transmissions that share the same time and frequency band and are separated in the spatial domain. Massive MIMO is one of the most critical technologies for 5G communications. With massive antenna arrays at the NE, massive MIMO can improve the spectral efficiency by orders of magnitude through beamforming or multiplexing. Herein, the terms "antenna element" and "antenna" may be used interchangeably.

[0057] For 6G communications, extremely large-scale MIMO (XL-MIMO), which is a MIMO technology where an NE may be equipped with a number of antennas much larger than that for massive MIMO, can effectively achieve 10-fold increases in spectral efficiency. On the

other hand, benefiting from the rich spectrum resource at millimeter-wave (mmWave) band or terahertz (THz) band, high-frequency communications may provide largely available bandwidth. Meanwhile, the very small size of high-frequency antennas favorably enables the deployment of XL-MIMO with an extremely large number of antenna elements. Therefore, high-frequency XL-MIMO may be a key enabling technology for 6G communications.

[0058] As the size of the antenna array increases, the EM field begins to exhibit some near field properties. In particular, the Rayleigh distance (e.g., denoted as L_R), which defines the boundary between the near field and the far field, is calculated as follows:

$$L_R = \frac{2D^2}{\lambda}$$

where D is the largest dimension of the antenna array, and λ is the wavelength.

[0059] As the value of D increases with the size of the antenna array, and the value of λ decreases as the frequency increases, the Rayleigh distance may increase, which means that the near field region increases, and thus more UEs are included in the near field region.

[0060] The electromagnetic wave propagation in the near field is explained as follows.

[0061] The typical antenna element in an extremely large antenna array may still be an electric dipole antenna (unidirectional or cross polarized). The electric field ($\vec{E}$) from an oscillating electric dipole is as follows:

$$\vec{E} = \frac{1}{4\pi\epsilon_0} k^2 \vec{p}_{0\perp} \left\{ \frac{e^{i(kr-\omega t)}}{r} \right\}$$

where:

- $\vec{p}_{0\perp}$ is perpendicular to the direction vector $\hat{r}$ ($\hat{r} \cdot \vec{p}_{0\perp} = 0$), $\vec{p}_{0\perp} = \vec{p}_0 - \hat{r}(\hat{r} \cdot \vec{p}_0)$,
- $\vec{p}_0$ is the electric dipole moment of the electric dipole at the origin,
- $\hat{r} = \sin\theta\cos\phi\hat{x} + \sin\theta\sin\phi\hat{y} + \cos\theta\hat{z}$,
- $k = \frac{\omega}{c}$, and

- $\frac{e^{i(kr-\omega t)}}{r}$ is the outgoing spherical wave with speed c .

[0062] Because vacuum (or air) is a linear medium, the electric field of the near field EM wave radiated from an antenna array is the summation of the electric field radiated from all the antennas in the antenna array. Accordingly, a near field signal received from the antenna array can be calculated as a sum of the signals from all the antennas in the antenna array.

[0063] In the far field, the EM wave radiated from an antenna array can be treated as a planar wave (or a combination of planar waves). As a result, the design of massive MIMO in 5G NR is based on the planar wave assumption. For example, the beamforming vector driving a subset or all of the antenna elements in the antenna array is a DFT vector steering towards the direction of the outgoing or incoming wave.

[0064] However, in the near field, the EM wave radiated from an antenna array cannot be treated as a planar wave (or a combination of planar waves). Therefore, the design of massive MIMO in 5G NR may be inapplicable for XL-MIMO, and the use of XL-MIMO in 6G with near field requires new designs for channel model, transceiver architecture, channel estimation, transmission scheme, etc. For example, the DFT vector used under the planar wave assumption may no longer apply. The ideal beamforming vector needs to accommodate the non-planar EM wavefront and is very complicated. Therefore, it is very important to find a solution with low complexity to simplify the design and reduce the implementation cost.

[0065] Embodiments of the present disclosure provide solutions for transmitting one or more data layers from a large antenna array (e.g., ELAA). More details will be described in the following text in combination with the appended drawings.

[0066] In some embodiments of the present disclosure, it is assumed that the antenna array at a BS is a large antenna array (e.g., ELAA) and the antenna array at a UE is of a regular size. It is contemplated that the described solutions may be applicable to a UE with a large antenna array (e.g., ELAA) without departing from the spirit and scope of the present disclosure.

[0067] **Subarray-partition based transmission scheme**

[0068] 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 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.

[0069] As shown in Figure 2, in step 201, the BS may partition an antenna array (e.g., ELAA) into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector.

[0070] In some embodiments, the respective beamforming vector associated with each subarray of the N subarrays is a DFT beamforming vector, which may steer a beam associated with (e.g., transmitted from) the subarray towards a receiver (e.g., an antenna array) of a UE.

[0071] Figure 3 illustrates an example of transmission with an antenna array partitioned into subarrays in accordance with aspects of the present disclosure.

[0072] In the example shown in Figure 3, a one-dimensional antenna array of a BS is partitioned into N subarrays (e.g., labelled 0 to $N-1$), wherein $N \geq 1$. Each subarray consists of M adjacent antennas (e.g., labelled 0 to $M-1$), wherein $M \geq 1$. For simplicity, only three subarrays are shown in Figure 3. Please note that, although solutions for one-dimensional antenna arrays are described in the present disclosure, it is contemplated that the solutions described herein may also apply to a two-dimensional antenna array or a three-dimensional antenna array with some arithmetic manipulations. For example, a two-dimensional antenna array may be partitioned into multiple two-dimensional subarrays, and the described solutions for one-dimensional antenna arrays may be similarly applied in each dimension.

[0073] In the example shown in Figure 3, the antenna array at a UE is of a regular size and is not partitioned. Subarray i ($i \in \{0, 1, \dots, N-1\}$) of the antenna array of the BS may be associated with a beamforming vector steering towards the UE. For example, the line between the center of subarray i and the center of the antenna array of the UE may represent the direction of a signal transmitted from subarray i to the UE with the beamforming vector. The angle of arrival (AOA) of the signal is φ_i^r , which is the angle between the direction of the signal and the

line that is vertical to the antenna array of the UE. The angle of departure (AOD) of the signal is φ_i^t , which is the angle between the direction of the signal and the line that is vertical to subarray i .

[0074] Referring back to Figure 2, in step 202, the BS may transmit N_r data layers (e.g., in a physical downlink shared channel (PDSCH)) from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

[0075] Assuming that a signal $\mathbf{x}$ is transmitted from a transmitter at the BS to a receiver at the UE, the corresponding received signal $\mathbf{Y}$ at the receiver may be represented as:

$$\mathbf{Y} = \mathbf{H}\mathbf{W}\mathbf{x} + \mathbf{n} = \sum_{i=0}^{N-1} \mathbf{H}_i \mathbf{W}_i \mathbf{x} + \mathbf{n} = \sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r) \mathbf{a}_t^T(\theta_i^t) \mathbf{W}_i \mathbf{x} + \mathbf{n}$$

where:

- $\mathbf{H}$ is a channel matrix, $\mathbf{H} = [\mathbf{H}_0, \mathbf{H}_1, \dots, \mathbf{H}_{N-1}]$:
- ◆ $\mathbf{H}_i$ represents a channel between subarray i of the antenna array of the BS and the receiver, $\mathbf{H}_i = \beta_i \mathbf{a}_r(\theta_i^r) \mathbf{a}_t^T(\theta_i^t)$:
 - β_i is a complex number representing the amplitude and phase for the channel of subarray i ;
 - $\mathbf{a}_t(\theta_i^t)$ is an array response function of a uniform linear array at the transmitter,

$$\mathbf{a}_t(\theta_i^t) = \frac{1}{\sqrt{M_t}} [1, e^{-j\theta_i^t}, e^{-j2\theta_i^t}, \dots, e^{-j(M_t-1)\theta_i^t}]^T$$
 - ✓ θ_i^t is associated with AOD (φ_i^t) with respect to subarray i at the transmitter, e.g., $\theta_i^t = \frac{2\pi d_t}{\lambda} \sin(\varphi_i^t)$, where d_t is a distance between adjacent antennas in subarray i ; and
 - ✓ M_t is a number of antennas within subarray i ; and
 - $\mathbf{a}_r(\theta_i^r)$ is an array response function of a uniform linear array at the receiver,

$$\mathbf{a}_r(\theta_i^r) = \frac{1}{\sqrt{M_r}} [1, e^{-j\theta_i^r}, e^{-j2\theta_i^r}, \dots, e^{-j(M_r-1)\theta_i^r}]^T$$

- ✓ θ_i^r is associated with AOA (φ_i^r) with respect to subarray i at the receiver, e.g., $\theta_i^r = \frac{2\pi d_r}{\lambda} \sin(\varphi_i^r)$, where d_r is a distance between adjacent antennas in the antenna array of the UE; and
- ✓ M_r is a number of antennas within the antenna array of the UE;
- $\mathbf{W}$ is a transmission precoder for the entire antenna array of the BS, $\mathbf{W} = \begin{bmatrix} \mathbf{W}_0 \\ \vdots \\ \mathbf{W}_{N-1} \end{bmatrix}$, wherein $\mathbf{W}_i$ is the precoder for subarray i ; and
- n is noise.

[0076] Herein, for a matrix $\mathbf{A}$, $\mathbf{A}^T$ is its transpose and $\mathbf{A}^H$ is its Hermitian matrix (conjugate transpose).

[0077] In some embodiments of the present disclosure, the BS may divide the N subarrays of the antenna array into N_r subarray groups, and each subarray group of the N_r subarray groups is used to transmit a respective data layer of the N_r data layers.

[0078] **Rank 1 transmission**

[0079] In the case of $N_r=1$ (i.e., rank 1 transmission), a single data layer is transmitted from the N subarrays of the BS to the UE, and each subarray transmits the same data layer (i.e., the same signal(s) or symbol(s)) using its respective beamforming vector. Thus, the UE receives the same data layer from all the subarrays in a coherent joint transmission (CJT) manner.

[0080] In such case, the transmitted signal $\mathbf{x} = x$, which is a scalar, and the corresponding received signal $\mathbf{Y} = \mathbf{H}\mathbf{W}\mathbf{x} + \mathbf{n} = \sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r) \mathbf{a}_t^T(\theta_i^t) \mathbf{W}_i x + \mathbf{n}$.

[0081] The optimal precoder $\mathbf{W}_i$ for subarray i may satisfy $\mathbf{a}_t^T(\theta_i^t) \mathbf{W}_i = 1$. Therefore, $\mathbf{W}_i = \mathbf{U}_i = \left(\frac{1}{\sqrt{M_t}} [1, e^{j\theta_i^t}, e^{j2\theta_i^t}, \dots, e^{j(M_t-1)\theta_i^t}] \right)^T = \left(\mathbf{a}_t(\theta_i^t) \right)^*$, where $\mathbf{U}_i$ may represent the beamforming vector associated with subarray i . Then, the precoder $\mathbf{W}$ for the entire antenna array may be represented as follows:

$$\mathbf{W} = \begin{bmatrix} \mathbf{W}_0 \\ \vdots \\ \mathbf{W}_{N-1} \end{bmatrix} = \begin{bmatrix} \mathbf{U}_0 \\ \vdots \\ \mathbf{U}_{N-1} \end{bmatrix} = \begin{bmatrix} \mathbf{U}_0 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \ddots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{U}_{N-1} \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} = \mathbf{diag}([\mathbf{U}_0, \dots, \mathbf{U}_{N-1}]) \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix}.$$

[0082] In the case that the optimal precoder for each subarray is applied, the received signal $\mathbf{Y}$ is:

$$\mathbf{Y} = \sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r) x + \mathbf{n}.$$

[0083] The UE may receive the signal $\mathbf{Y}$ with a receiver filter, which may be represented as a receiving matrix $\mathbf{V}$. The filtered received signal $z = \mathbf{V}\mathbf{Y}$. In some embodiments, the receiver at the UE may be a standard MIMO receiver, such as a minimum mean square error (MMSE) receiver with $\mathbf{V} = \mathbf{B}^H(\mathbf{B}\mathbf{B}^H + \rho^{-1}\mathbf{I})^{-1}$, where $\mathbf{B} = \sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r)$, and ρ is a signal-noise ratio (SNR).

[0084] If the antenna array of the UE is large enough, the UE may be able to distinguish different AOAs from different subarrays of the BS or even attain mutual orthogonality between these subarrays. In some embodiments, if the SNR is large, $\mathbf{V}$ may be represented as:

$$\mathbf{V} = (\sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r))^{-1} \approx \sum_{i=0}^{N-1} \beta_i^* \mathbf{a}_r(\theta_i^r)^H,$$

[0085] Then, the filtered received signal z may be represented as:

$$\begin{aligned} z &= \mathbf{V} \left(\sum_{i=0}^{N-1} \beta_i \mathbf{a}_r(\theta_i^r) \right) x + \mathbf{V} \mathbf{n} = \sum_{i=0}^{N-1} \sum_{i'=0}^{N-1} \beta_{i'}^* \mathbf{a}_r(\theta_{i'}^r)^H \beta_i \mathbf{a}_r(\theta_i^r) x + \sum_{i'=0}^{N-1} \beta_{i'}^* \mathbf{a}_r(\theta_{i'}^r)^H \mathbf{n} \\ &\cong \sum_{i=0}^{N-1} \beta_i^* \beta_i \mathbf{a}_r(\theta_i^r)^H \mathbf{a}_r(\theta_i^r) x + \sum_{i'=0}^{N-1} \beta_{i'}^* \mathbf{a}_r(\theta_{i'}^r)^H \mathbf{n} \\ &= \sum_{i=0}^{N-1} \beta_i^* \beta_i x + \sum_{i=0}^{N-1} \beta_i^* \mathbf{a}_r(\theta_i^r)^H \mathbf{n} \end{aligned}$$

[0086] The effective channel between the transmitter and the receiver for the transmitted signal x is $\sum_{i=0}^N \beta_i^* \beta_i$. In the case that $x = \sqrt{P_{tx}} s$, wherein P_{tx} is a transmitted power per subarray (the total transmitted power of the antenna array of the BS is $N P_{tx}$) and s is the

normalized transmitted modulation symbol ($E(|s|^2) = 1$), the SNR of the received symbol is

$$SNR = \frac{P_{tx}(\sum_{i=0}^{N-1} |\beta_i|^2)^2}{P_{n0} \sum_{i=0}^{N-1} |\beta_i|^2}, \text{ wherein } P_{n0} = E(|n|^2) \text{ is the noise power at the receiver.}$$

[0087] Higher rank transmission

[0088] In the case of $N_r > 1$, the transmitted signal $\mathbf{x}$ is a vector with a length of N_r . The precoder $\mathbf{W}_i$ for subarray i may determine how the vector is transmitted by subarray i .

[0089] In such case, the N subarrays of the antenna array of the BS may be divided into N_r subarray groups, and each subarray group of the N_r subarray groups may consist of one or more subarrays. Each subarray group of the N_r subarray groups is used to transmit a respective data layer of the N_r data layers using the respective beamforming vectors associated with the one or more subarrays in the subarray group. Different subarray groups do not include any identical subarray. That is, each subarray belongs to only one subarray group. For each data layer transmitted from a respective subarray group, the UE may receive the data layer in a CJT manner. For different data layers, the UE may receive the data layers from different subarray groups in a non-coherent joint transmission (NCJT) manner.

[0090] In some embodiments, each subarray group of the N_r subarray groups may consist of at least K subarray(s), wherein $K = \lfloor \frac{N}{N_r} \rfloor$. Each subarray group of the N_r subarray groups is used to transmit a respective data layer of the N_r data layers using the respective beamforming vectors associated with the at least K subarray(s) in the subarray group. For example, each subarray group of the N_r subarray groups, except for the last subarray group, consists of K subarray(s), and the last subarray group consists of $N - K(N_r - 1)$ subarray(s). Data layer j ($j \in \{0, 1, \dots, N_r - 1\}$) is transmitted from subarray group j .

[0091] In some embodiments, the at least K subarray(s) of each subarray group of the N_r subarray groups are adjacent subarray(s). For example, subarray group j ($j \in \{0, 1, \dots, N_r - 2\}$) may consist of subarrays $[jK, jK + 1, jK + 2, \dots, (j + 1)K - 1]$, and subarray group $N_r - 1$ may consist of subarrays $[(N_r - 1)K, (N_r - 1)K + 1, (N_r - 1)K + 2, \dots, N - 1]$.

[0092] In some other embodiments, the at least K subarray(s) of each subarray group of the N_r subarray groups are interleaved subarrays. For example, subarray group j ($j \in \{0, 1, \dots, N_r - 1\}$) may consist of subarrays $[j, j + N_r, j + 2N_r, \dots]$. Transmitting a data layer by a subarray group consisting of interleaved subarrays may enhance transmission robustness in the presence of spatial non-stationarity (e.g., partial blocking) where some paths between some of the antennas and the UE are blocked by an obstacle but the others not.

[0093] Figure 4 illustrates an example of transmission of multiple data layers with an antenna array partitioned into subarrays in accordance with aspects of the present disclosure, where each subarray group consists of adjacent subarrays.

[0094] In the example shown in Figure 4, the antenna array of the BS includes six subarrays (e.g., denoted as subarrays 0-5), each subarray includes M antennas, and two data layers (e.g., denoted as data layer 0 and data layer 1) are transmitted from the antenna array of the BS. That is, $N=6$ and $N_r=2$. Subarrays 0-5 are divided into two subarray groups (e.g., denoted as subarray group 0 and subarray group 1), and each subarray group consists of $K = \lfloor \frac{N}{N_r} \rfloor = 3$ subarrays: subarray group 0 consists of subarrays 0, 1 and 2, and subarray group 1 consists of subarrays 3, 4 and 5. Data layer 0 is transmitted from subarray group 0, and data layer 1 is transmitted from subarray group 1. The precoder $\mathbf{W}_i$ ($i \in [0, 5]$) is applied to subarray i .

[0095] In such example, the precoder $\mathbf{W}$ for the entire antenna array may be represented as follows:

$$\mathbf{W} = \begin{bmatrix} \mathbf{W}_0 \\ \vdots \\ \mathbf{W}_5 \end{bmatrix} = \begin{bmatrix} \mathbf{U}_0 & \mathbf{0} \\ \mathbf{U}_1 & \mathbf{0} \\ \mathbf{U}_2 & \mathbf{0} \\ \mathbf{0} & \mathbf{U}_3 \\ \mathbf{0} & \mathbf{U}_4 \\ \mathbf{0} & \mathbf{U}_5 \end{bmatrix} = \text{diag}([\mathbf{U}_0, \dots, \mathbf{U}_5]) \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix},$$

where $\mathbf{U}_i = \left(\frac{1}{\sqrt{M}} [1, e^{j\theta_i^t}, e^{j2\theta_i^t}, \dots, e^{j(M-1)\theta_i^t}] \right)^T$, $i \in [0, 5]$.

[0096] Figure 5 illustrates another example of transmission of multiple data layers with an antenna array partitioned into subarrays in accordance with aspects of the present disclosure, where each subarray group consists of interleaved subarrays.

[0097] In the example shown in Figure 5, the antenna array of the BS includes six subarrays (e.g., denoted as subarrays 0-5), each subarray includes M antennas, and two data layers (e.g., denoted as data layer 0 and data layer 1) are transmitted from the antenna array of the BS. That is, $N=6$ and $N_r=2$. Subarrays 0-5 are divided into two subarray groups (e.g., denoted as subarray group 0 and subarray group 1), and each subarray group consists of $K = \left\lfloor \frac{N}{N_r} \right\rfloor = 3$ subarrays: subarray group 0 includes subarrays 0, 2 and 4, and subarray group 1 includes subarrays 1, 3 and 5. Data layer 0 is transmitted from subarray group 0, and data layer 1 is transmitted from subarray group 1. The precoder $\mathbf{W}_i$ ($i \in [0, 5]$) is applied to subarray i .

[0098] In such example, the precoder $\mathbf{W}$ for the entire antenna array may be represented as follows:

$$\mathbf{W} = \begin{bmatrix} \mathbf{W}_0 \\ \vdots \\ \mathbf{W}_5 \end{bmatrix} = \begin{bmatrix} U_0 & \mathbf{0} \\ \mathbf{0} & U_1 \\ U_2 & \mathbf{0} \\ \mathbf{0} & U_3 \\ U_4 & \mathbf{0} \\ \mathbf{0} & U_5 \end{bmatrix} = \text{diag}([U_0, \dots, U_5]) \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix},$$

$$\text{where } \mathbf{U}_i = \left(\frac{1}{\sqrt{M}} [1, e^{j\theta_i^t}, e^{j2\theta_i^t}, \dots, e^{j(M-1)\theta_i^t}] \right)^T, i \in [0, 5].$$

[0099] It can be seen that, regardless of rank 1 transmission or higher rank transmission, the precoder $\mathbf{W}$ for the entire antenna array may be represented in the form of $\text{diag}([U_0, \dots, U_{N-1}])\mathbf{W}^D$, where $\mathbf{U}_i$ is the beamforming vector associated with subarray i , $i \in \{0, 1, \dots, N-1\}$. For example, $\mathbf{U}_i = \left(\frac{1}{\sqrt{M_t}} [1, e^{j\theta_i^t}, e^{j2\theta_i^t}, \dots, e^{j(M_t-1)\theta_i^t}] \right)^T$, which takes the form of a DFT vector. That is, $\mathbf{W}$ includes an analogue beamforming part (i.e., $\text{diag}([U_0, \dots, U_{N-1}])$) and a digital precoder (i.e., $\mathbf{W}^D$). For $\mathbf{W}$ for transmissions with different ranks, they share a common analogue beamforming part, and the difference is only in the digital precoder. In some embodiments, the analogue beamforming part may also be implemented by an all-digital transmitter structure. In some other embodiments, the analogue beamforming part may be implemented by an analogue beamforming structure using a phase shifter at each antenna. In other words, hybrid beamforming may be used to implement $\mathbf{W}$.

[0100] **Hybrid beamforming**

[0101] Hybrid beamforming is widely used in mmWave systems to reduce the hardware cost and simplify the systems, and is supported in 5G NR system. Instead of driving each antenna port with a dedicated radio frequency (RF) chain (which may include analog-to-digital converter (ADC), digital-to-analog converter (DAC), power amplifier (PA), up/down converter, etc.), an RF chain is used to drive a subset of antenna elements in an antenna array.

[0102] According to some embodiments of the present disclosure, the transmission precoder $\mathbf{W}$ applied to the antenna array of the BS for transmitting the N_r data layers is a hybrid beamforming precoder, which includes an analogue beamforming part and a digital precoder. The analogue beamforming part is applied to each subarray of the N subarrays of the antenna array to apply the respective beamforming vector to the subarray. For example, the analogue beamforming part may be implemented by a set of phase shifters. For each subarray of the antenna array, the digital precoder may determine a data layer of the N_r data layers to be transmitted from the subarray.

[0103] In some embodiments, the transmission precoder $\mathbf{W}$ may be represented as:

$$\mathbf{W} = \begin{bmatrix} \mathbf{W}_0 \\ \vdots \\ \mathbf{W}_{N-1} \end{bmatrix} = \mathbf{diag}([\mathbf{U}_0, \dots, \mathbf{U}_{N-1}])\mathbf{W}^D,$$

wherein $\mathbf{diag}([\mathbf{U}_0, \dots, \mathbf{U}_{N-1}])$ is the analog beamforming part, and $\mathbf{W}^D$ is the digital precoder.

[0104] $\mathbf{U}_i$ ($i \in \{0, 1, \dots, N-1\}$) may be a beamforming vector applied to subarray i for steering towards the UE. In some embodiments, the beamforming vector $\mathbf{U}_i$ may take a form of a DFT vector. Each element in $\mathbf{U}_i$ may represent the phase shift applied to a respective antenna by a respective phase shifter. For example, the beamforming vector $\mathbf{U}_i$ for subarray i may be:

$$\mathbf{U}_i = \left(\frac{1}{\sqrt{M_t}} [1, e^{j\theta_i^t}, e^{j2\theta_i^t}, \dots, e^{j(M_t-1)\theta_i^t}] \right)^T = (\mathbf{a}_t(\theta_i^t))^*.$$

[0105] $\mathbf{W}^D$ may be a N^*N_r matrix (including N rows, e.g., denoted as rows 0 through $N-1$, and N_r columns, e.g., denoted as columns 0 through N_r-1), and each element in $\mathbf{W}^D$ is 0 or 1. Each row of $\mathbf{W}^D$ may correspond to a respective subarray, and each column of $\mathbf{W}^D$ may

correspond to a respective data layer. For example, if subarray i ($0 \leq i \leq N - 1$) of the N subarrays is used to transmit data layer m of the N_r data layers ($0 \leq m \leq N_r - 1$), then the element $w_{i,m}$ (i.e., the element in row i and column m) in $\mathbf{W}^D$ is 1, and other elements in row i is 0.

[0106] For example, in the example shown in Figure 4, $\mathbf{W}^D = \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$, which may indicate

that subarrays 0, 1 and 2 are used for transmitting data layer 0, and subarrays 3, 4 and 5 are used

for transmitting data layer 1; in the example shown in Figure 5, $\mathbf{W}^D = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$, which may indicate

that subarrays 0, 2 and 4 are used for transmitting data layer 0, and subarrays 1, 3 and 5 are used for transmitting data layer 1.

[0107] TCI state groups

[0108] The BS may transmit DCI for scheduling the transmission of the N_r data layers from the antenna array of the BS to the UE. For the UE to receive downlink data effectively, the DCI may indicate TCI states of the subarrays used for transmitting the N_r data layers. According to the TCI states, the UE may obtain Quasi co-location (QCL) parameter(s) for PDSCH and the associated demodulation reference signal (DMRS) reception. In some embodiments, the QCL parameter(s) may include at least one of Doppler shift, Doppler spread, average delay, delay spread or spatial receiver filter parameters for receiving signals. Since different subarrays may transmit signals to the UE with different downlink beams, each subarray may have its own TCI state. Each TCI state may configure a downlink reference signal, e.g., a tracking reference signal (TRS), for the UE to obtain the QCL parameter(s) for the PDSCH and the associated DMRS reception.

[0109] According to some embodiments of the present disclosure, the TCI states associated with the subarrays for transmitting the same data layer may form a TCI state group. Thus, the DCI for scheduling the transmission of the N_r data layers may indicate N_r TCI state groups, wherein each TCI state group of the N_r TCI state groups is associated with a respective subarray group which is used for transmitting a respective data layer of the N_r data layers. In some embodiments, each TCI state group of the N_r TCI state groups may include one or more TCI states, and each TCI state of the one or more TCI states is associated with a respective subarray used to transmit the respective data layer associated with the TCI state group.

[0110] In some embodiments, the one or more TCI states included in each TCI state group of the N_r TCI state groups are transmitted in the DCI.

[0111] In some embodiments, each TCI state group of the N_r TCI state groups is associated with a group index, and the group index associated with each TCI state group of the N_r TCI state groups is transmitted in the DCI. In an embodiment, the BS may transmit the one or more TCI states included in each TCI state group of the N_r TCI state groups via, e.g., an RRC or MAC-CE configuration message.

[0112] For example, it is assumed that the antenna array of the BS includes 6 subarrays, i.e., $N = 6$, and each subarray is associated with a respective TCI state, e.g., TCI_i ($i \in [0, 5]$) is the TCI state associated with subarray i . In some cases, some possible TCI state groups and associated group indexes may be configured, specified or predefined. An example of the possible TCI state groups and associated group indexes is provided in the following Table 1:

Table 1

Group index	TCI state group
0	$\{TCI_0, TCI_1, TCI_2, TCI_3, TCI_4, TCI_5\}$
1	$\{TCI_0, TCI_1, TCI_2\}$
2	$\{TCI_3, TCI_4, TCI_5\}$
3	$\{TCI_0, TCI_2, TCI_4\}$

4	$\{TCI_1, TCI_3, TCI_5\}$
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[0113] In the case that only one data layer is transmitted from the antenna array of the BS, i.e., $N_r = 1$, all the subarrays are used for transmitting the data layer, and there may be one TCI state group used for transmitting the data layer. For example, the TCI state group may be $\{TCI_0, TCI_1, TCI_2, TCI_3, TCI_4, TCI_5\}$. In some embodiments, the DCI for scheduling the transmission of the data layer may contain all the TCI states in an order of $TCI_0, TCI_1, TCI_2, TCI_3, TCI_4, TCI_5$. In some other embodiments, the DCI may contain the group index (e.g., 0 as listed in Table 1) associated with $\{TCI_0, TCI_1, TCI_2, TCI_3, TCI_4, TCI_5\}$, and the BS may transmit $TCI_0, TCI_1, TCI_2, TCI_3, TCI_4$ and TCI_5 in an RRC or MAC-CE configuration message.

[0114] In the case that two data layers are transmitted from the antenna array of the BS, i.e., $N_r=2$, there may be two TCI state groups.

[0115] For the example shown in Figure 4 (i.e., subarray group 0 for transmitting data layer 0 consists of subarrays 0, 1 and 2, and subarray group 1 for transmitting data layer 1 consists of subarrays 3, 4 and 5), a first TCI state group used for transmitting data layer 0 is $\{TCI_0, TCI_1, TCI_2\}$, and a second TCI state group used for transmitting data layer 1 is $\{TCI_3, TCI_4, TCI_5\}$. In some embodiments, the DCI may contain the TCI states in the form of two groups, wherein the first group contains TCI states in an order of TCI_0, TCI_1, TCI_2 , and the second group contains TCI states in an order of TCI_3, TCI_4, TCI_5 . In some other embodiments, the DCI may contain two group indexes (e.g., 1 and 2 as listed in Table 1) respectively associated with the two TCI state groups, and the BS may transmit $TCI_0, TCI_1, TCI_2, TCI_3, TCI_4$ and TCI_5 in an RRC or MAC-CE configuration message.

[0116] For the example shown in Figure 5 (i.e., subarray group 0 for transmitting data layer 0 consists of subarrays 0, 2 and 4, and subarray group 1 for transmitting data layer 1 consists of subarrays 1, 3 and 5), a first TCI state group used for transmitting data layer 0 is $\{TCI_0, TCI_2, TCI_4\}$, and a second TCI state group used for transmitting data layer 1 is $\{TCI_1, TCI_3, TCI_5\}$. In some embodiments, the DCI may contain the TCI states in the form of two groups, wherein the first group contains TCI states in an order of TCI_0, TCI_2, TCI_4 , and

the second group contains TCI_1 , TCI_3 , TCI_5 . In some other embodiments, the DCI may contain two group indexes (e.g., 3 and 4 as listed in Table 1) respectively associated with the two TCI state groups, and the BS may transmit TCI_0 , TCI_1 , TCI_2 , TCI_3 , TCI_4 and TCI_5 in an RRC or MAC-CE configuration message.

[0117] It should be noted that the methods described herein describe possible implementations, and that the operations and the steps may be arranged or otherwise modified and that other implementations are possible.

[0118] Figure 6 illustrates a flowchart of an exemplary method in accordance with aspects of the present disclosure. The operations of the method illustrated in Figure 6 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 BS to perform the described operations or functions.

[0119] As shown in Figure 6, in step 601, the UE may receive, from a BS (e.g., NE 102 in Figure 1), DCI scheduling transmission of N_r data layers from an antenna array of the BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state.

[0120] As shown in Figure 6, in step 602, the UE may receive, from the BS, the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

[0121] According to some embodiments of the present disclosure, the N TCI states may be divided into N_r TCI state groups. All the definitions and configurations related to TCI state groups provided in the embodiments described with respect to Figures 2-5 may also apply here. Thus, details are omitted for simplicity.

[0122] It should be noted that the methods described herein describe possible implementations, and that the operations and the steps may be arranged or otherwise modified and that other implementations are possible.

[0123] Figure 7 illustrates an example of a BS 700 in accordance with aspects of the present disclosure. The BS 700 may include at least one processor 702 and at least one memory 704. Additionally, the BS 700 may also include one or more of at least one controller 706 or at least one transceiver 708. The processor 702, the memory 704, the controller 706, or the transceiver 708, 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.

[0124] The processor 702, the memory 704, the controller 706, or the transceiver 708, 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.

[0125] The processor 702 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 702 may be configured to operate the memory 704. In some other implementations, the memory 704 may be integrated into the processor 702. The processor 702 may be configured to execute computer-readable instructions stored in the memory 704 to cause the BS 700 to perform various functions of the present disclosure.

[0126] The memory 704 may include volatile or non-volatile memory. The memory 704 may store computer-readable, computer-executable code including instructions when executed by the processor 702 cause the BS 700 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 704 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.

[0127] In some implementations, the processor 702 and the memory 704 coupled with the processor 702 may be configured to cause the BS 700 to perform one or more of the functions described herein (e.g., executing, by the processor 702, instructions stored in the memory 704). For example, the processor 702 may support wireless communication at the BS 700 in accordance with examples as disclosed herein. The BS 700 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 702 may be configured to cause the BS 700 to: partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

[0128] The controller 706 may manage input and output signals for the BS 700. The controller 706 may also manage peripherals not integrated into the BS 700. In some implementations, the controller 706 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 706 may be implemented as part of the processor 702.

[0129] In some implementations, the BS 700 may include at least one transceiver 708. In some other implementations, the BS 700 may have more than one transceiver 708. The transceiver 708 may represent a wireless transceiver. The transceiver 708 may include one or more receiver chains 710, one or more transmitter chains 712, or a combination thereof.

[0130] A receiver chain 710 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 710 may include one or more antennas for receive the signal over the air or wireless medium. The receiver chain 710 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 710 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 710 may include at least one decoder for decoding the demodulated signal to receive the transmitted data.

[0131] A transmitter chain 712 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 712 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 712 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 712 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0132] Figure 8 illustrates an example of a processor 800 in accordance with aspects of the present disclosure. The processor 800 may be an example of a processor configured to perform various operations in accordance with examples as described herein. The processor 800 may include at least one controller 802 configured to perform various operations in accordance with examples as described herein. The processor 800 may optionally include at least one memory 804, which may be, for example, a layer 1 (L1), layer 2 (L2), or layer 3 (L3) cache. Additionally, or alternatively, the processor 800 may optionally include one or more arithmetic-logic units (ALUs) 806. 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).

[0133] The processor 800 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 800) 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).

[0134] The controller 802 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 800 to cause the processor 800 to support various operations in accordance with examples as described herein. For example, the controller 802 may operate as a control unit of the processor 800, generating control signals that manage the operation of various components of the processor 800. These control signals include enabling or disabling functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

[0135] The controller 802 may be configured to fetch (e.g., obtain, retrieve, receive) instructions from the memory 804 and determine subsequent instruction(s) to be executed to cause the processor 800 to support various operations in accordance with examples as described herein. The controller 802 may be configured to track memory address of instructions associated with the memory 804. The controller 802 may be configured to decode instructions to determine the operation to be performed and the operands involved. For example, the controller 802 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 800 to cause the processor 800 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 802 may be configured to manage flow of data within the processor 800. The controller 802 may be configured to control transfer of data between registers, ALUs, and other functional units of the processor 800.

[0136] The memory 804 may include one or more caches (e.g., memory local to or included in the processor 800 or other memory, such RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc.). In some implementations, the memory 804 may reside within or on a processor chipset (e.g., local to the processor 800). In some other implementations, the memory 804 may reside external to the processor chipset (e.g., remote to the processor 800).

[0137] The memory 804 may store computer-readable, computer-executable code including instructions that, when executed by the processor 800, cause the processor 800 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 802 and/or

the processor 800 may be configured to execute computer-readable instructions stored in the memory 804 to cause the processor 800 to perform various functions. For example, the processor 800 and/or the controller 802 may be coupled with or to the memory 804, the processor 800, the controller 802, and the memory 804 may be configured to perform various functions described herein. In some examples, the processor 800 may include multiple processors and the memory 804 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.

[0138] The one or more ALUs 806 may be configured to support various operations in accordance with examples as described herein. In some implementations, the one or more ALUs 806 may reside within or on a processor chipset (e.g., the processor 800). In some other implementations, the one or more ALUs 806 may reside external to the processor chipset (e.g., the processor 800). One or more ALUs 806 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 806 may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 806 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 806 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 806 to handle conditional operations, comparisons, and bitwise operations.

[0139] The processor 800 may support wireless communication in accordance with examples as disclosed herein. The processor 800 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 processor 800 may be implemented in a BS, and the controller 802 may cause the processor 800 to: partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data

layer of the N_r data layers. In another embodiment, the processor 800 may be implemented in a UE, and the controller 802 may cause the processor 800 to: receive DCI scheduling transmission of N_r data layers from an antenna array of a BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state; and receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

[0140] Figure 9 illustrates an example of a UE 900 in accordance with aspects of the present disclosure. The UE 900 may include at least one processor 902 and at least one memory 904. Additionally, the UE 900 may also include one or more of at least one controller 906 or at least one transceiver 908. The processor 902, the memory 904, the controller 906, or the transceiver 908, 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.

[0141] The processor 902, the memory 904, the controller 906, or the transceiver 908, 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.

[0142] The processor 902 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 902 may be configured to operate the memory 904. In some other implementations, the memory 904 may be integrated into the processor 902. The processor 902 may be configured to execute computer-readable instructions stored in the memory 904 to cause the UE 900 to perform various functions of the present disclosure.

[0143] The memory 904 may include volatile or non-volatile memory. The memory 904 may store computer-readable, computer-executable code including instructions when executed

by the processor 902 cause the UE 900 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 904 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.

[0144] In some implementations, the processor 902 and the memory 904 coupled with the processor 902 may be configured to cause the UE 900 to perform one or more of the functions described herein (e.g., executing, by the processor 902, instructions stored in the memory 904). For example, the processor 902 may support wireless communication at the UE 900 in accordance with examples as disclosed herein. The UE 900 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 902 may be configured to cause the UE 900 to: receive DCI scheduling transmission of N_r data layers from an antenna array of a BS, wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective TCI state; and receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

[0145] The controller 906 may manage input and output signals for the UE 900. The controller 906 may also manage peripherals not integrated into the UE 900. In some implementations, the controller 906 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 906 may be implemented as part of the processor 902.

[0146] In some implementations, the UE 900 may include at least one transceiver 908. In some other implementations, the UE 900 may have more than one transceiver 908. The transceiver 908 may represent a wireless transceiver. The transceiver 908 may include one or more receiver chains 910, one or more transmitter chains 912, or a combination thereof.

[0147] A receiver chain 910 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 910 may include one or

more antennas for receive the signal over the air or wireless medium. The receiver chain 910 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 910 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 910 may include at least one decoder for decoding the demodulated signal to receive the transmitted data.

[0148] A transmitter chain 912 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 912 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 912 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 912 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0149] 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 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:
 partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and
 transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.
2. The BS of Claim 1, wherein the at least one processor is further configured to cause the BS to divide the N subarrays into N_r subarray groups, and each subarray group of the N_r subarray groups is used to transmit a respective data layer of the N_r data layers.
3. The BS of Claim 1 or 2, wherein N_r is 1, and a single data layer is transmitted from the N subarrays using the respective beamforming vectors associated with the N subarrays.
4. The BS of Claim 2, wherein $N_r > 1$, each subarray group of the N_r subarray groups consists of at least K subarray(s), and is used to transmit the respective data layer of the N_r data layers using the respective beamforming vectors associated with the at least K subarray(s) in the subarray group, and $K = \left\lfloor \frac{N}{N_r} \right\rfloor$.
5. The BS of Claim 4, wherein the at least K subarray(s) of the subarray group are adjacent subarrays or interleaved subarrays.
6. The BS of Claim 1 or 2, wherein the at least one processor is further configured to cause the BS to transmit downlink control information (DCI) scheduling transmission of the N_r data layers, the DCI indicates N_r transmission configuration indication (TCI) state groups,

and each TCI state group of the N_r TCI state groups is associated with a respective data layer of the N_r data layers.

7. The BS of Claim 6, wherein each TCI state group of the N_r TCI state groups includes one or more TCI states, and each TCI state of the one or more TCI states is associated with a respective subarray used to transmit the respective data layer associated with the TCI state group.
8. The BS of Claim 7, wherein the one or more TCI states included in each TCI state group of the N_r TCI state groups are transmitted in the DCI.
9. The BS of Claim 7, wherein each TCI state group of the N_r TCI state groups is associated with a group index, and the group index associated with each TCI state group of the N_r TCI state groups is transmitted in the DCI.
10. The BS of Claim 9, wherein the at least one processor is further configured to cause the BS to transmit a radio resource control (RRC) or medium access control (MAC) control element (CE) configuration message including the one or more TCI states included in each TCI state group of the N_r TCI state groups.
11. The BS of Claim 1, wherein the respective beamforming vector associated with each subarray of the N subarrays is a discrete-time Fourier transform (DFT) beamforming vector for steering a beam associated with the subarray towards a receiver of a user equipment (UE).
12. The BS of Claim 1, wherein the at least one processor is configured to cause the BS to apply a hybrid beamforming precoder to the antenna array for transmission of the N_r data layers, and the hybrid beamforming precoder includes an analogue beamforming part and a digital precoder.
13. The BS of Claim 12, wherein:

the analogue beamforming part is applied to each subarray of the N subarrays to apply the respective beamforming vector to the subarray; or

for each subarray of the antenna array, the digital precoder determines a data layer of the N_r data layers to be transmitted from the subarray.

14. 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 downlink control information (DCI) scheduling transmission of N_r data layers from an antenna array of a base station (BS), wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective transmission configuration indication (TCI) state; and

receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

15. The UE of Claim 14, wherein the N TCI states are divided into N_r TCI state groups, each TCI state group of the N_r TCI state groups is associated with a respective data layer of the N_r data layers, and each TCI state of the N TCI states is included in a single TCI state group of the N_r TCI state groups.

16. The UE of Claim 15, wherein each TCI state group of the N_r TCI state groups includes one or more TCI states, and the one or more TCI states included in each TCI state group of the N_r TCI state groups are included in the DCI.

17. The UE of Claim 15, wherein each TCI state group of the N_r TCI state groups is associated with a group index, and the group index associated with each TCI state group of the N_r TCI state groups is included in the DCI.

18. The UE of Claim 17, wherein each TCI state group of the N_r TCI state groups includes one or more TCI states, and the at least one processor is further configured to cause the UE to receive a radio resource control (RRC) or medium access control (MAC) control element (CE) configuration message including the one or more TCI states included in each TCI state group of the N_r TCI state groups.

19. A processor for wireless communication, comprising:

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

partition an antenna array into N subarrays, wherein $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective beamforming vector; and

transmit N_r data layers from the antenna array, wherein $N_r \geq 1$, and each subarray of the antenna array is used to transmit a single data layer of the N_r data layers.

20. A processor for wireless communication, comprising:

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

receive downlink control information (DCI) scheduling transmission of N_r data layers from an antenna array of a base station (BS), wherein $N_r \geq 1$, the antenna array includes N subarrays, $N \geq 1$, and each subarray of the antenna array includes a number of adjacent antennas and is associated with a respective transmission configuration indication (TCI) state; and

receive the N_r data layers with N TCI states associated with the N subarrays, wherein the N TCI states are indicated by the DCI.

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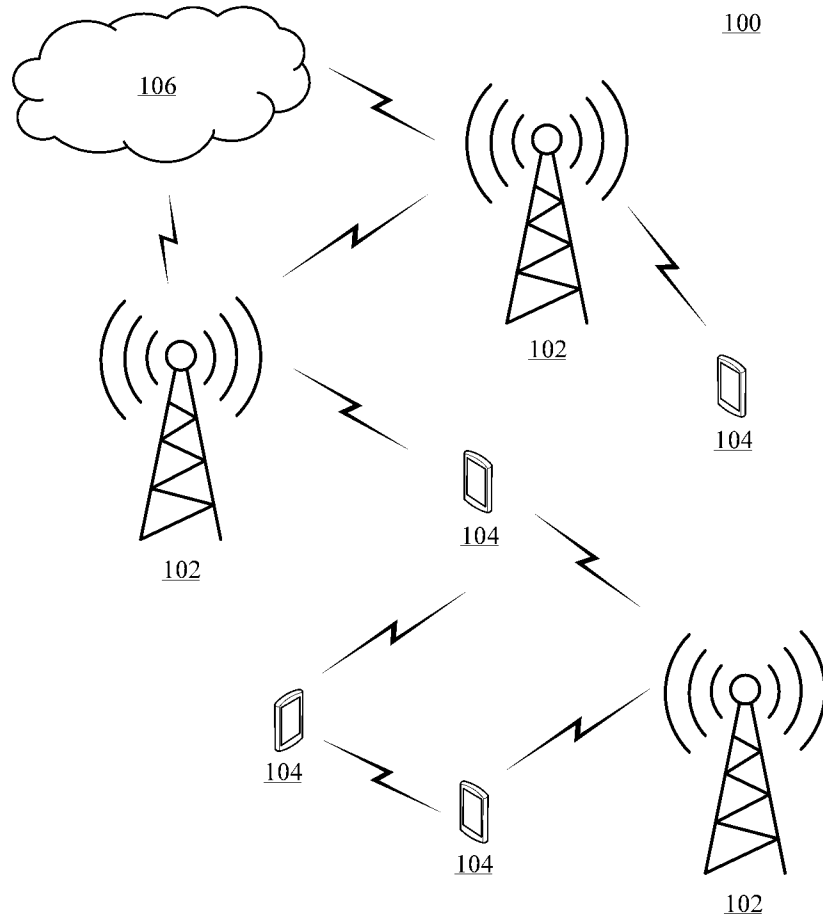


Figure 1

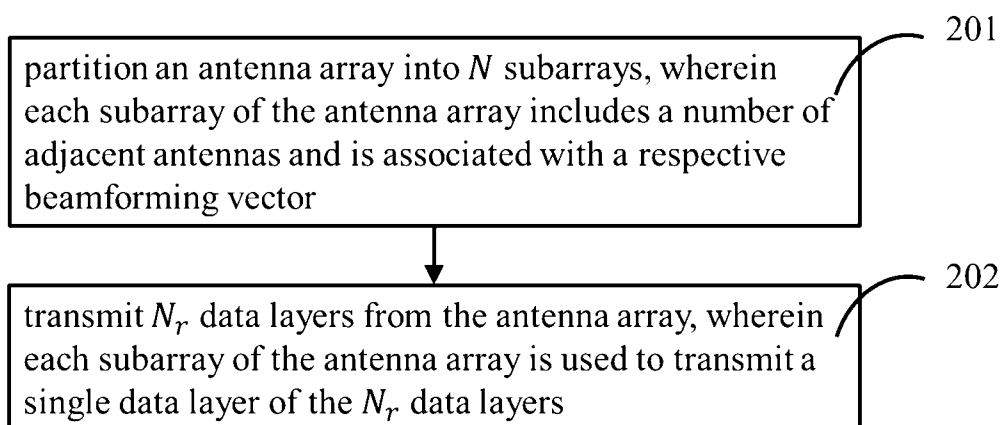


Figure 2

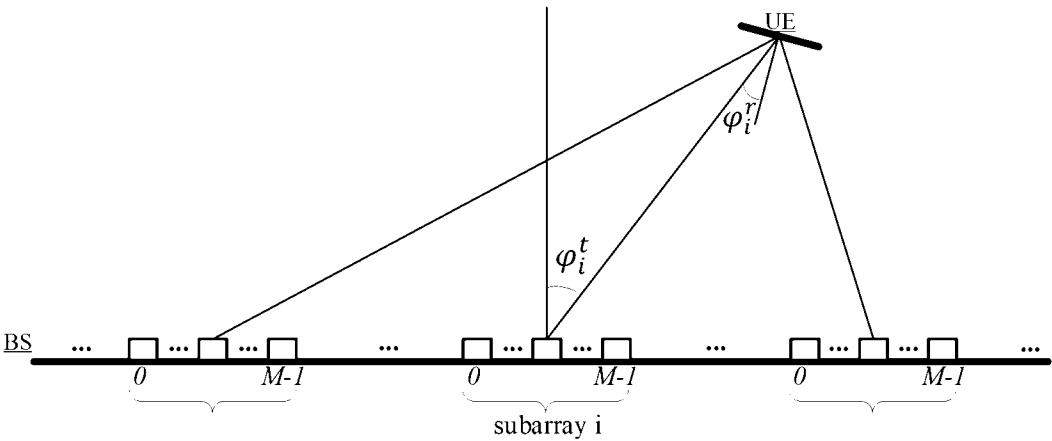


Figure 3

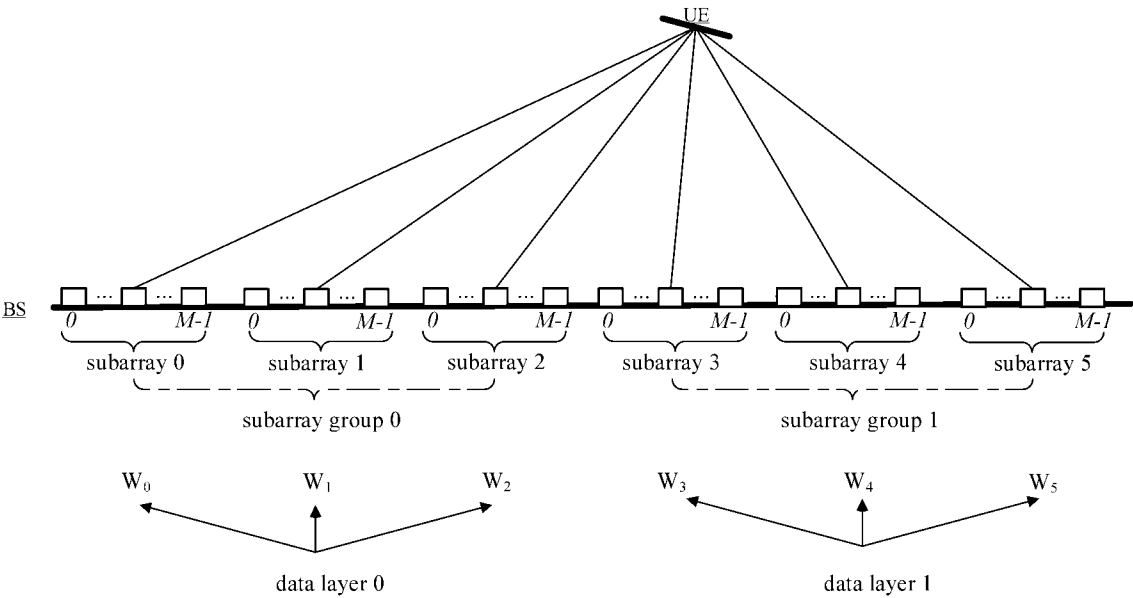


Figure 4

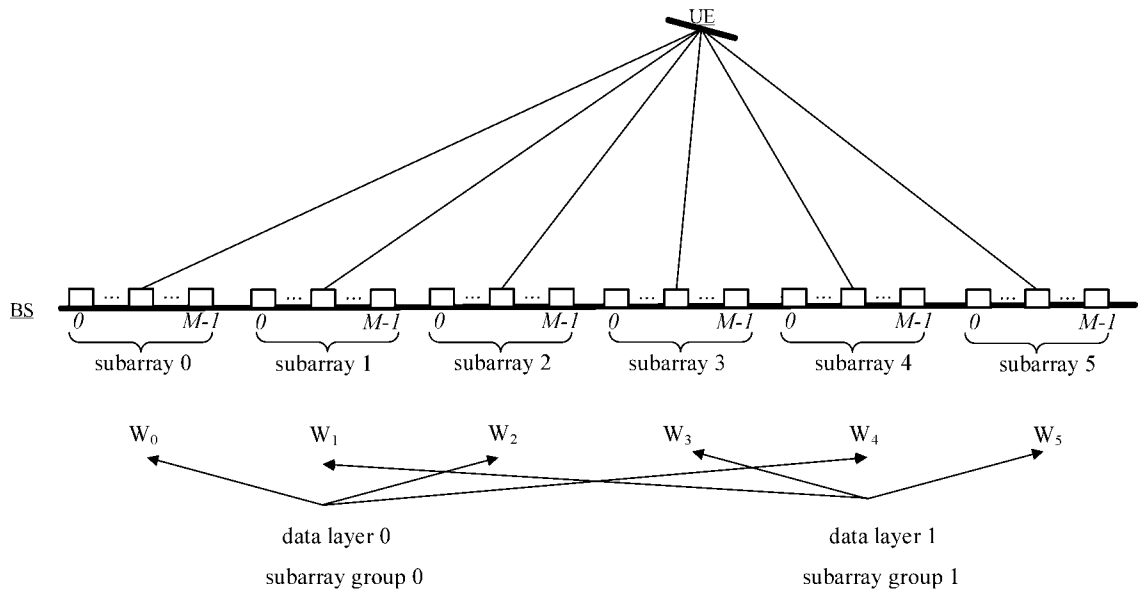


Figure 5

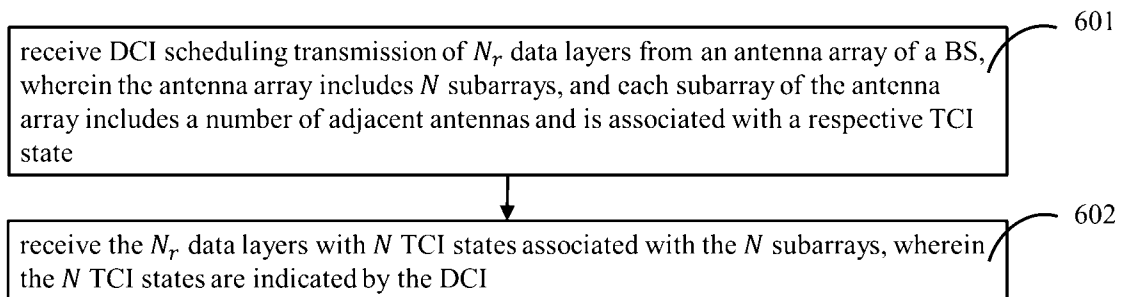


Figure 6

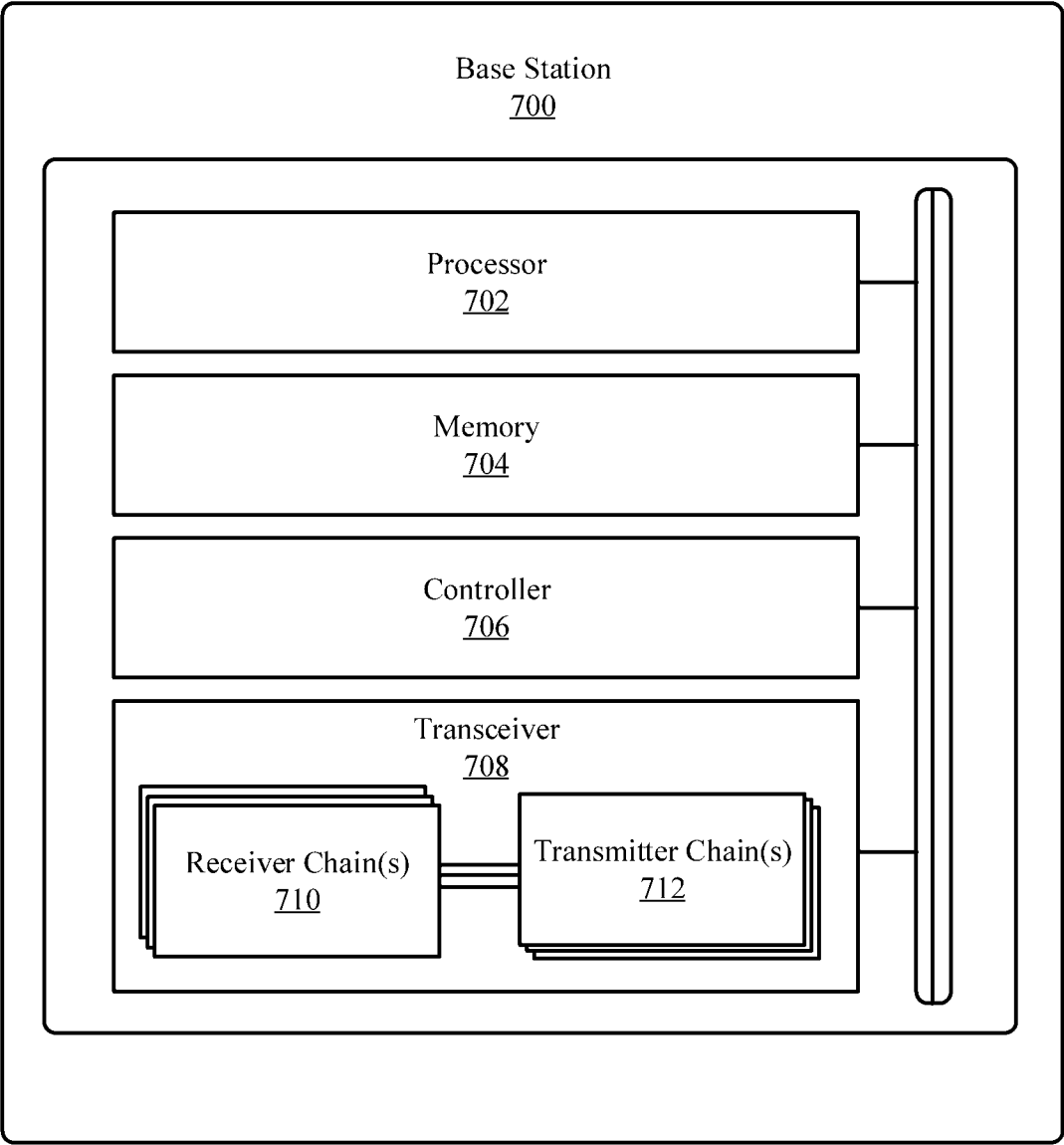


Figure 7

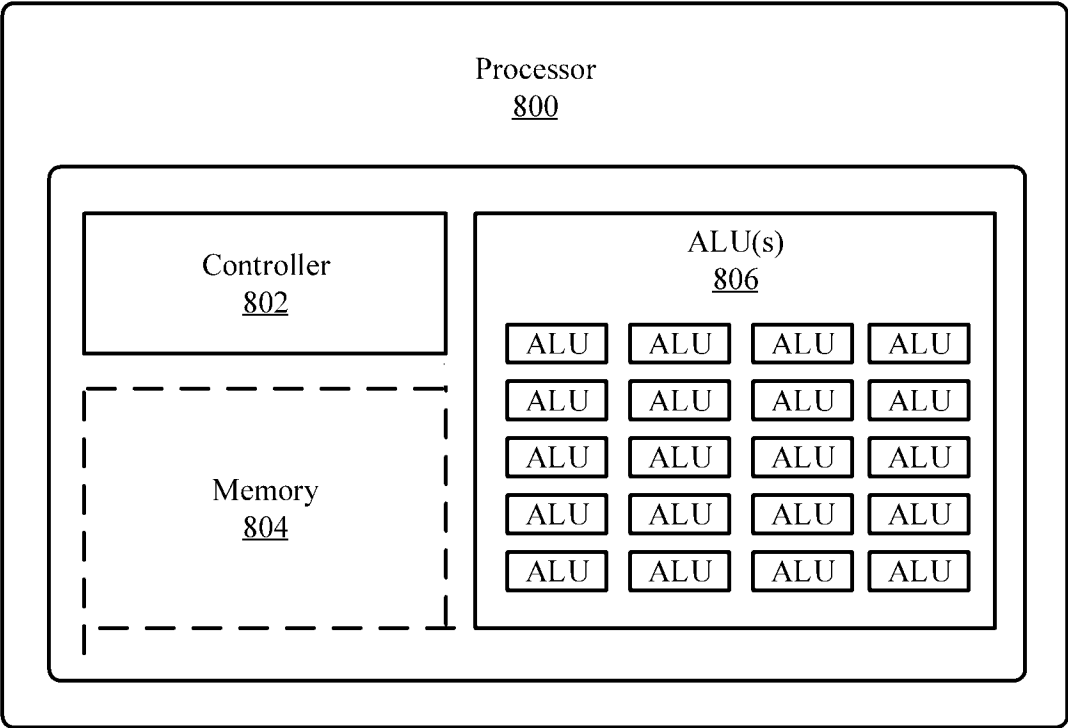


Figure 8

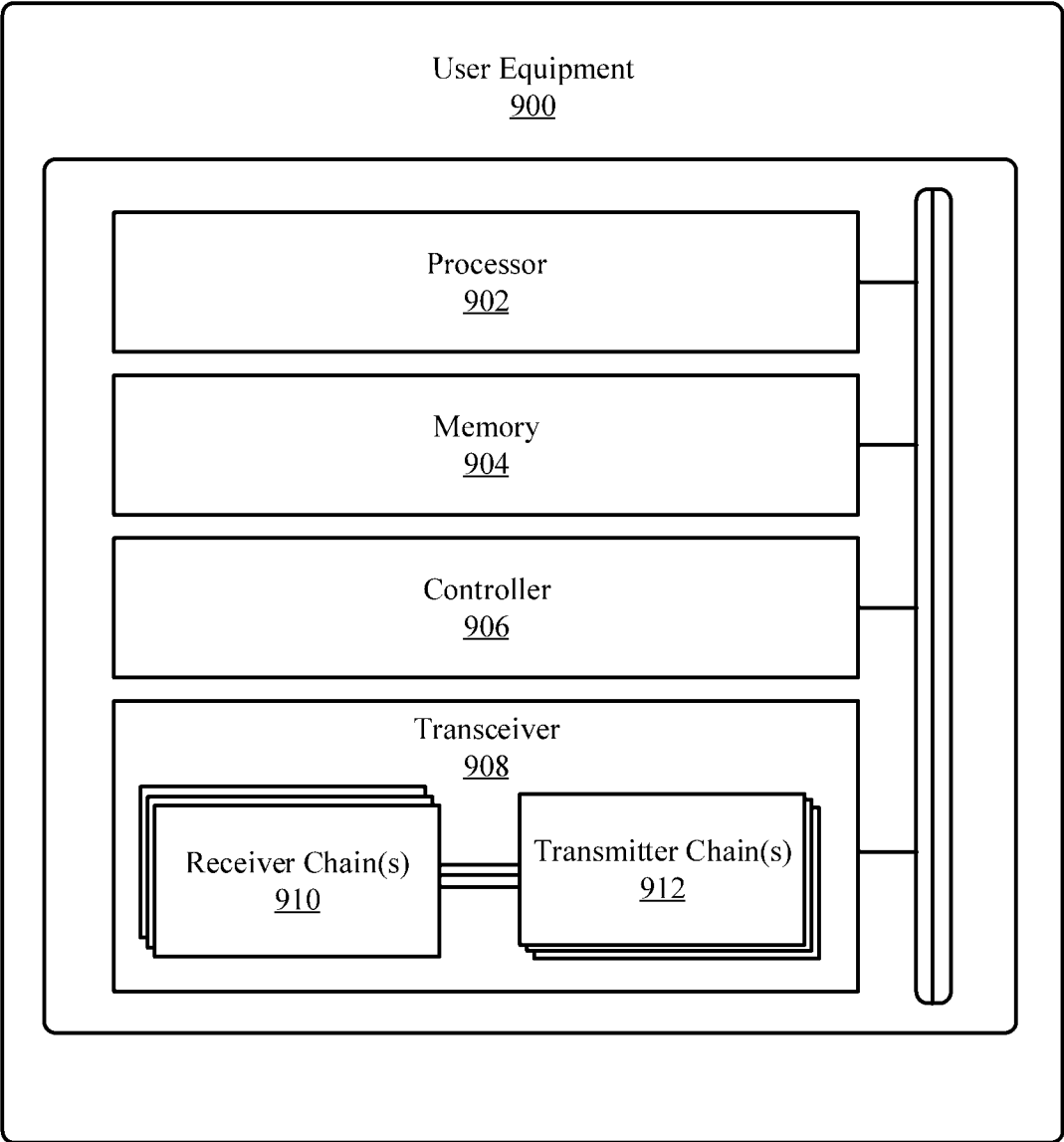


Figure 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/115911

A. CLASSIFICATION OF SUBJECT MATTER H04B7/0413(2017.01)i According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC:H04B H04W Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) CNTXT, ENTXT, WPABS, DWPI, VCN, CNKI, 3GPP: antenna, array, subarray, beamform+, layer, associated, DCI, TCI, index, MAC CE, DFT, precoder		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2022006581 A1 (SHARP KABUSHIKI KAISHA et al.) 06 January 2022 (2022-01-06) description paragraphs 0134-0149, 0208	1-20
X	US 2021135742 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 06 May 2021 (2021-05-06) description paragraphs 0008-0030	1-20
X	CN 113261322 A (SHARP KABUSHIKI KAISHA et al.) 13 August 2021 (2021-08-13) description paragraphs 0121-0141	1-20
X	CN 112956234 A (SHARP KABUSHIKI KAISHA) 11 June 2021 (2021-06-11) description paragraphs 0120-0140	1-20
A	CN 107431520 A (SONY CORPORATION) 01 December 2017 (2017-12-01) the whole document	1-20
A	US 2018234979 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 16 August 2018 (2018-08-16) the whole document	1-20
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: “A” document defining the general state of the art which is not considered to be of particular relevance “D” document cited by the applicant in the international application “E” earlier application or patent but published on or after the international filing date “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) “O” document referring to an oral disclosure, use, exhibition or other means “P” document published prior to the international filing date but later than the priority date claimed “T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art “&” document member of the same patent family		
Date of the actual completion of the international search 19 May 2025		Date of mailing of the international search report 22 May 2025
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International application No.

PCT/CN2024/115911

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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