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(54) **Title:** METHODS AND APPARATUSES FOR WIRELESS COMMUNICATION WITH EXTREMELY LARGE ANTENNA ARRAYS

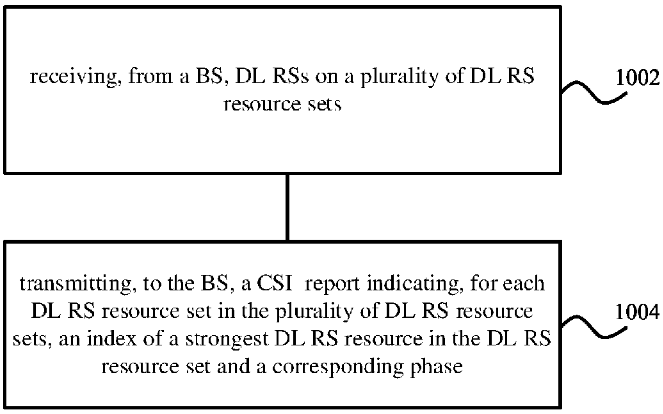

Figure 10

(57) **Abstract:** Various aspects of the present disclosure relate to methods and apparatuses for wireless communication with extremely large antenna arrays. Some implementations of the methods and apparatuses described herein may include 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, from a base station (BS), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmit, to the BS, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

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[Continued on next page]

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METHODS AND APPARATUSES FOR WIRELESS COMMUNICATION WITH EXTREMELY LARGE ANTENNA ARRAYS

TECHNICAL FIELD

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

BACKGROUND

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

SUMMARY

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

[0004] Some implementations of the methods and apparatuses described herein may include a UE for wireless communication, 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, from a base station (BS), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmit, to the BS, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0005] In some implementations of the UE described herein, the at least one processor is further configured to cause the UE to: perform measurement of DL RSs on all DL RS resources in the plurality of DL RS resource sets to determine the strongest DL RS resource and the corresponding phase for each DL RS resource set.

[0006] In some implementations of the UE described herein, different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

[0007] In some implementations of the UE described herein, each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource.

[0008] In some implementations of the UE described herein, the at least one processor is further configured to cause the UE to: receive, from the BS, configuration information indicating the plurality of DL RS resource sets.

[0009] In some implementations of the UE described herein, the at least one processor is further configured to cause the UE to: receive, from the BS, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

[0010] In some implementations of the UE described herein, each corresponding phase indicated by the CSI report is a phase offset relative to one of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report.

[0011] In some implementations of the UE described herein, the one is a largest received phase among all the DL RSs on the strongest DL RS resources indicated by the CSI report.

[0012] In some implementations of the UE described herein, the corresponding phases indicated by the CSI report are quantized.

[0013] In some implementations of the UE described herein, the at least one processor is further configured to cause the UE to: receive, from the BS, a DL transmission with a subarray-based maximal ratio combining (MRC) scheme based on the CSI report, in which for each subarray used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied.

[0014] In some implementations of the UE described herein, the DL transmission is a transmission of a CSI-RS on a single CSI-RS resource using all subarrays of the antenna array.

[0015] In some implementations of the UE described herein, the CSI-RS is a tracking RS (TRS) for the UE to perform time and frequency tracking of the antenna array.

[0016] Some implementations of the methods and apparatuses described herein may include a BS for wireless communication, comprising: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the BS to: transmit, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and receive, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0017] In some implementations of the BS described herein, the DL RSs on all DL RS resources in the plurality of DL RS resource sets are transmitted with a common phase offset.

[0018] In some implementations of the BS described herein, the common phase offset is zero.

[0019] In some implementations of the BS described herein, different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

[0020] In some implementations of the BS described herein, each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource.

[0021] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to: transmit, to the UE, configuration information indicating the plurality of DL RS resource sets.

[0022] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to: transmit, to the UE, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

[0023] In some implementations of the BS described herein, each corresponding phase indicated by the CSI report is a phase offset relative to one of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report.

[0024] In some implementations of the BS described herein, the one is a largest received phase among all the DL RSs on the strongest DL RS resources indicated by the CSI report.

[0025] In some implementations of the BS described herein, the corresponding phases indicated by the CSI report are quantized.

[0026] In some implementations of the BS described herein, the at least one processor is further configured to cause the BS to: transmit, to the UE, a DL transmission with a subarray-based MRC scheme based on the CSI report, in which for each subarrary used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied.

[0027] In some implementations of the BS described herein, the DL transmission is a transmission of a CSI-RS on a single CSI-RS resource using all subarrays of the antenna array.

[0028] In some implementations of the BS described herein, the CSI-RS is a TRS for the UE to perform time and frequency tracking for the antenna array.

[0029] Some implementations of the methods and apparatuses described herein may include a processor for wireless communication, comprising: at least one controller coupled with at least one memory and configured to cause the processor to: receive, from a BS, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmit, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0030] Some implementations of the methods and apparatuses described herein may include a processor for wireless communication, comprising: at least one controller coupled with at least one memory and configured to cause the processor to: transmit, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and receive, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0031] Some implementations of the methods and apparatuses described herein may include a method performed by a UE, the method comprising: receiving, from a BS, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmitting, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0032] Some implementations of the methods and apparatuses described herein may include a method performed by a BS, the method comprising: transmitting, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and receiving, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Figure 1 illustrates an example of a wireless communications system in accordance with aspects of the present disclosure.

[0034] Figure 2 illustrates an example of hybrid beamforming architecture in accordance with aspects of the present disclosure.

[0035] Figures 3A-3D illustrate exemplary beam patterns of three different beamforming schemes for a UE at different distances from an antenna array in accordance with aspects of the present disclosure.

[0036] Figure 4 illustrates received phases of respective strongest DL RSs from a plurality of subarrays of an antenna array in accordance with aspects of the present disclosure.

[0037] Figure 5 illustrates transmitting phases for antenna elements in an antenna array in accordance with aspects of the present disclosure.

[0038] Figure 6 illustrates a comparison between a beam pattern of a DL transmission with a subarray-based MRC scheme and an ideal beamforming pattern in accordance with aspects of the present disclosure.

[0039] Figure 7 illustrates an example of a UE in accordance with aspects of the present disclosure.

[0040] Figure 8 illustrates an example of a processor in accordance with aspects of the present disclosure.

[0041] Figure 9 illustrates an example of a network equipment (NE) in accordance with aspects of the present disclosure.

[0042] Figure 10 illustrate a flowchart of an exemplary method performed by a UE in accordance with aspects of the present disclosure.

[0043] Figure 11 illustrate a flowchart of an exemplary method performed by an NE in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0044] To facilitate understanding, embodiments of the present disclosure are provided under specific network architectures 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.

[0045] Aspects of the present disclosure are described in the context of a wireless communications system.

[0046] 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 NEs 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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).

[0052] 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.

[0053] 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).

[0054] 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 (i.e., multiple frame structures). The NEs 102 and the UEs 104 may support various frame structures based on one or more numerologies.

[0055] 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., μ=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., μ=0) associated with the first subcarrier spacing (e.g., 15 kHz) may utilize one slot per subframe. A second numerology (e.g., μ=1) may be associated with a second subcarrier spacing (e.g., 30 kHz) and a normal cyclic prefix. A third numerology (e.g., μ=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., μ=3) may be associated with a fourth subcarrier spacing (e.g., 120 kHz) and a normal cyclic prefix. A fifth numerology (e.g., μ=4) may be associated with a fifth subcarrier spacing (e.g., 240 kHz) and a normal cyclic prefix.

[0056] 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.

[0057] 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 (i.e., μ=0, μ=1, μ=2, μ=3, μ=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., μ=0) associated with a first subcarrier spacing (e.g., 15 kHz) may be used interchangeably between subframes and slots.

[0058] 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.

[0059] 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., μ=0), which includes 15 kHz subcarrier spacing; a second numerology (e.g., μ=1), which includes 30 kHz subcarrier spacing; and a third numerology (e.g., μ=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., μ=2), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g., μ=3), which includes 120 kHz subcarrier spacing.

[0060] 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 elements" and "antennas" may be used interchangeably.

[0061] 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 antennas. Therefore, high-frequency XL-MIMO may be a key enabling technology for 6G communications.

[0062] As the size of the antenna array increases, the electromagnetic (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.

[0063] 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.

[0064] The electromagnetic wave propagation in the near field is explained as follows.

[0065] The typical antenna 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:

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

$$\vec{p}_{0\perp} = \vec{p}_0 - \hat{r}(\hat{r} \cdot \vec{p}_0),$$

$$\hat{\mathrm{r}} = sin\theta cos\phi \hat{\mathrm{x}} + sin\theta sin\phi \hat{\mathrm{y}} + cos\theta \hat{\mathrm{z}},$$

where

$\vec{p}_0$ is the electric dipole moment of the electric dipole at the origin;

$\vec{p}_{0\perp}$ is perpendicular to the direction vector $\hat{r}$ ($\hat{r} \cdot \vec{p}_{0\perp}$=0);

$k = \frac{\omega}{c}$; and

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

[0066] 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.

[0067] In the far field, the EM wave radiated from an antenna array can be treated as a combination of planar waves. As a result, the design of massive MIMO in 5G NR is based on the planar wave assumption. However, in the near field, the EM wave radiated from an antenna array cannot be treated as 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.

[0068] Hybrid beamforming is widely used in the mmWave system to reduce the hardware cost and simplify the system, 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.

[0069] Figure 2 illustrates an example of hybrid beamforming architecture in accordance with aspects of the present disclosure. This example includes both a transmitter side and a receiver side.

[0070] The hybrid beamforming architecture may include beamforming in both digital and analog domains. Specifically, digital weights are applied at each RF chain (e.g., through baseband digital precoding), and at the antenna element level, a signal is adjusted by analog phase shifters (e.g., through RF analog precoding), which only changes the phase of the signal. Thus, the precoding is done in two stages at the transmitter side. The corresponding combining operation is also done in two stages at the receiver side, e.g., RF analog combining and baseband digital combining.

[0071] In Figure 2, sharp beams formed with analog beamforming (e.g., by the phase shifters) compensate for the large path loss at mmWave bands, and digital beamforming provides the necessary flexibility to perform advanced multi-antenna techniques such as multi-beam MIMO.

[0072] In traditional beamforming, it is assumed that the UE is in the far field, and thus the same angle of departure or the same angle of arrival can be applied to the entire antenna array. Because in the far field, the EM wave can be considered as a planar wave (or a combination of planar waves), the beamforming vector driving a subset or all of the antenna elements in the antenna array is a Discrete Fourier Transform (DFT) vector steering towards the direction of the outgoing or incoming wave.

[0073] However, in the near field, the EM wave is no longer a planar wave (or a combination of planar waves), the DFT vector used under the planar wave assumption may no longer apply.

[0074] The ideal beamforming vector needs to accommodate the non-planar EM wavefront and is very complicated. Therefore, it is advantageous to find a low complexity solution to simplify the design and reduce the implementation cost.

[0075] To this end, the present disclosure proposes simplified designs in which an antenna array with non-negligible near field effect (e.g., extremely large antenna array) may be partitioned into multiple subarrays. For each subarray, a respective beamforming vector may be applied to steer a corresponding beam in a respective direction towards a target UE. That is, different subarrays may use different beamforming vectors to steer their beams in different directions towards a same target UE. The present disclosure proposes some solutions for determining different beamforming vectors for different subarrays, which may include estimation of the near field channel by a UE and CSI feedback reporting.

[0076] In the present disclosure, an antenna array of an NE (e.g., a BS) is partitioned into multiple subarrays (for example, K subarrays), and each subarray may have a corresponding index and may include a number of contiguous antenna elements. For example, in the case that the antenna array is one-dimensional, the k^{th} subarray, i.e., a subarray with an index of k (also referred to as subarray k), may include a total number of $2M+1$ antenna elements in one dimension. The distance between neighboring antenna elements in the subarray is d. The antenna element in the center of the subarray is referred to as the 0^{th} antenna element, the antenna elements next to the 0^{th} antenna element are referred to as the 1^{st} antenna element and the $(-1)^{th}$ antenna element, …, and the antenna elements on the edge of the subarray are referred to as the M^{th} antenna element and the $(-M)^{th}$ antenna element. The traditional analog beamforming architecture (e.g., similar to that illustrated in Figure 2) may be applied to each subarray. In some embodiments, a DFT-based beamforming vector may be applied to each subarray.

[0077] However, the BS may not know how to apply the DFT-based beamforming vector for transmission to a UE, and what DFT-based beamforming vector to use in the transmission. The ideal way to transmit from an antenna array to a UE is MRC, in which the phases of all the antennas in the antenna array are fine tuned to well align at the UE for achieving a maximal signal strength. This may require the UE to estimate the phases for all the antennas and provide a proper feedback, which may be complicated and impractical. According to some embodiments of the present disclosure, a subarray-based MRC scheme (also referred to as a subarray-based DFT beamforming scheme) may be used to simplify system designs.

[0078] For an antenna array partitioned into K subarrays, to implement the subarray-based MRC scheme, different beamforming vectors may be applied for different subarrays. For example, a beamforming vector, V_k, may be applied for subarray k, which may be a DFT-based beamforming vector as follows:

$$V_k = \frac{e^{j\omega_k}}{\sqrt{2M+1}} \begin{bmatrix} e^{(-M)j\phi_k} \\ \vdots \\ e^{(m)j\phi_k} \\ \vdots \\ e^{(M)j\phi_k} \end{bmatrix}$$

wherein:

ω_k is an offset phase for subarray k with respect to a reference subarray (e.g., the center subarray);

$2M + 1$ is a total number of antenna elements in subarray k;

ϕ_k is a DFT phase gradient in subarray k; and

m is an index of an antenna element in subarray k, and $m \in \{-M + 1, \ldots, -1, 0, 1, \ldots, M - 1\}$.

[0079] V_k is applied to the $2M + 1$ antenna elements in subarray k to direct a beam transmitted from subarray k to the direction of the UE or a reflector which reflects the beam to the UE. Because only the relative phase is important, the offset phase for subarray k, i.e., ω_k, may be the relative phase (also referred to as phase offset) from the center antenna element of subarray k to the center antenna element of the entire antenna array in the subarray-based MRC scheme.

[0080] Figures 3A-3D illustrate exemplary beam patterns of three different beamforming schemes for a UE at different distances from an antenna array in accordance with aspects of the present disclosure. The three different beamforming schemes are an ideal MRC beamforming scheme (e.g., denoted as IdealBF), a whole array DFT based beamforming scheme (denoted as wholeArrayDFT, in which a DFT-based beamforming vector is applied to the whole array), and a subarray-based DFT beamforming scheme (denoted as subarrayDFT).

[0081] In the examples illustrated in Figures 3A-3D, an antenna array of a BS is partitioned into 5 subarrays. The beam patterns are represented by normalized powers (vertical coordinates, in units of "dB") received by the UE at different locations (horizontal coordinates, represented by displacements relative to a center point, in unis of "wavelength") on a plane parallel to the antenna array.

[0082] Figure 3A illustrates beam patterns for the UE at 0.05 Rayleigh distance from the antenna array. As depicted, the beam pattern of the whole array DFT based beamforming scheme has a wider beam and a lower gain compared with the beam pattern of the ideal MRC beamforming scheme. In particular, it can be seen that the normalized received power of the whole array DFT based beamforming scheme at the center point (i.e., the horizontal coordinate is 0) is around 9 dB smaller than that of the ideal MRC beamforming scheme, and the normalized received power of the sidebeam (e.g., the horizontal coordinate is around 50 wavelengths) of the whole array DFT based beamforming scheme is much higher than that of the ideal MRC beamforming scheme. In contrast, the beam pattern of the subarray-based DFT beamforming scheme is similar to that of the ideal MRC beamforming scheme.

[0083] Figure 3B illustrates beam patterns for the UE at 0.1 Rayleigh distance from the antenna array. The beam pattern of the whole array DFT based beamforming scheme still has a wider beam and a lower gain compared with that of the ideal MRC beamforming scheme. In particular, it can be seen that the normalized received power of the whole array DFT based beamforming scheme at the center point (i.e., the horizontal coordinate is 0) is around 5 dB smaller than that of the ideal MRC beamforming scheme, and the normalized received power of the sidebeam (e.g., the horizontal coordinate is around 50 wavelengths) of the whole array DFT based beamforming scheme is still higher than that of the ideal MRC beamforming scheme. In contrast, the beam pattern of the subarray-based DFT beamforming scheme is also similar to that of the ideal MRC beamforming scheme.

[0084] Figure 3C illustrates beam patterns for the UE at 0.25 Rayleigh distance from the antenna array. The beam pattern of the whole array DFT based beamforming scheme still has a wider beam and a lower gain compared with that of the ideal MRC beamforming scheme. In particular, it can be seen that the normalized received power of the whole array DFT based beamforming scheme at the center point (i.e., the horizontal coordinate is 0) is around 3 dB smaller than that of the ideal MRC beamforming, and the normalized received power of the sidebeam (e.g., the horizontal coordinate is around 50 wavelengths) of the whole array DFT based beamforming scheme is still higher than that of the ideal MRC beamforming scheme. In contrast, the beam pattern of the subarray-based DFT beamforming scheme is also similar to that of the ideal MRC beamforming scheme.

[0085] Figure 3D illustrates beam patterns for the UE at 0.5 Rayleigh distance. Since the electric field at such distance may begin to exhibit some far field properties, beam patterns of the three beamforming schemes are similar.

[0086] To implement the subarray-based DFT beamforming scheme, the present disclosure proposes various solutions for the UE to perform channel estimation (i.e., estimation of the near field channel) and provide measurement results (e.g., a CSI report) to the BS, so that the BS can determine a respective beamforming vector for each subarray of the antenna array based on measurement results. The detailed solutions are described as follows.

[0087] According to some embodiments of the present disclosure, a BS may transmit DL RSs (e.g., CSI-RSs) to a UE for channel estimation. The DL RSs may be transmitted on a plurality of DL RS resource sets. Each DL RS resource set may be associated with a respective subarray of an antenna array of the BS (i.e., DL RSs on a DL RS resource set are transmitted using the respective subarray associated with the DL RS resource set). For each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted using different beamforming vectors (e.g., DFT-based beamforming vectors). That is, each DL RS resource is associated with a respective beamforming vector applied to the respectively subarray associated with the DL RS resource set.

[0088] For example, the antenna array is partitioned into K subarrays, and each subarray includes $2M + 1$ antenna elements. For subarray k, a DL RS resource set (referred to as DL RS resource set k) including multiple DL RS resources may be configured for transmitting DL RSs using subarray k. For example, the i^{th} DL RS (referred to as DL RS^{i}_{k}) transmitted by subarray k may be transmitted on the i^{th} DL RS resource in DL RS resource set k. DL RS^{i}_{k} may be transmitted with a beamforming vector V_k^i having a DFT phase gradient ϕ_k^i and a phase offset ω_k^i. In some embodiments, ω_k^i may equal the phase of the center antenna element of subarray k, e.g., the antenna element with an index of zero among the $2M + 1$ antenna elements of subarray k.

[0089] In some embodiments, DL RSs on all DL RS resources in the plurality of DL RS resource sets may be transmitted with a common phase offset, that is, different DL RSs transmitted from the same subarray or from different subarrays may have a common phase offset. In some embodiments, the common phase offset may be zero. That is, $\omega_k^i = 0$ for all i and k. Although each DL RS is sent from all the antenna elements in a subarray, each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource. In other words, the entire subarray is virtualized as a single antenna port with each of the subarrays transmitting using the virtualization vector (i.e., beamforming vector) with $\omega_k^i = 0$ for all i and k.

[0090] In an embodiment, the beamforming vector V_k^i applied to subarray k for transmitting DL RS^i_k is as follows:

$$V_k^i = \frac{e^{j\omega_k^i}}{\sqrt{2M+1}} \begin{bmatrix} e^{(-M)j\phi_k^i} \\ \vdots \\ e^{(m)j\phi_k^i} \\ \vdots \\ e^{(M)j\phi_k^i} \end{bmatrix} = \frac{1}{\sqrt{2M+1}} \begin{bmatrix} e^{(-M)j\phi_k^i} \\ \vdots \\ e^{(m)j\phi_k^i} \\ \vdots \\ e^{(M)j\phi_k^i} \end{bmatrix}$$

[0091] For the K subarrays, a total of K DL RS resource sets may be configured. In some embodiments, the K DL RS resource sets may be jointly configured as a DL RS resource super set. Since DL RSs on different DL RS resources in a same DL RS resource set are transmitted using antenna elements in the same subarray, different DL RS resources in a same DL RS resource set do not overlap in time domain. Different DL RS resources in different DL RS resource sets may be associated with a same time-domain resource or different time-domain resources (e.g., symbols, slots, etc.).

[0092] The BS may transmit configuration information indicating the K DL RS resource sets to the UE, for example, via a radio resource control (RRC) configuration message (e.g., *CSI-ResourceConfig* as specified in 3GPP standard documents) or other messages. The UE may perform channel estimation based on the configuration information, e.g., receiving and measuring DL RSs on the configured K DL RS resource sets.

[0093] For example, for DL RS resource set k, which is associated with subarray k, the UE may measure a received signal strength (e.g., L1-RSRP) of DL RS on each DL RS resource in DL RS resource set k, and select the strongest DL RS (denoted as DL RS_{k^*}), e.g., the DL RS with a highest L1-RSRP among all the DL RSs received on DL RS resource set k. The DL RS resource on which the strongest DL RS is received may be referred to as a strongest DL RS resource in DL RS resource set k. The index of the strongest DL RS or the strongest DL RS resource in DL RS resource set k may be denoted as k^*. As described above, each DL RS resource is associated with a respective beamforming vector used to transmit a DL RS on the DL RS resource. Accordingly, the beamforming vector used to transmit DL

RS$_{k^*}$ is the beamforming vector associated with DL RS resource k^* in DL RS resource set k, which may be denoted as V_{k^*} and have a DFT phase gradient ϕ_{k^*} (assuming that phase offset $\omega_k^i = 0$ for all i and k):

$$V_{k^*} = \frac{1}{\sqrt{2M+1}} \begin{bmatrix} e^{(-M)\, i\phi_{k^*}} \\ \vdots \\ e^{(m)\, i\phi_{k^*}} \\ \vdots \\ e^{(M)\, i\phi_{k^*}} \end{bmatrix}$$

[0094] For DL RS resource set k, the UE may also measure a received phase (denoted as ρ_{k^*}) of DL RS$_{k^*}$. Although different antenna elements of a subarray transmit with different phases for DL RS$_{k^*}$, the UE may receive the combined signal from all antenna elements of the subarray approximately as a plane wave and measure a single phase as ρ_{k^*}.

[0095] To assist the BS to determine an optimal beamforming vector for each subarray, the UE may transmit, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource. For example, for subarray k, the CSI report may indicate (e.g., include) k^* (e.g., a CSI-RS resource indicator (CRI) of the strongest DL RS resource in DL RS resource set k) and ρ_{k^*}. In some embodiments, the corresponding phase indicated by the CSI report may be a relative phase, e.g., a phase offset relative to one (e.g., a largest one) of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report. In some embodiments, the corresponding phase may be quantized using a quantization scheme such as 16PSK or 32PSK and transmitted in the CSI report.

[0096] As an example, the indices of the strongest DL RS resources for the K subarrays may be reported as Beam = $[1^*, 2^*, \ldots, K^*]$, wherein j^* ($j \in \{1,2, \ldots, K\}$) is the index of the strongest DL RS resource for subarray j. The corresponding phases for the K subarrays may be reported as $\mathrm{P}^* = [\rho_1^*, \rho_2^*, \ldots, \rho_K^*]$, wherein ρ_j^* ($j \in \{1,2, \ldots, K\}$) is the relative phase of the DL RS on the strongest DL RS resource for subarray j.

[0097] Figure 4 illustrates received phases of respective strongest DL RSs from a plurality of subarrays of an antenna array in accordance with aspects of the present disclosure.

[0098] In the example illustrated in Figure 4, the antenna array includes 5 subarrays. The indices of subarrays are represented by horizontal coordinates, and values of relative phases corresponding to the subarrays are represented by vertical coordinates. The relative phases corresponding to the 5 subarrays are [-2.5257, -0.6314, 0, -0.6314, -2.5257] respectively. That is, the phase corresponding to subarray 3 is used as a reference for the relative phases, whose relative phase is 0. As depicted, subarray 3 has the largest phase, which means that subarray 3 is the closest subarray to the UE. In an embodiment, these relative phases may be quantized using a quantization scheme such as 16PSK or 32PSK and transmitted in a CSI report.

[0099] In some other embodiments, the UE may transmit the phase values in another form, for example, $-\mathrm{P}^* = [2.5257, 0.6314, 0, 0.6314, 2.5257]$ may be included in the CSI report.

[0100] In some embodiments, the BS may transmit a CSI report configuration to the UE, for example, via an RRC configuration message (e.g., *CSI-ReportConfig* as specified in 3GPP standard documents) or other messages. The CSI report configuration may be associated with the plurality of DL RS resource sets configured for DL RS transmission, and may indicate that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase of the DL RS on the strongest DL RS resource.

[0101] According some embodiments of the present disclosure, a CSI report format may be designed as follows:

CSI field	bitwidth
CRI#1	$\lceil \log_2(K_s^1) \rceil$
CRI#2	$\lceil \log_2(K_s^2) \rceil$
…	…
CRI#K	$\lceil \log_2(K_s^K) \rceil$
Phase#1	$\lceil \log_2 N \rceil$
Phase#2	$\lceil \log_2 N \rceil$
…	
Phase#K	$\lceil \log_2 N \rceil$

[0102] In the above table, CRI#k may be the CRI of the strongest DL RS resource for subarray k, K_s^k is the total number of DL RS resources in DL RS resource set k, and the bitwidth for CRI#k is $\lceil \log_2(K_s^k) \rceil$; Phase#$k$ may be the corresponding phase of DL RS on the strongest DL RS resource for subarray k, the bidwidth for Phase#k is $\lceil \log_2 N \rceil$ for N-PSK quantization, and $k \in \{1,2,\dots,K\}$.

[0103] The BS may receive the CSI report from the UE, which indicates k^* and ρ_{k^*} for subarray k, $k \in \{1,2,\dots,K\}$. Then the BS may determine the beamforming vector associated with DL RS resource k^* in DL RS resource set k for subarray k.

[0104] The beamforming vector for subarray k may be:

$$V_{k^*}{}^{o} = \frac{1}{\sqrt{2M+1}} \begin{bmatrix} e^{(-M)\, i\phi_{k^*}} \\ \vdots \\ e^{(-m)\, i\phi_{k^*}} \\ \vdots \\ e^{(M)\, i\phi_{k^*}} \end{bmatrix}$$

[0105] The BS may transmit a DL transmission to the UE from the K subarrays using a subarray-based MRC scheme as follows, i.e., for each subarray used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied:

$$V_{k^*}{}^{MRC} = e^{-i\rho_{k^*}} V_{k^*}{}^{o}, 1 \le k \le K$$

[0106] In some embodiments, the DL transmission is a transmission of a new CSI-RS on a single CSI-RS resource using all subarrays of the antenna array. For example, the new CSI-RS may be a TRS for the UE to perform time and frequency tracking for the antenna array. In some embodiments, assuming that the entire array is driven by a single time domain resource or a single frequency resource, the UE may use the TRS to track the time and frequency deviation of the entire array.

[0107] As can be seen, based on the CSI report feedback by the UE, the BS may determine which beamforming vector to use, and construct the transmission phase for each subarray and for each antenna elements of the subarray.

[0108] Figure 5 illustrates transmitting phase (denoted as subarray MRC) for antenna elements in an antenna array constructed based on the received CSI report according to a subarray-based MRC scheme in accordance with aspects of the present disclosure.

[0109] The antenna array may include a total number of 405 antenna elements, which are indexed from -202 to 202, and are partitioned into 5 subarrays, wherein each subarray includes 81 antenna elements. The indices of antenna elements in a first subarray may range from -202 to -122; the indices of antenna elements in a second subarray may range from -121 to -41; the indices of antenna elements in a third subarray may range from -40 to 40; the indices of antenna elements in a fourth subarray may range from 41 to 121; and the indices of antenna elements in a fifth subarray may range from 122 to 202.

[0110] The indices of the antenna elements are represented by horizontal coordinates, and the transmitting phases of the antenna elements are represented by vertical coordinates. Figure 5 also shows transmitting phase for the antenna elements constructed based on the ideal MRC scheme (denoted as ideal beamforming) for reference. It can be seen that the transmitting phases constructed based on the ideal MRC scheme and the transmitting phases constructed based on the subarray-based MRC scheme are similar.

[0111] Figure 6 illustrates a comparison between a beam pattern of a DL transmission with a subarray-based MRC scheme and an ideal beamforming pattern in accordance with aspects of the present disclosure.

[0112] As can be been, the two beam patterns are very close to each other, which suggests that the subarray-based DFT beamforming may concentrate the DL signal to the UE as well as the ideal MRC scheme.

[0113] Figure 7 illustrates an example of a UE 700 in accordance with aspects of the present disclosure. The UE 700 may include at least one processor 702 and at least one memory 704. Additionally, the UE 700 may also include one or more of at least one controller 706 and 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.

[0114] 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.

[0115] 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 UE 700 to perform various functions of the present disclosure.

[0116] 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 UE 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.

[0117] In some implementations, the processor 702 and the memory 704 coupled with the processor 702 may be configured to cause the UE 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 UE 700 in accordance with examples as disclosed herein. The UE 700 may be configured to support a means for performing the operations of the methods described in the embodiments of the present disclosure.

[0118] In an embodiment, the processor 702 may be configured to cause the UE 700 to: receive, from a BS, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmit, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0119] The controller 706 may manage input and output signals for the UE 700. The controller 706 may also manage peripherals not integrated into the UE 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.

[0120] In some implementations, the UE 700 may include at least one transceiver 708. In some other implementations, the UE 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.

[0121] 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.

[0122] 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.

[0123] 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 a 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, an L1/L2/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).

[0124] 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).

[0125] 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.

[0126] 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, arithmetic logic units (ALUs), and other functional units of the processor 800.

[0127] 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).

[0128] 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.

[0129] 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.

[0130] 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.

[0131] In an embodiment, the processor 800 may be applicable for a UE or a device with similar functions. The controller 802 may be configured to cause the processor 800 to: receive, from a BS, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and transmit, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource..

[0132] In an embodiment, the processor 800 may be applicable for an NE (e.g., a base station) or a device with similar functions. The controller 802 may be configured to cause the processor 800 to: transmit, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and receive, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0133] Figure 9 illustrates an example of an NE 900 (e.g., a BS) in accordance with aspects of the present disclosure. The NE 900 may include at least one processor 902 and at least one memory 904. Additionally, the NE 900 may also include one or more of at least one controller 906 and 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.

[0134] 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.

[0135] 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 NE 900 to perform various functions of the present disclosure.

[0136] 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 NE 900 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such 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.

[0137] In some implementations, the processor 902 and the memory 904 coupled with the processor 902 may be configured to cause the NE 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 NE 900 in accordance with examples as disclosed herein. The NE 900 may be configured to support a means for performing the operations of the methods described in the embodiments of the present disclosure.

[0138] In an embodiment, the processor 902 may be configured to cause the NE 900 to: transmit, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and receive, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

[0139] The controller 906 may manage input and output signals for the NE 900. The controller 906 may also manage peripherals not integrated into the NE 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.

[0140] In some implementations, the NE 900 may include at least one transceiver 908. In some other implementations, the NE 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.

[0141] 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.

[0142] 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.

[0143] Figure 10 illustrates a flowchart of an exemplary method in accordance with aspects of the present disclosure. The operations of the method may be implemented by a UE as described herein. In some implementations, the UE may execute a set of instructions to control the function elements of the UE to perform the described functions.

[0144] At 1002, the method may include receiving, from a BS, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set. The operations of 1002 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1002 may be performed by a UE as described with reference to Figure 7. In some embodiments, the DL RSs may be CSI-RSs, and the plurality of DL RS resource sets may be a plurality of CSI-RS resource sets.

[0145] At 1004, the method may include transmitting, to the BS, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource. The operations of 1004 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1004 may be performed by a UE as described with reference to Figure 7.

[0146] In some embodiments, different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

[0147] In some embodiments, each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource.

[0148] In some embodiments, the method may further include receiving, from the BS, configuration information indicating the plurality of DL RS resource sets.

[0149] In some embodiments, the method may further include receiving, from the BS, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

[0150] In some embodiments, each corresponding phase indicated by the CSI report is a phase offset relative to one of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report.

[0151] In some embodiments, the one is a largest received phase among all the DL RSs on the strongest DL RS resources indicated by the CSI report.

[0152] In some embodiments, the corresponding phases indicated by the CSI report are quantized.

[0153] In some embodiments, the method may further include receiving, from the BS, a DL transmission with a subarray-based MRC scheme based on the CSI report, in which for each subarrary used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied.

[0154] In some embodiments, the DL transmission is a transmission of a CSI-RS on a single CSI-RS resource using all subarrays of the antenna array.

[0155] In some embodiments, the CSI-RS is a TRS for the UE to perform time and frequency tracking of the antenna array.

[0156] It should be noted that the method described herein describes a possible implementation, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible.

[0157] Figure 11 illustrates a flowchart of an exemplary method in accordance with aspects of the present disclosure. The operations of the method may be implemented by an NE (e.g., a BS) as described herein. In some implementations, the NE may execute a set of instructions to control the function elements of the NE to perform the described functions.

[0158] At 1102, the method may include transmitting, to a UE, DL RSs on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors. The operations of 1102 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1102 may be performed by an NE as described with reference to Figure 9.

[0159] At 1104, the method may include receiving, from the UE, a CSI report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource. The operations of 1104 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 1104 may be performed by an NE as described with reference to Figure 9.

[0160] In some embodiments, the DL RSs on all DL RS resources in the plurality of DL RS resource sets are transmitted with a common phase offset.

[0161] In some embodiments, the common phase offset is zero.

[0162] In some embodiments, different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

[0163] In some embodiments, each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource.

[0164] In some embodiments, the method may further include transmitting, to the UE, configuration information indicating the plurality of DL RS resource sets.

[0165] In some embodiments, the method may further include transmitting, to the UE, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

[0166] In some embodiments, each corresponding phase indicated by the CSI report is a phase offset relative to one of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report.

[0167] In some embodiments, the one is a largest received phase among all the DL RSs on the strongest DL RS resources indicated by the CSI report.

[0168] In some embodiments, the corresponding phases indicated by the CSI report are quantized.

[0169] In some embodiments, the method may further include transmitting, to the UE, a DL transmission with a subarray-based MRC scheme based on the CSI report, in which for each subarrary used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied.

[0170] In some embodiments, the DL transmission is a transmission of a CSI-RS on a single CSI-RS resource using all subarrays of the antenna array.

[0171] In some embodiments, the CSI-RS is a TRS for the UE to perform time and frequency tracking for the antenna array.

[0172] It should be noted that the method described herein describes a possible implementation, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible.

[0173] 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:

transmit, to a user equipment (UE), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and

receive, from the UE, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

2. The BS of claim 1, wherein the DL RSs on all DL RS resources in the plurality of DL RS resource sets are transmitted with a common phase offset.

3. The BS of claim 2, wherein the common phase offset is zero.

4. The BS of claim 1, wherein different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

5. The BS of claim 1, wherein each DL RS resource in the plurality of DL RS resource sets is a single-port DL RS resource.

6. The BS of claim 1, wherein the at least one processor is further configured to cause the BS to:

transmit, to the UE, configuration information indicating the plurality of DL RS resource sets.

7. The BS of claim 6, wherein the at least one processor is further configured to cause the BS to:

transmit, to the UE, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

8. The BS of claim 1, wherein each corresponding phase indicated by the CSI report is a phase offset relative to one of the received phases of DL RSs on the strongest DL RS resources indicated by the CSI report.

9. The BS of claim 8, wherein the one is a largest received phase among all the DL RSs on the strongest DL RS resources indicated by the CSI report.

10. The BS of claim 1, wherein the corresponding phases indicated by the CSI report are quantized.

11. The BS of claim 1, wherein the at least one processor is further configured to cause the BS to:

transmit, to the UE, a DL transmission with a subarray-based maximal ratio combining (MRC) scheme based on the CSI report, in which for each subarrary used for the DL transmission, a beamforming vector associated with the strongest DL RS resource in the DL RS resource set associated with the subarray indicated by the CSI report and the corresponding phase for the DL RS resource set associated with the subarray indicated by the CSI report are applied.

12. The BS of claim 11, wherein the DL transmission is a transmission of a CSI-RS on a single CSI-RS resource using all subarrays of the antenna array.

13. The BS of claim 12, wherein the CSI-RS is a tracking RS (TRS) for the UE to perform time and frequency tracking for the antenna array.

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, from a base station (BS), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and

transmit, to the BS, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

15. The UE of claim 14, wherein the at least one processor is further configured to cause the UE to:

perform measurement of DL RSs on all DL RS resources in the plurality of DL RS resource sets to determine the strongest DL RS resource and the corresponding phase for each DL RS resource set.

16. The UE of claim 14, wherein different DL RS resources in a same DL RS resource set do not overlap in time domain, and different DL RS resources in different DL RS resource sets are associated with a same time-domain resource or different time-domain resources.

17. The UE of claim 14, wherein the at least one processor is further configured to cause the UE to:

receive, from the BS, configuration information indicating the plurality of DL RS resource sets.

18. The UE of claim 17, wherein the at least one processor is further configured to cause the UE to:

receive, from the BS, a CSI report configuration associated with the plurality of DL RS resource sets, wherein the CSI report configuration indicates that a CSI report based on measurement of DL RSs on the plurality of DL RS resource sets indicates, for each DL RS resource set in the plurality of DL RS resource sets, the index of the strongest DL RS resource in the DL RS resource set and the corresponding phase.

19. A processor for wireless communication, comprising:

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

transmit, to a user equipment (UE), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs transmitted on different DL RS resources in the DL RS resource set are transmitted by the respective subarray associated with the DL RS resource set using different beamforming vectors; and

receive, from the UE, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

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, from a base station (BS), downlink (DL) reference signals (RSs) on a plurality of DL RS resource sets, wherein each DL RS resource set is associated with a respective subarray of an antenna array, and for each DL RS resource set, DL RSs on different DL RS resources in the DL

RS resource set are associated with different beamforming vectors applied to the respective subarray associated with the DL RS resource set; and

transmit, to the BS, a channel state information (CSI) report indicating, for each DL RS resource set in the plurality of DL RS resource sets, an index of a strongest DL RS resource in the DL RS resource set and a corresponding phase, wherein the DL RS of the strongest DL RS resource has a highest received strength among DL RSs on all DL RS resources in the DL RS resource set, and the corresponding phase corresponds to a received phase of the DL RS on the strongest DL RS resource.

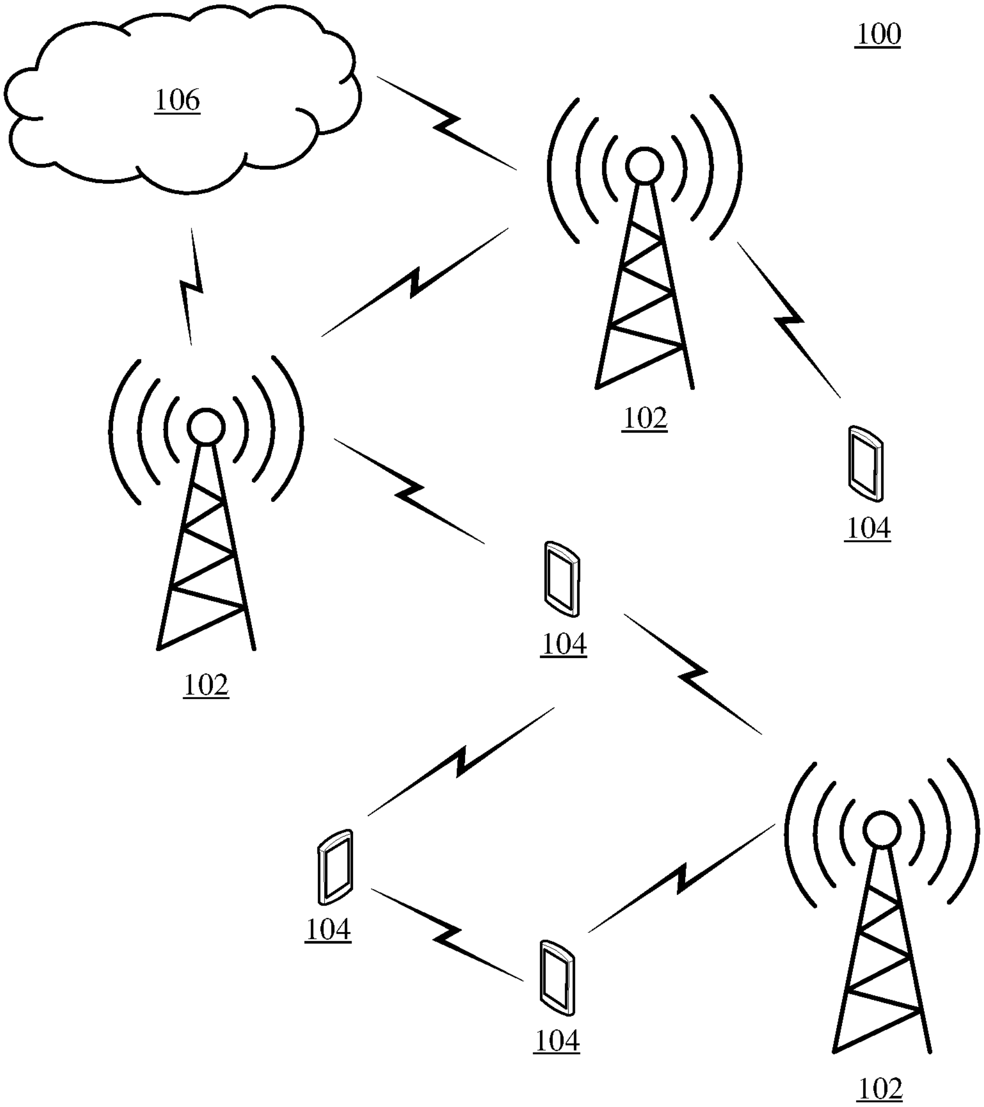
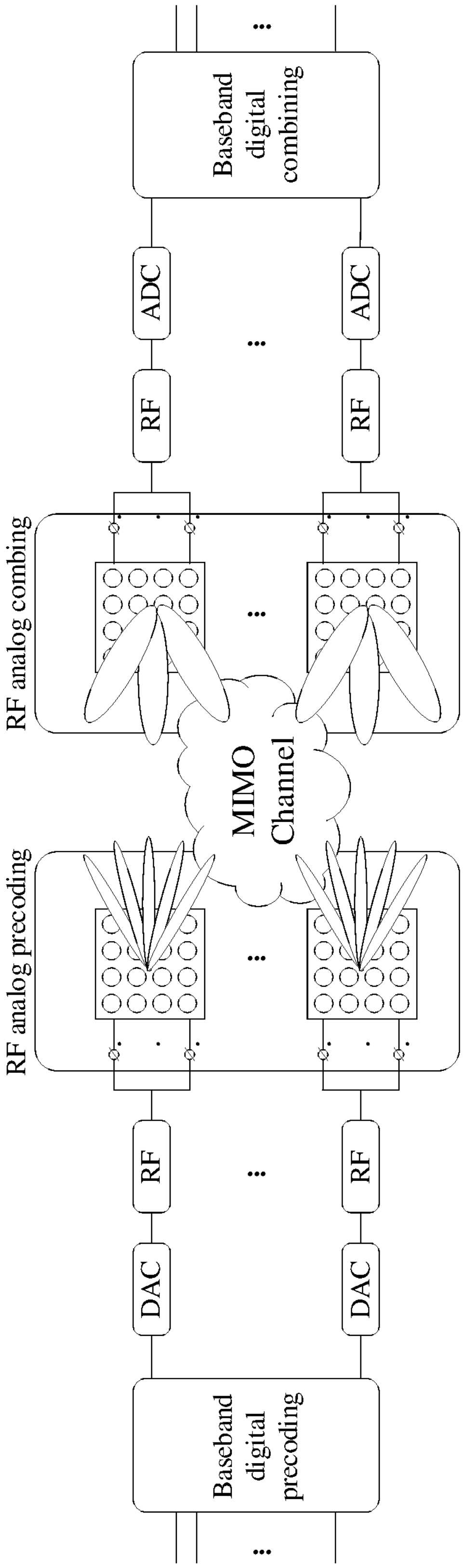


Figure 1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DAC
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RF
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RF
RF
ADC
ADC
Baseband digital combining

Figure 2

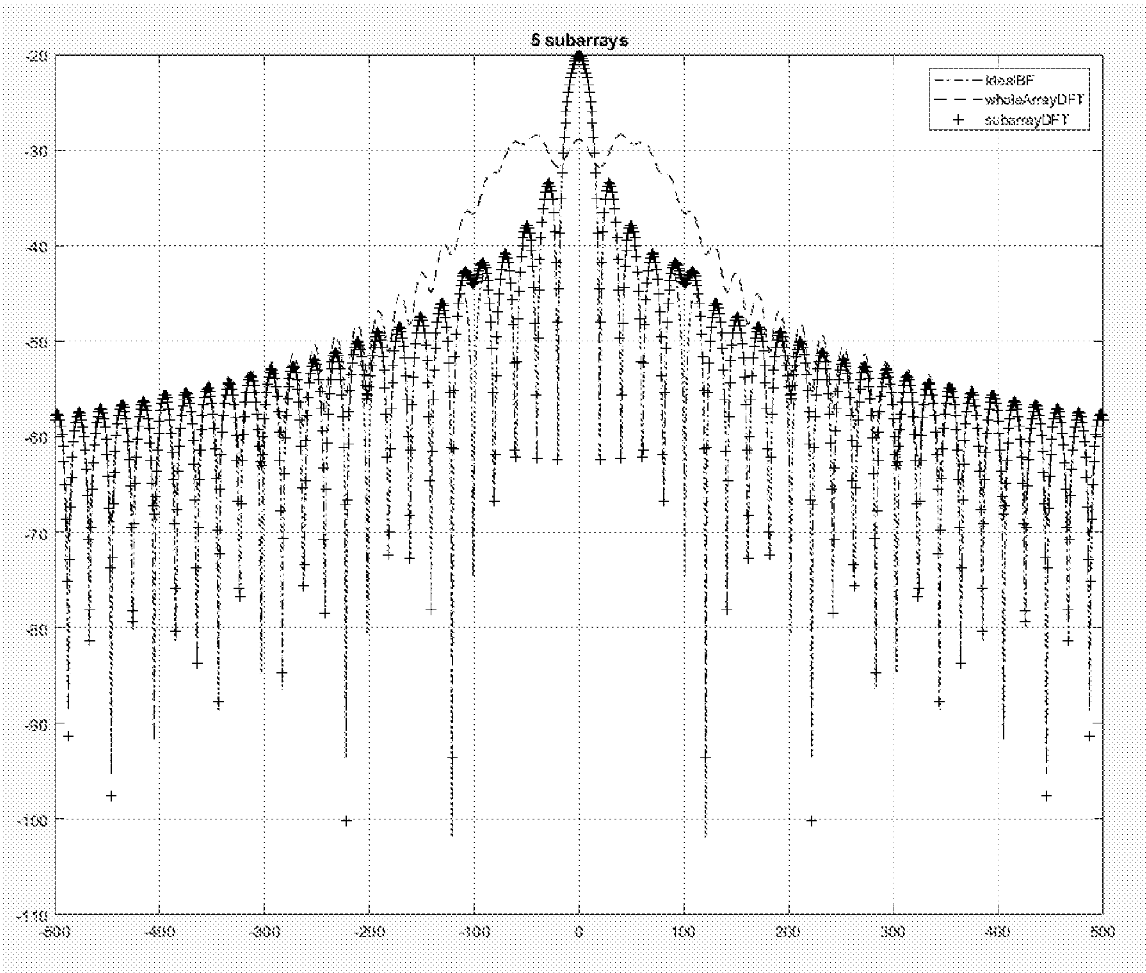
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Figure 3A

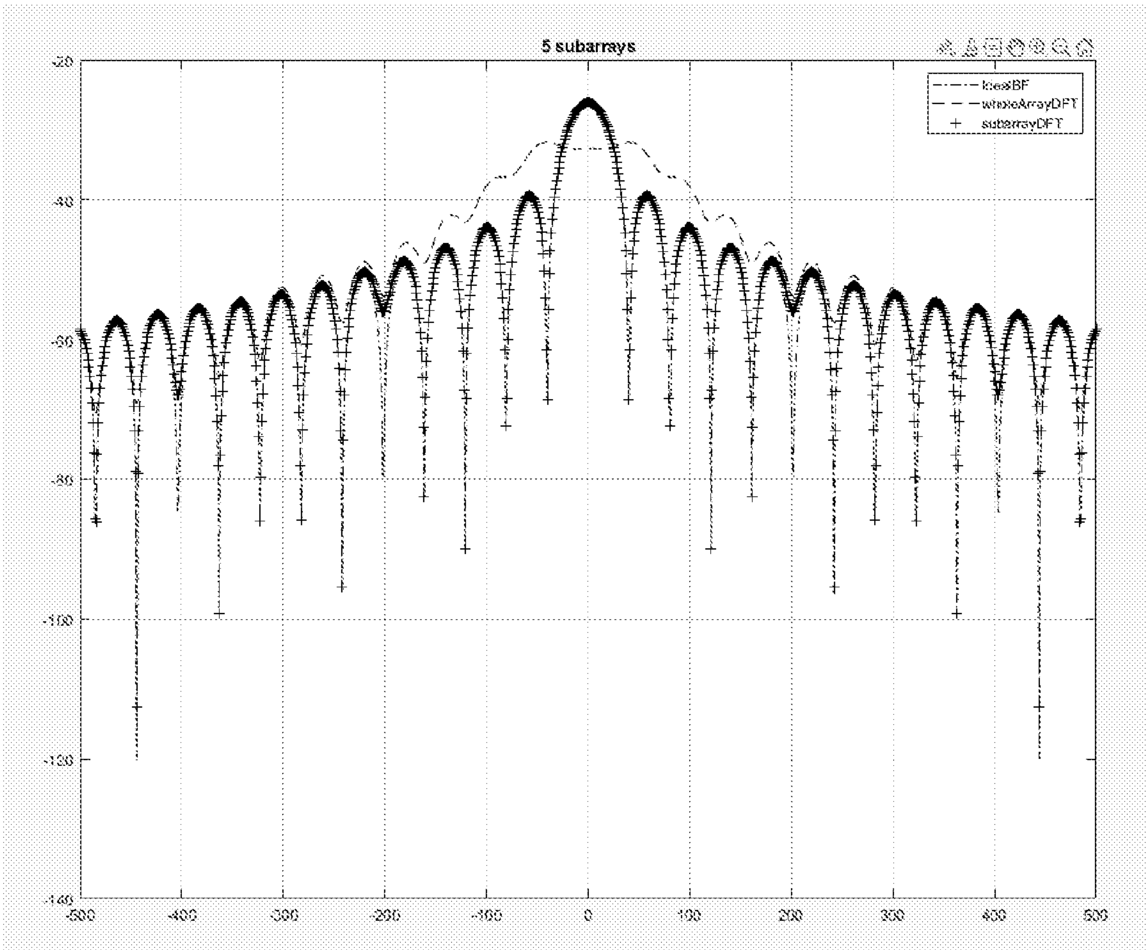
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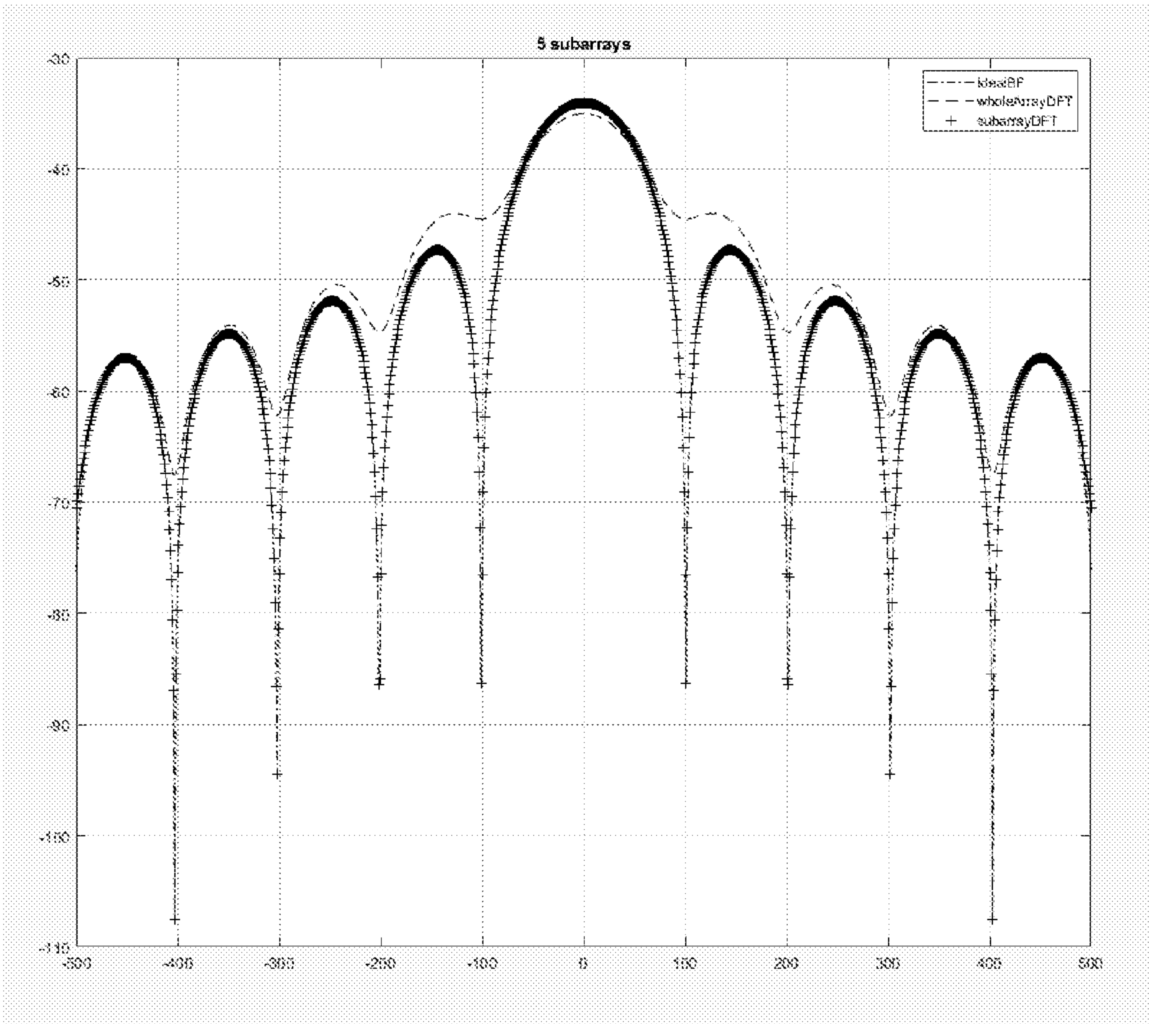
Figure 3B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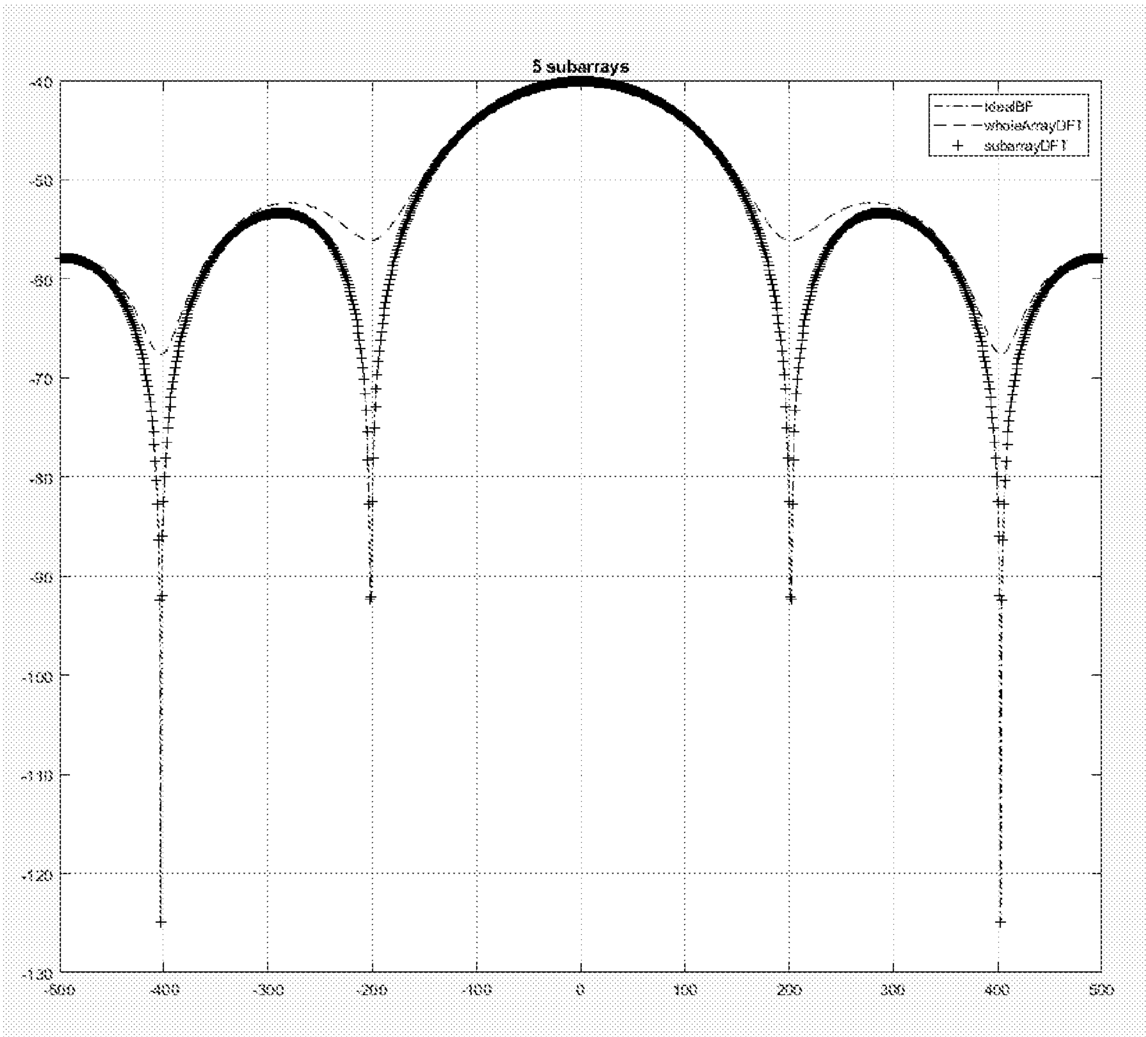
400
500

Figure 3C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-400
-300
-200
-100
0
100
200
300
400
500

Figure 3D

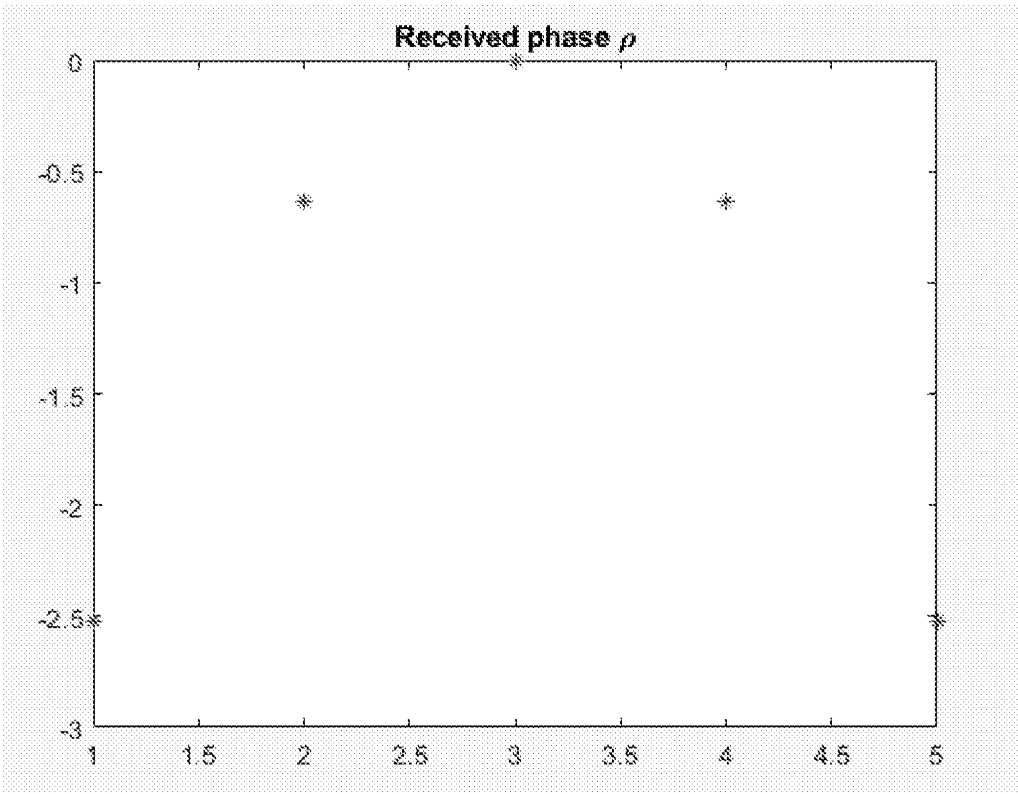

Figure 4

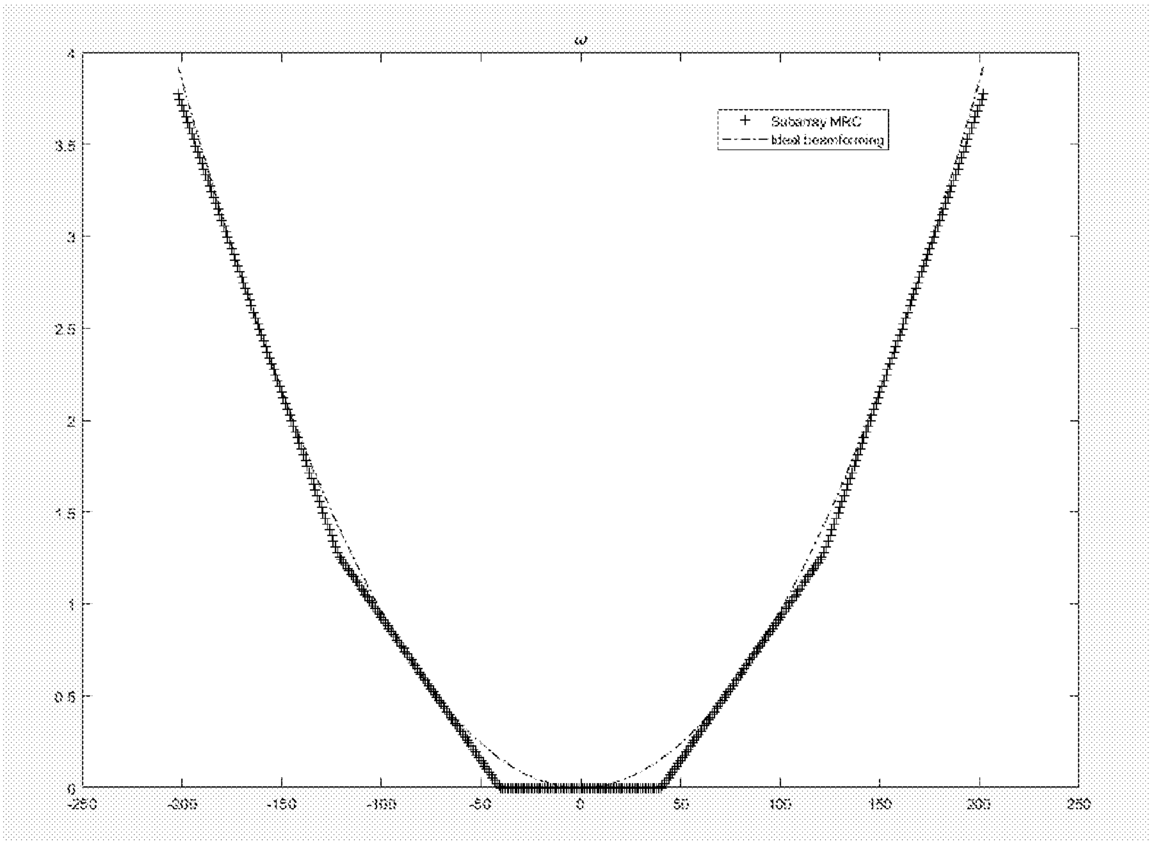
ω
Subarray MRC
Ideal beamforming
4
3.5
3
2.5
2
1.5
1
0.5
0
-250
-200
-150
-100
-50
0
50
100
150
200
250

Figure 5

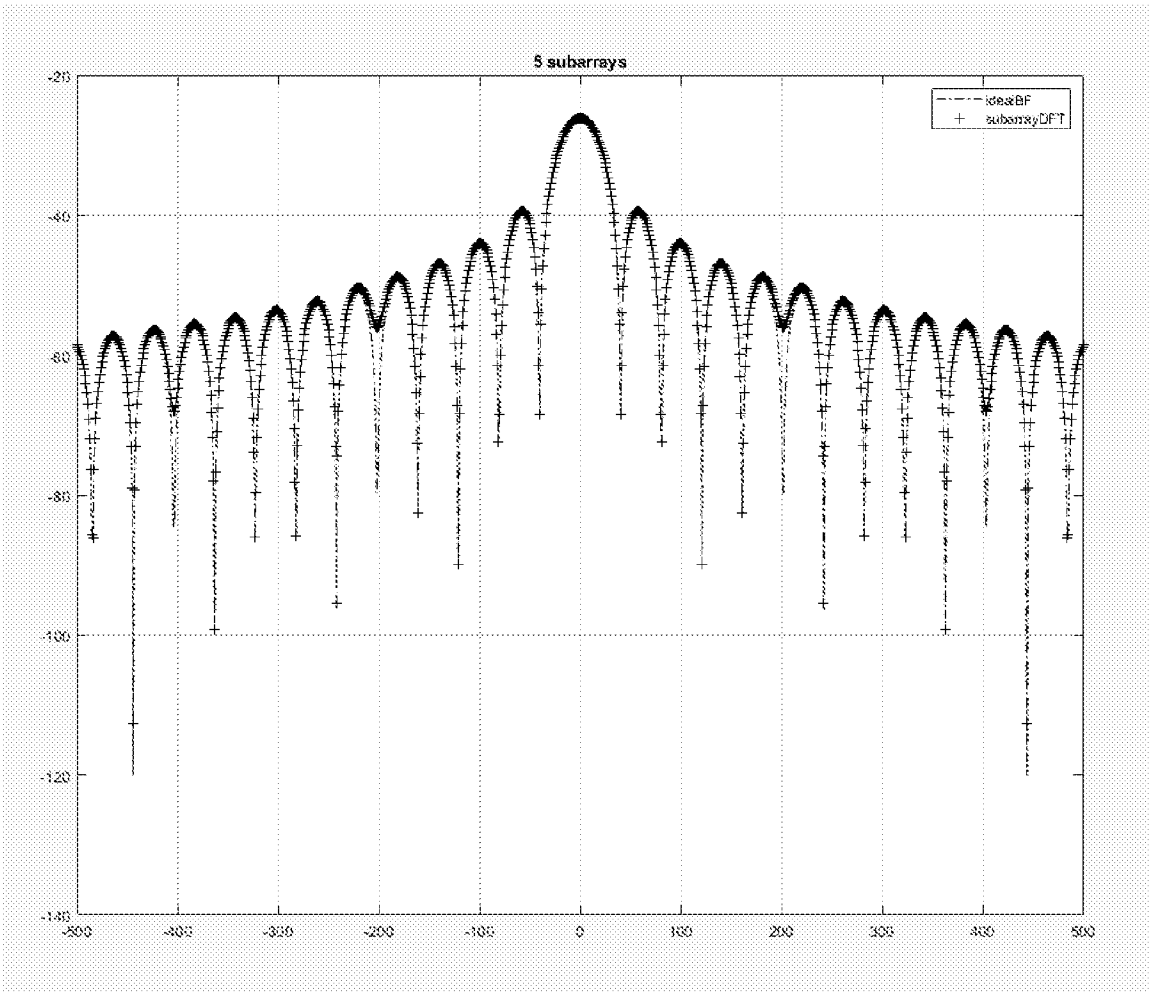
5 subarrays
idealBF
subarrayDFT
-20
-40
-60
-80
-100
-120
-140
-500
-400
-300
-200
-100
0
100
200
300
400
500

Figure 6

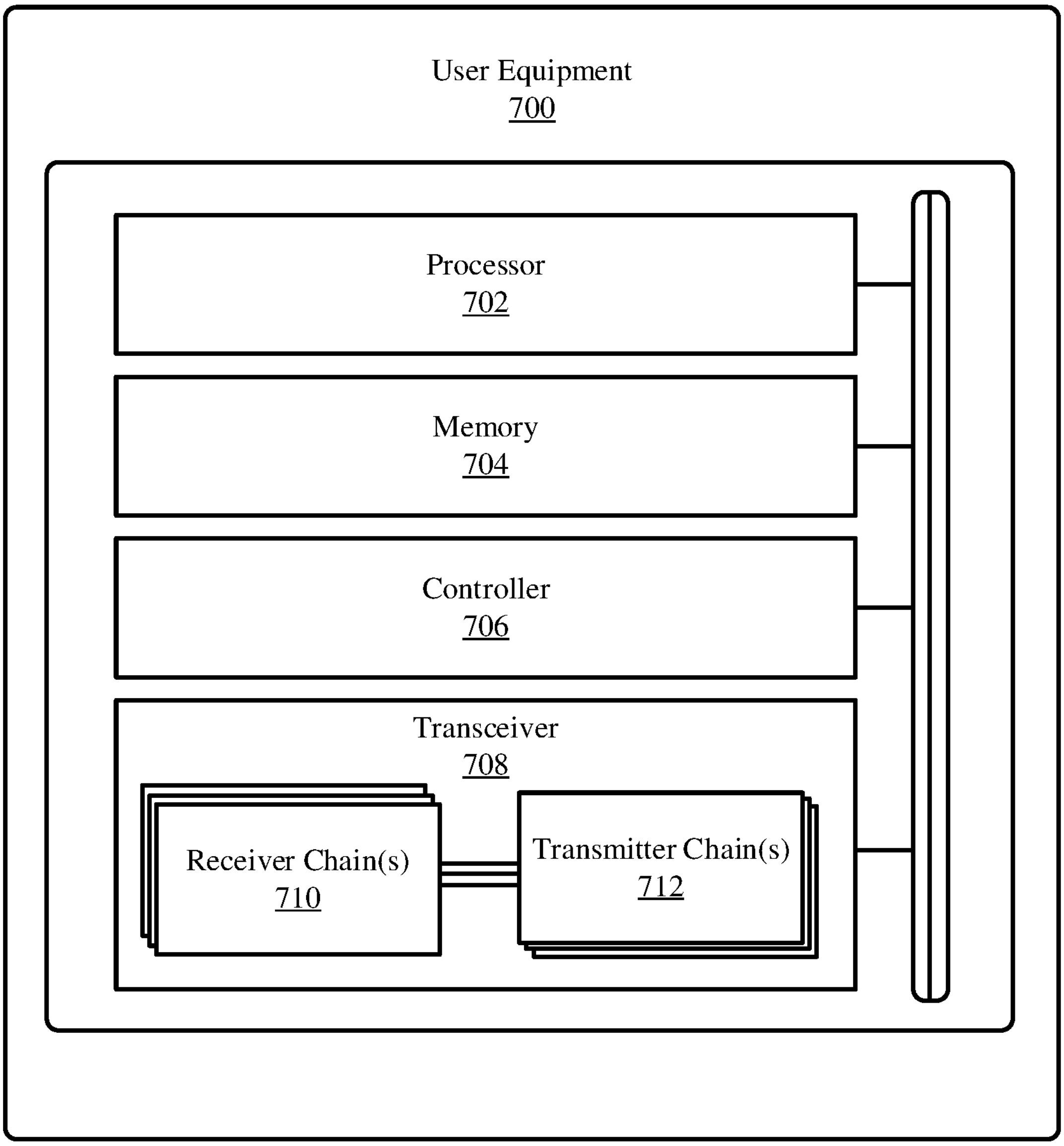
User Equipment
700
Processor
702
Memory
704
Controller
706
Transceiver
708
Receiver Chain(s)
710
Transmitter Chain(s)
712

Figure 7

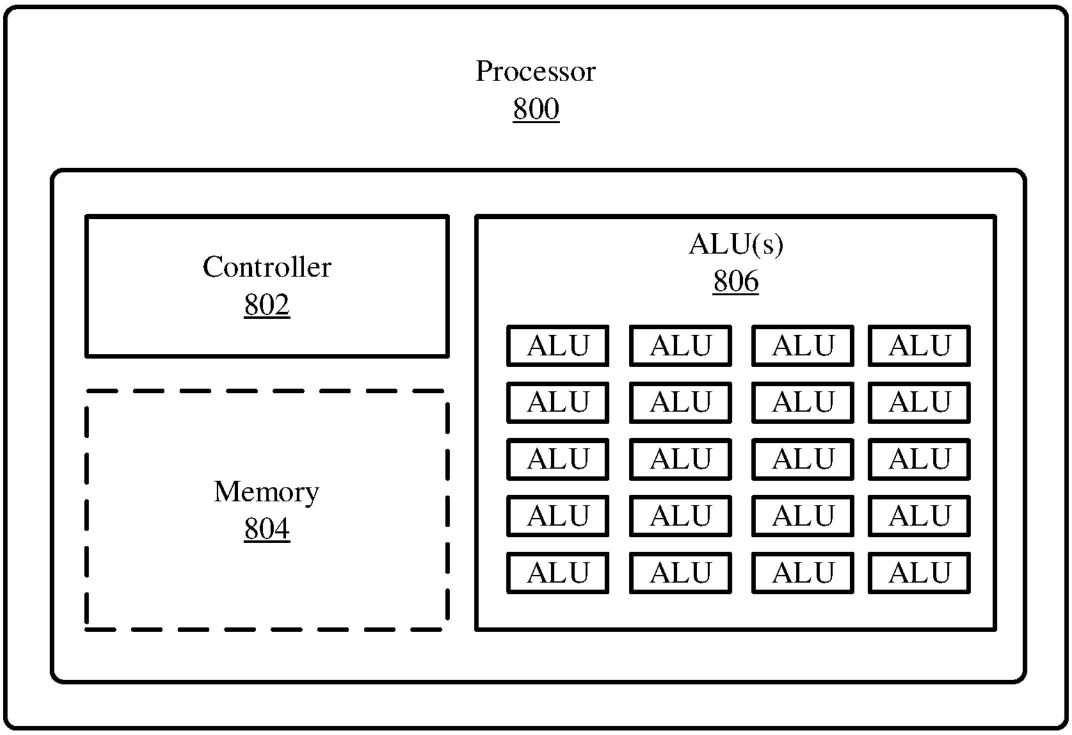
Processor
800
Controller
802
Memory
804
ALU(s)
806
ALU ALU ALU ALU
ALU ALU ALU ALU
ALU ALU ALU ALU
ALU ALU ALU ALU
ALU ALU ALU ALU

Figure 8

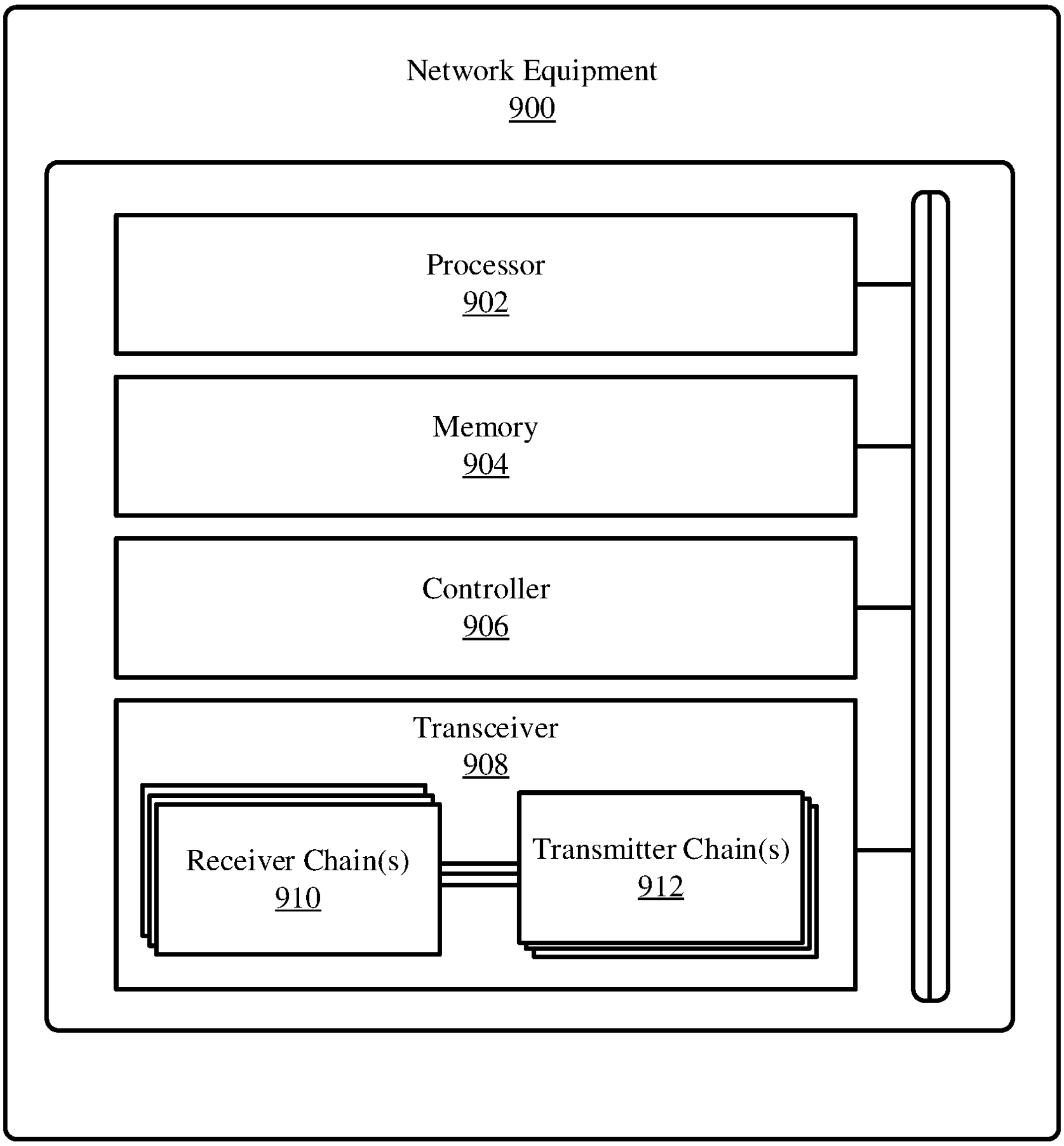
Network Equipment
900
Processor
902
Memory
904
Controller
906
Transceiver
908
Receiver Chain(s)
910
Transmitter Chain(s)
912

Figure 9

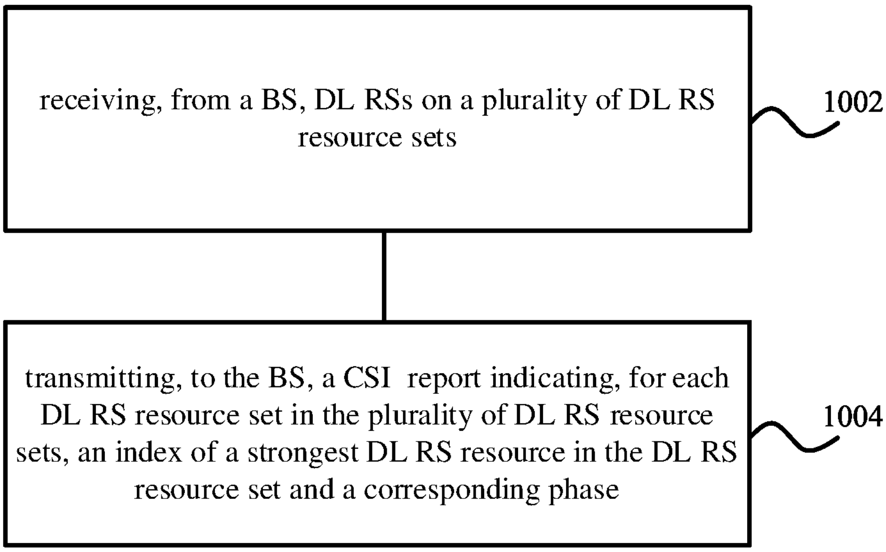

Figure 10

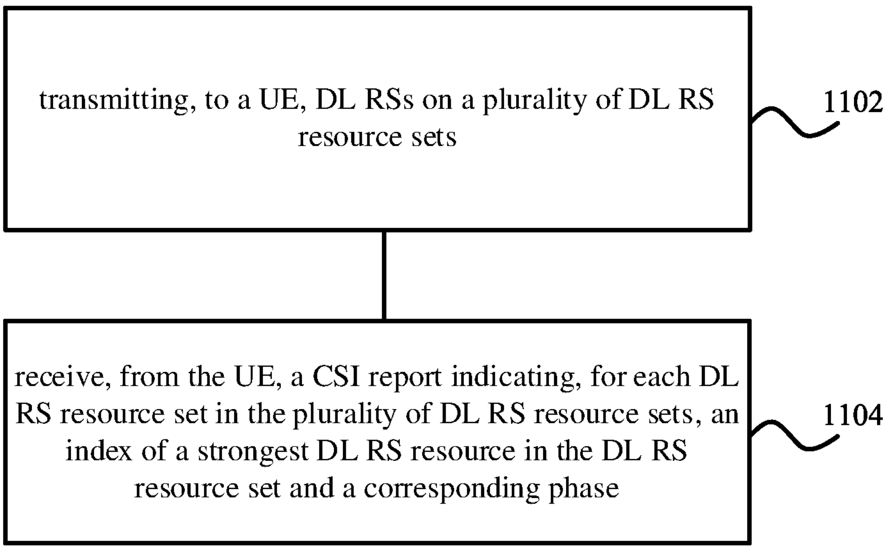

Figure 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2024/076670

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/23(2023.01)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:H04W,H04L,H04B

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)

3GPP,VEN,DWPI,ENTXT,CNTXT,ENTXTC:array,CSI,id,index,intensity,peak,phase,report,RS,RSRP,strongest,max+,reference signal,value,beam??,measure.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2023184135 A1 (QUALCOMM INCORPORATED et al.) 05 October 2023 (2023-10-05) description,paragraphs[0007]-[0050],paragraphs[0088]-[0150],paragraphs[0198]-[0268]	1-20
X	WO 2022152832 A1 (TELEFONAKTIEBOLAGET LM ERICSSON(PUBL)) 21 July 2022 (2022-07-21) description,page 13 paragraph 6-page 28 paragraph 2	1-20
A	US 2020403746 A1 (QUALCOMM INCORPORATED) 24 December 2020 (2020-12-24) the whole document	1-20
A	US 2023188229 A1 (QUALCOMM INCORPORATED) 15 June 2023 (2023-06-15) the whole document	1-20
A	LENOVO et al. "CSI enhancements for multi-TRP and FDD reciprocity" *3GPP TSG RAN WG1 #104bis-e R1-2103607,* 20 April 2021 (2021-04-20), 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	Date of mailing of the international search report
28 October 2024	**31 October 2024**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**MENG,WeiZhi** Telephone No. **(+86) 010-53961614**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2024/076670

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2023184135	A1	05 October 2023	IN	202427052335	A	09 August 2024
WO	2022152832	A1	21 July 2022	EP	4278474	A1	22 November 2023
				JP	2024503682	A	26 January 2024
				US	2024056247	A1	15 February 2024
				CN	116783840	A	19 September 2023
US	2020403746	A1	24 December 2020	WO	2020257081	A1	24 December 2020
US	2023188229	A1	15 June 2023	EP	4165895	A1	19 April 2023
				WO	2021248397	A1	16 December 2021
				CN	115699861	A	03 February 2023
				IN	202247060027	A	28 October 2022