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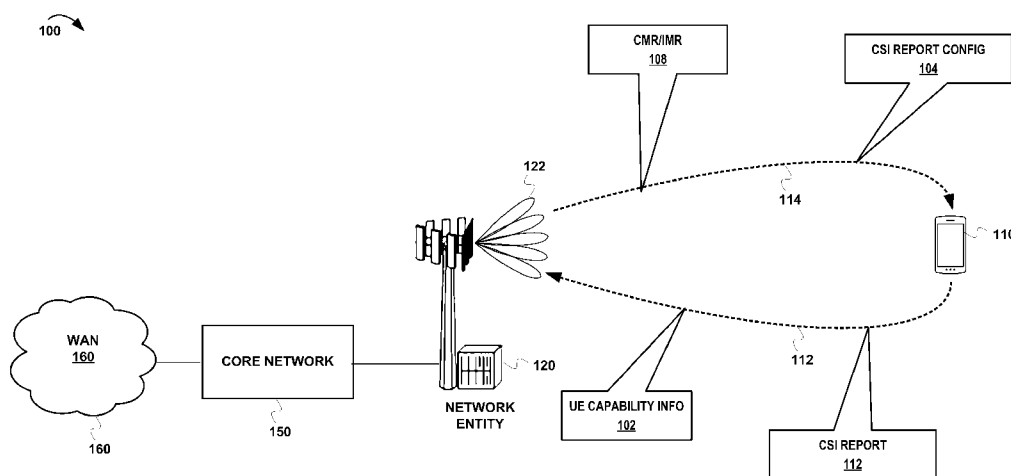


FIGURE 1

(57) Abstract: Systems, methods and apparatuses provide channel state information (CSI) feedback based on one or more codebooks and power backoff values corresponding to the codebooks. A user equipment (UE) (110) receives (404), from a network entity (120), at least one channel state information (CSI) report configuration including codebook entities, one or more power relationship indicators indicating a power relationship between a physical downlink shared channel (PDSCH) and a CSI reference signal (CSI-RS) for each codebook entity, and one or more channel measurement resources (CMRs) associated with the CSI-RS. The UE receives (408) one or more CMRs from the network entity. The UE transmits (412), to the network entity, at least one CSI report based on the at least one CSI report configuration and the one or more CMRs.

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CSI FEEDBACK BASED ON CODEBOOKS ASSOCIATED WITH POWER BACKOFF VALUES

TECHNICAL FIELD

[0001] Aspects of the present disclosure relate generally to wireless communication and techniques for providing channel state information (CSI) feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

BACKGROUND

[0002] Multiple-Input Multiple-Output (MIMO) techniques can improve the reliability and efficiency of communications between a UE and a network entity. MIMO technology employs multiple antennas at both the network entity and the UE to concurrently transmit and receive multiple spatial streams. MIMO may be used to improve data throughput, increase spectral efficiency, and enhance overall network performance. Beamforming is another technique that can enhance the signal quality between a network entity and a UE thereby improving data rates, reducing latency, and increasing overall network performance. In beamforming, the transmitter directs radio frequency (RF) transmission towards a specific direction (e.g., towards an intended receiver), creating a "beam" of focused energy, rather than radiating the signal in all directions equally.

[0003] The network entity and the UE can cooperate to determine appropriate operating parameters for MIMO and beamforming operation. For example, the network entity can provide a reference signal referred to as channel state information reference signal (CSI-RS) to the UE. The UE can measure various characteristics of the CSI-RS and provide channel state information (CSI) feedback to the network entity based on the measured characteristics. The network entity can use the CSI feedback to adjust transmission parameters to optimize MIMO and beamforming operation.

BRIEF SUMMARY

[0004] The systems, methods, and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0005] One innovative aspect of the subject matter described in this disclosure can be implemented as a method for wireless communications by a user equipment. The method may include receiving, from a network entity, at least one channel state information (CSI) report configuration, the at least one CSI report configuration including: a plurality of codebook entities, one or more power relationship indicators indicating a power relationship between a physical downlink shared

channel (PDSCH) and a CSI reference signal (CSI-RS) for each codebook entity of the plurality of codebook entities, and one or more channel measurement resources (CMRs) associated with the CSI-RS. The method may further include receiving, from the network entity, the one or more CMRs. The method may further include transmitting, to the network entity, at least one CSI report based on the at least one CSI report configuration and the one or more CMRs.

[0006] Another innovative aspect of the subject matter described in this disclosure can be implemented as a method for wireless communications by a network entity. The method may include transmitting, to a user equipment (UE), at least one channel state information (CSI) report configuration, the at least one CSI report configuration including: a plurality of codebook entities, one or more power relationship indicators indicating a power relationship between a physical downlink shared channel (PDSCH) and a CSI reference signal (CSI-RS) for each codebook entity of plurality of codebook entities, and one or more channel measurement resources (CMRs) associated with the CSI-RS. The method may further include transmitting, to the UE, the one or more CMRs. The method may further include receiving, from the UE, at least one CSI report based on the at least one CSI report configuration and the one or more CMRs.

[0007] Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Note that the relative dimensions of the following figures may not be drawn to scale. Like reference numbers and designations in the various drawings indicate like elements. To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

[0009] **Figure 1** is a diagram illustrating an example wireless system including a user equipment communicating with a network entity.

[0010] **Figure 2** is a block diagram illustrating example configurations of a network entity and a user equipment.

[0011] **Figure 3A** is a diagram illustrating an antenna port configuration for PDSCH transmission using a type 1 precoder.

[0012] **Figure 3B** is a diagram illustrating an antenna port configuration for PDSCH transmission using a type 2 precoder.

[0013] **Figure 4A** is a sequence diagram illustrating example operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks where the UE selects a codebook.

[0014] **Figure 4B** is a sequence diagram illustrating example operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks where the UE provides multiple CSIs to the network entity.

[0015] **Figure 5** is a flow chart diagram illustrating example UE operations of a method for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

[0016] **Figure 6** is a flow chart diagram illustrating example network entity operations of a method for receiving CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

[0017] **Figure 7** is a diagram illustrating an example of CSI feedback with waveform and power backoff aware codebooks.

[0018] **Figure 8** is a diagram illustrating an example of CSI feedback with waveform and power backoff aware codebook subsets.

[0019] **Figure 9** is a diagram illustrating an example of CSI feedback with waveform specific codebook and power backoff aware codebook subsets.

[0020] **Figure 10** is a diagram illustrating an example UE selected codebook for CSI feedback.

[0021] **Figure 11** is a diagram illustrating an example CSI report with separate CSIs for configured codebooks.

[0022] **Figure 12** is a diagram illustrating an example CSI report with a common RI for configured codebooks.

[0023] **Figure 13** is a diagram illustrating an example CSI report with RI or PMI for configured codebooks.

DETAILED DESCRIPTION

[0024] The following description is directed to certain implementations for the purpose of describing the innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. Some of the examples in this disclosure are based on wireless communication according to the 3rd Generation Partnership Project (3GPP) wireless standards, such as the 4th generation (4G) Long Term Evolution (LTE) and 5th generation (5G) New Radio (NR) standards. However, the described implementations can be implemented in any device, system, or network that is capable of transmitting and receiving radio frequency signals according to any of the wireless communication standards, including any of the Institute of Electrical and Electronics Engineers (IEEE) 802.11, 802.15, or 802.16 wireless standards, or other known signals that are used to

communicate within a wireless, cellular, or internet of things (IOT) network, such as a system utilizing 3G, 4G, 5G, WiFi or future radio technology.

[0025] As noted above, MIMO techniques can improve the reliability and efficiency of communications between a UE and a network entity. In systems that implement MIMO, channel state information (CSI) can provide information that a network entity can use to select a digital precoder for use when communicating with a UE. In some aspects, the network entity can configure a CSI report using RRC signaling, e.g., *CSI-ReportConfig*, where a channel state information reference signal (CSI-RS) is used as channel measurement resource (CMR) for the UE to measure the downlink channel. In some aspects, the network entity may configure an interference measurement resource (IMR) for UE to measure interference.

[0026] The network entity and the UE can cooperate to determine appropriate operating parameters for MIMO and beamforming operation. For example, the UE may identify the CSI based on the configured CMR and IMR (if IMR is available). The CSI may include at least one of a rank indicator (RI), a precoder matrix indicator (PMI), a channel quality indicator (CQI) and layer indicator (LI). RI and PMI are used to indicate the digital precoder, CQI is used to indicate the signal-to-interference plus noise (SINR) status in order to assist the network entity to determine the modulation and coding scheme (MCS), and LI is used to identify the strongest layer for the reported precoder indicated by RI and PMI. The UE may provide CSI feedback to the network entity based on the measured characteristics. The network entity may use the CSI feedback to adjust transmission parameters to optimize MIMO and beamforming operation.

[0027] The network entity may transmit data to the UE via the physical downlink shared channel (PDSCH). The network entity can choose different waveforms and different precoders for PDSCH transmissions depending on wireless network conditions and CSI received from the UE. Different waveforms may have different peak average power ratios (PAPRs). It may be desirable for the network entity to transmit a downlink signal with low PAPR and a higher transmission power when compared to a downlink signal with high PAPR. A downlink signal with high PAPR may produce a less accurate signal (e.g., a signal with a higher Error Vector Magnitude (EVM)). Therefore, to transmit the downlink signal with higher PAPR, the network entity may apply a power backoff to the PDSCH transmission.

[0028] In some aspects, the network entity can utilize a Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) waveform to transmit the PDSCH. In some aspects, to reduce the PAPR and provide a high power-amplifier efficiency, the network entity may utilize Discrete Fourier Transform spread Orthogonal Frequency Division Multiplexing (DFT-s-OFDM) waveform, single-carrier frequency division multiple access (SC-FDMA) waveform, or other single carrier waveform to transmit the PDSCH. Accordingly, the network entity may transmit

such low PAPR waveforms at a higher power as compared to high PAPR waveforms such as CP-OFDM. Different types of precoders and different waveforms may produce different PAPRs. Thus, different types of precoders and different waveforms may lead to different downlink transmission power backoff values or power offset values.

[0029] A first potential problem when using MIMO and beamforming is that the network entity may lack information in choosing an appropriate precoder and waveform for a PDSCH. A second potential problem is that the UE may lack information that may be used to provide appropriate CSI feedback to facilitate the network entity in choosing the appropriate precoder and waveform.

[0030] According to aspects of the disclosure, different techniques may be used by a UE and network entity to facilitate choosing an appropriate precoder and waveform for PDSCH transmission. In some aspects, the UE can inform the network entity that the UE is capable of providing CSI feedback based on codebooks (or codebook subsets) that correspond to different power backoff values or power offset values between the PDSCH and CSI-RS. The network entity can provide the UE with CSI report configurations that indicate the codebooks corresponding to one or more of the different power backoff or power offset values, along with channel measurement resources (CMRs) to be used to measure CSI associated with the different codebooks. The network entity may trigger the UE to provide a CSI report, or the UE may be configured to periodically provide a CSI report. In response to the trigger or expiration of a period, the UE may measure CSI with respect to different codebooks configured in the CSI report configuration and generate a CSI report in accordance with the CSI report configuration. In some aspects, the UE selects and recommends a codebook that is associated with CSI that is better than the CSIs associated with other codebooks. In some aspects, the UE provides CSI reports for multiple codebooks, and the network entity can select a codebook based on the reported CSIs. The network entity may use the CSI feedback provided by the UE to determine a waveform and codebook that may achieve better PDSCH transmission quality than other candidate waveforms and codebooks.

[0031] **Figure 1** is a diagram illustrating an example wireless system 100 including a user equipment 110 communicating with a network entity 120. Although illustrated as a smartphone in Figure 1, the UE 110 may be implemented as any suitable computing or electronic device, such as a mobile communication device, a modem, cellular phone, gaming device, navigation device, media device, laptop computer, desktop computer, tablet computer, smart appliance, vehicle-based communication system, an Internet-of-things (IoT) device (e.g., sensor node, controller/actuator node, combination thereof), and the like. Network entity 120 (e.g., base station, an Evolved Universal Terrestrial Radio Access Network Node B (E-UTRAN Node B), evolved Node B,

eNodeB, eNB, Next Generation Node B, gNode B, gNB, ng-eNB, access point, radio head or the like) may be implemented in a macrocell, microcell, small cell, picocell, or the like, or any combination thereof. The network entity 120 and UE 110 may be configured to use MIMO communication in which multiple beams 122 are used to exchange wireless communication signals with UE 110.

[0032] In some aspects, the functionality, and thus the hardware components, of the network entity 120 may be distributed across multiple network nodes or devices and may be distributed in a manner to perform the functions described herein. As one example, the functionality of network entity 120 may be distributed across a radio unit (RU), distributed unit (DU), or central unit (CU).

[0033] The UE 110 may communicate with network entity 120 using wireless links, which may be implemented as any suitable type of wireless link. The wireless links may include one or more wireless links (e.g., radio links) or bearers implemented using any suitable communication protocol or standard, or combination of communication protocols or standards, such as 3rd Generation Partnership Project Long-Term Evolution (3GPP LTE), Fifth Generation New Radio (5G NR), and so forth. Multiple wireless links may be aggregated in a carrier aggregation to provide a higher data rate for the UE 110.

[0034] The network entity 120 supports wireless communication with one or more UEs, such as UE 110, via radio frequency (RF) signaling using one or more applicable radio access technologies (RATs) as specified by one or more communications protocols or standards. The network entity 120 may employ any of a variety of RATs, such as operating as a NodeB (or base transceiver station (BTS)) for a Universal Mobile Telecommunications System (UMTS) RAT (also known as “3G”), operating as an enhanced NodeB (“eNB”) for a Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) RAT, operating as a 5G node B (“gNB”) for a 3GPP Fifth Generation (5G) New Radio (NR) RAT, and the like.

[0035] The network entity 120 may be part of a radio access network (RAN), for example, an Evolved Universal Terrestrial Radio Access Network, E-UTRAN, 5G NR RAN, or NR RAN. The network entity 120 may be connected to a core network 150. For example, the network entity 120 may connect to the core network 150 through an NG2 interface for control-plane signaling and using an NG3 interface for user-plane data communications when connecting to a 5G core network, or using an Si interface for control-plane signaling and user-plane data communications when connecting to an Evolved Packet Core (EPC) network. The network entity 120 may communicate using an Xn Application Protocol (XnAP) through an Xn interface or using an X2 Application Protocol (X2AP) through an X2 interface to exchange user-plane and control-plane data. The UE 110 may connect, via the network entity 120 and the core network 150, to one or more wide area networks (WANs) 160 or other packet data networks (PDNs), such as the Internet.

[0036] Communications between network entity 120 and UE 110 utilize an uplink (UL) transmission path 112 for RF transmissions from the UE 110 to the network entity 120 and a downlink (DL) transmission path 114 for RF transmissions from the network entity 120 to the UE 110. As such, in the context of the UL transmission path 112, the UE 110 serves as the data sending device and the network entity 120 serves as the data receiving device, whereas in the context of the DL transmission path 114, the network entity 120 serves as the data sending device and the UE 110 serves as the data receiving device. UL transmission path 112 and DL transmission path 114 may utilize multiple communications channels for signal transmission. The multiple channels may each have different purposes.

[0037] UL transmission path 112 may include a Physical Uplink Shared Channel (PUSCH), a Physical Uplink Control Channel (PUCCH), and a Physical Random Access Channel (PRACH). The PUSCH is used for the transmission of user data, such as voice data, video data, or text message data from UE 110 to network entity 120. Additionally, the PUSCH may be used to transmit control information (e.g., uplink control information (UCI)). The PUSCH may be shared by multiple UEs. The PUCCH is used for transmitting control information (e.g., UCI) from the UE to the network, such as channel quality feedback, scheduling requests, and acknowledgments. The PRACH is used for random access in the uplink direction, enabling the UE to access the system without a prior reservation.

[0038] DL transmission path 114 may include one or more of a Physical Downlink Shared Channel (PDSCH), a Physical Downlink Control Channel (PDCCH), a Physical Broadcast Channel (PBCH), or a paging channel. The PDSCH is used for transmission of user data from the network entity to the UE. The PDSCH may be shared by multiple UEs. As with the PUSCH, the data may be any type of information, such as voice data, video data, or text message data. The paging channel is used to notify the UE 110 that there is incoming traffic for it from the network entity 120.

[0039] UE 110 and network entity 120 may use channel state information (CSI) to optimize the quality of communications between the UE 110 and network entity 120 or a TRP. The UE 110 may provide UE capability information 102 indicating whether or not the UE 110 supports CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. If the UE indicates in supports providing such CSI feedback, the network entity 120 may configure the UE 110 to provide multiple CSIs for different codebooks and codebook subsets, where different power backoff values are associated with the codebooks and codebook subsets. For example, the network entity 120 may provide a CSI report configuration 104 to the UE 110 for use in reporting the CSI to the network entity 120. The network entity 120 can transmit reference signals 108 that can be used by the UE 110 to measure CSI. The UE 110 may use the

CSI report configuration 104 to generate a CSI report 112. For example, the UE may report at least one of rank indicator (RI), precoder matrix indicator (PMI), channel quality indicator (CQI), and layer indicator (LI) for each codebook or codebook subset. RI and PMI may be used to indicate the digital precoder, CQI may be used to indicate the signal-to-interference plus noise (SINR) status. In some aspects, the UE selects a codebook or codebook subset that the network entity should use based on the CSIs of the codebooks and codebook subsets along with the power backoff values associated with the codebooks or codebook subsets. In some other aspects, the network entity selects a codebook or codebook subset based on the CSIs for the codebooks or codebook subsets based on the CSIs reported by the UE in the CSI report.

[0040] Further details of various techniques and aspects of disclosure are provided below with respect to Figures 2, 3A, 3B, 4A, 4B, and 5-13.

[0041] **Figure 2** is a block diagram illustrating example configurations of a network entity 120 and a UE 110. Note that the depicted hardware configurations represent the processing components and communication components related to providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. The depicted hardware configurations may omit certain components well-understood to be frequently implemented in such electronic devices, such as displays, peripherals, power supplies, and the like.

[0042] The UE 110 includes antennas 202, a radio frequency front end (RF front end) 204, and radio-frequency transceivers (e.g., an LTE transceiver 206 and a 5G NR transceiver 208) for communicating with network entity 120.

[0043] The RF front end 204 includes one or more modems configured for the corresponding RAT(s) employed (for example, Third Generation Partnership Project (3GPP) Fifth Generation New Radio (5G NR)), one or more analog-to-digital converters (ADCs), one or more digital-to-analog converters (DACs), signal processors, and the like. In the example illustrated in Figure 2, the RF front end 204 of the UE 110 may couple or connect the LTE transceiver 206, and the 5G NR transceiver 208 to the antennas 202 to facilitate various types of wireless communication. The RF front end 204 operates, in effect, as a physical (PHY) transceiver interface to conduct and process signaling between the one or more processors 214 and the antennas 202 so as to facilitate various types of wireless communication.

[0044] The antennas 202 of the UE 110 may include an array of multiple antennas that are configured similar to or different from each other and may be tuned to one or more frequency bands associated with a corresponding RAT. The antennas 202 and the RF front end 204 may be tuned to, and/or be tunable to, one or more frequency bands defined by the 2GPP LTE and 5G NR communication standards and implemented by the LTE transceiver 206, and/or the 5G NR transceiver 208. Additionally, the antennas 202, the RF front end 204, the LTE transceiver 206,

and/or the 5G NR transceiver 208 may be configured to support beamforming for the transmission and reception of communications with the network entity 120 and/or with one or more transmit/receive points (TRPs, not shown in Figure 2). By way of example and not limitation, the antennas 202 and the RF front end 204 may be implemented for operation in sub-gigahertz bands, sub-6 GHz bands, and/or above 6 GHz bands that are defined by the 2GPP LTE and 5G NR communication standards.

[0045] The UE 110 also includes processor(s) 214 and computer-readable storage media (CRM) 216. The processor 214 may include, for example, one or more central processing units, graphics processing units (GPUs), or other application-specific integrated circuits (ASIC), and the like. To illustrate, the processors 214 may include an application processor (AP) utilized by the UE 110 to execute an operating system and various user-level software applications, as well as one or more processors utilized by modems or a baseband processor of the RF front end 204.

[0046] CRM 216 may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), Flash memory, solid-state drive (SSD) or other mass-storage devices, and the like useable to store one or more sets of executable software instructions and associated data that manipulate the one or more processors 214 and other components of the UE 110 to perform the various functions described herein and attributed to the UE 110. The sets of executable software instructions include, for example, an operating system (OS) and various drivers (not shown), and various software applications (not shown), which are executable by processor(s) 214 to enable user-plane communication, control-plane signaling, and user interaction with the UE 110. The data 218 stored in the CRM 216 represents, for example, user data, multimedia data, software application configuration information, and the like. Data 218 may include codebook entities 220 and CSI report configurations 219. Codebook entities 220 may be codebooks or codebook subsets that contain various beamforming vectors or MIMO precoding matrices that may be used to adjust signals transmitted by a network entity and to align the transmitted signals with the UE's antennas to attempt to optimize the transmission and reception of signals in a multiple-antenna wireless communication system. CSI report configurations may include one or more of the following parameters:

- A set of codebooks;
- A set of codebook subsets;
- A codebook and a set of codebook subsets;
- A set of power backoff or power offset indicators indicating the target power backoff or power offset for the PDSCH based on the reported CSI;
- One or more waveform indicators indicating the target waveform for the PDSCH based on the reported CSI;

- One or more CMRs;
- One or more IMRs;
- A rank restriction indicator indicating the candidate number of layers for CSI feedback;
- A set of indicator(s) for CQI table indication, where each indicator may indicate a CQI table for a codebook or codebook subset;
- A number of reported CSIs.

[0047] CRM 216 also includes a communications controller 222. Alternately or additionally, the communications controller 222 may be implemented in whole or part as hardware logic or circuitry integrated with or separate from other components of the UE 110. In some aspects, communications controller 222 configures the RF front end 204, the LTE transceiver 206, and/or the 5G NR transceiver 208 to implement the techniques described herein for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

[0048] Turning to the hardware configuration of the network entity 120, it is noted that although Figure 2 illustrates an implementation of the network entity 120 as a single network node (for example, a 5G NR Node B, or “gNB”), the functionality, and thus the hardware components, of the network entity 120 instead may be distributed across multiple network nodes or devices and may be distributed in a manner to perform the functions described herein. As one example, the functionality of network entity 120 may be distributed across a radio unit (RU), distributed unit (DU), and/or central unit (CU).

[0049] The network entity 120 includes antennas 252, a radio frequency front end (RF front end) 254, one or more LTE transceivers 256, and/or one or more 5G NR transceivers 258 for communicating with the UE 110. The RF front end 254 of the network entity 120 may couple or connect the LTE transceivers 256 and the 5G NR transceivers 258 to the antennas 252 to facilitate various types of wireless communication. Similar to RF front end 204, the RF front end 254 includes one or more modems, one or more ADCs, one or more DACs, and the like. RF front end 254 receives the one or more RF signals, for example, RF signals from UE 110, and pre-processes the one or more RF signals to generate data from the RF signals that is provided as input to processes and/or applications executing on network entity 120. This pre-processing may include, for example, power amplification, conversion of band-pass signaling to baseband signaling, initial analog-to-digital conversion, and the like.

[0050] The antennas 252 of the network entity 120 may be configured individually and/or as one or more arrays of multiple antennas. The antennas 252 and the RF front end 254 may be tuned to, and/or be tunable to, one or more frequency band defined by the 3GPP LTE and 5G NR communication standards, and implemented by the LTE transceivers 256, and/or the 5G NR

transceivers 258. Additionally, the antennas 252, the RF front end 254, the LTE transceivers 256, and/or the 5G NR transceivers 258 may be configured to support beamforming, such as Massive-MIMO, for the transmission and reception of communications with UE 110.

[0051] The network entity 120 also includes processor(s) 260 and computer-readable storage media (CRM) 262. The processor 260 may include, for example, one or more central processing units, graphics processing units (GPUs), or other application-specific integrated circuits (ASIC), and the like. To illustrate, the processors 260 may include an application processor (AP) utilized by the network entity 120 to execute an operating system and various user-level software applications, as well as one or more processors utilized by modems or a baseband processor of the RF front end 254 to enable communication with the UE 110.

[0052] CRM 262 may include any suitable memory or storage device such as random-access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), non-volatile RAM (NVRAM), read-only memory (ROM), or Flash memory useable to store device data of the network entity 120. The device data may include data 264, which includes network scheduling data, radio resource management data, software application configuration information, and the like. Data 264 may further include codebook entities 261 and CSI reports 263. Like codebook entities 220 described above, codebook entities 261 may be codebooks or codebook subsets. CSI reports 263 may be reports received from a UE that provide CSI feedback information regarding channel quality and channel conditions that the network entity may utilize to adjust signal transmission parameters to improve network performance.

[0053] CRM 262 also includes an RF resource manager 265. In some aspects, the RF resource manager 265 of the network entity 120 is implemented to perform various functions associated with allocating physical access (for example, resource blocks) or communication resources for the air interface of the network entity 120. The air interface of the network entity 120, may be partitioned or divided into various units (for example, frames, subframes, or slots) of one or more of bandwidth, time, symbols, or spatial layers. For example, within a framework of a 5G NR protocol, the RF resource manager 265 may allocate bandwidth and time intervals of access in resource blocks, each of which may be allocated in whole, or in part, to one or more channels for communicating with the UE 110. The channels may include one or more of a PRACH, a PUCCH, a PUSCH, a PDCCH, a PDSCH, a PBCH, or a paging channel. The resource blocks may include multiple subcarriers that each span a portion of a frequency domain of the resource blocks. The subcarriers may be further divided into resource elements, or orthogonal frequency-division multiplexing (OFDM) symbols, that each span a portion of a time domain of the subcarriers. Consequently, a resource block includes multiple OFDM symbols that may be grouped into subcarriers with other OFDM symbols having a common frequency bandwidth.

[0054] CRM 262 further includes network entity manager 266. Alternately or additionally, the network entity manager 266 may be implemented in whole or part as hardware logic or circuitry integrated with or separate from other components of the network entity 120. In at least some aspects, the network entity manager 266 configures the LTE transceivers 256 and the 5G NR transceivers 258 for communication with the UE 110, as well as communication with a core network 150 (Figure 1).

[0055] In some aspects, the network entity 120 includes an inter-network entity station interface 268, such as an Xn and/or X2 interface, which the network entity manager 266 configures to exchange user-plane and control-plane data between another network entity, to manage the communication of the network entity 120 with the UE 110. The network entity 120 includes a core network interface 270 that the network entity manager 266 configures to exchange user-plane and control-plane data with core network functions and entities.

[0056] As discussed above, the network entity 120 can utilize different waveforms and different precoders for PDSCH transmissions depending on wireless network conditions. In some aspects, the network entity 120 can utilize a Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) waveform to transmit the PDSCH. In some aspects, to reduce the Peak Average Power Ratio (PAPR) and provide a high power-amplifier efficiency, the network entity 120 may utilize Discrete Fourier Transform spread Orthogonal Frequency Division Multiplexing (DFT-s-OFDM) waveform, Single Carrier Frequency Division Multiple Access (SC-FDMA), or other single-carrier waveform to transmit the PDSCH. In some implementations, a low PAPR waveform refers to a waveform associated with a PAPR below a threshold decibel (dB) level (e.g., a PAPR below the PAPR of a CP-OFDM waveform). Different types of precoders and different waveforms may produce different PAPRs. Similarly, different types of precoders and different waveforms may lead to different downlink transmission power backoff values. Figures 3A and 3B illustrate different example antenna port mappings used by a network entity 120 when transmitting a PDSCH using a DFT-s-OFDM waveform and their associated precoder types. In the examples shown in Figures 3A and 3B, a set of antenna ports 352 may be mapped to different beamforming layers. The set of antenna ports 352 may represent some or all of antennas 252 of network entity 120.

[0057] Figures 3A, 3B, 4A, 4B, and 5-13 discussed below illustrate various techniques and examples for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. In some examples that follow, the operations may be described as utilizing RRC signaling. Unless specified otherwise, RRC signaling may indicate a RRC reconfiguration message from the network entity to the UE, or a system information block (SIB),

where the SIB may be an existing SIB (e.g., SIB1) or a new SIB (e.g., SIB J , where J is an integer above 21) transmitted by the network entity.

[0058] **Figure 3A** is a diagram illustrating an antenna port configuration 300 for PDSCH transmission using a type 1 precoder (Type1 precoder). A type 1 precoder is a type of precoder with different beamforming layers mapped to different antenna ports. In some aspects, the network entity 120 may select a digital precoder with one beamforming layer 306 mapped to two antenna ports 304. Here, the “X” configuration represents two antenna ports from two different polarizations (e.g., +45 degree and -45 degree). For example, layer 306A is mapped to two antenna ports 304A, layer 306B is mapped to another two antenna ports 304B and so on. In other words, each two antenna ports 304 is mapped to a different layer 306.

[0059] **Figure 3B** is a diagram illustrating an antenna port configuration 320 for PDSCH transmission using a type 2 precoder (Type2 precoder). A type 2 precoder is a type of precoder with different beamforming layers mapped to partially or fully overlapped antenna port(s). In some aspects, the network entity 120 may choose a precoder with each beamforming layer 306 may be mapped to more than one antenna port 304. In other words, the precoder may map different layers 306 to partially or fully overlapped antenna port(s) 304. Such a mapping may provide better precoding gain than the one layer to multiple antenna ports mapping shown in Figure 3A. In the example shown in Figure 3B, each layer 306 is mapped to each of the antenna ports 304. For example, each of layers 306A-306D is mapped to each of antenna ports 304A-304D. Here, the “X” configuration represents two antenna ports from two different polarizations (e.g., +45 degree and -45 degree).

[0060] Different combinations of waveforms and antenna port to layer mappings may result in different PAPRs. As an example, consider two waveforms, a CP-OFDM waveform and a DFT-s-OFDM waveform, where antenna ports transmitting the two waveforms may be mapped to one layer or four layers. A CP-OFDM waveform where an antenna port is mapped to four layers may result in a relatively high PAPR when compared to the other waveforms in the example. A CP-OFDM waveform where one antenna port is mapped to one layer may result in a somewhat lower PAPR than a CP-OFDM waveform where one antenna port is mapped to four layers. A DFT-s-OFDM waveform where an antenna port is mapped to four layers may result in a lower PAPR than the two CP-OFDM waveforms. A DFT-s-OFDM waveform where an antenna port is mapped to one layer may result in a relatively low PAPR when compared to the other waveforms.

[0061] **Figure 4A** is a sequence diagram illustrating example operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks where the UE selects a codebook. Although not illustrated for the sake of illustration clarity, various acknowledgements for messages illustrated in Figure 4A may be implemented to

ensure reliable operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

[0062] At operation 402, the UE 110 may transmit or report to network entity 120 the UE's capability(s) for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. In some aspects, UE 110 may communicate UE capability information to the network entity 120 during an initial communication session setup process between the UE 110 and the network entity 120. UE capability information may include supported frequency bands, radio access technologies, maximum transmission power, maximum data rates, and network protocols. In some implementations, the UE 110 may report UE capability information indicating whether the UE 110 supports CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks, the maximum supported number of codebooks or codebook subsets with different power backoff or power offsets between the PDSCH and CSI-RS in a CSI report configuration; and a maximum number of reported CSIs for the CSI report. In some implementations, the UE capability information may include an indication of support for CMRs that associated with different codebooks or codebook subsets being configured with a different number of ports, different bandwidth, different subcarriers, different periodicity, and/or different TCI state. In some other implementations, the UE includes, in the UE capability information, an indication of whether the UE supports different codebooks corresponding to different waveforms in a CSI report configuration.

[0063] In the example of Figure 4A, the UE 110 transmits UE capability information to network entity 120. In some implementations, the network entity may receive the UE capability from a core network (e.g., from an access and mobility management function (AMF) of the core network 150 of Figure 1). In some other implementations, the network entity receives the UE capability from another network entity (e.g., a gNB or eNB).

[0064] At operation 404, the network entity 120 may, depending on the UE capability information received at operation 402, configure at least one CSI report configuration that includes multiple codebooks or codebook subsets (collectively referred to as "codebook entities"), where the different codebooks or codebook subsets corresponding to different power backoff or power offsets. As discussed above with respect to CSI report configurations 219 of Figure 2, a CSI report configuration may include one or more of the following parameters:

- A set of codebooks;
- A codebook and a set of codebook subsets;
- A set of codebook subsets;
- A set of power backoff or power offset indicators indicating the target power backoff or power offset for the PDSCH based on the reported CSI;

- One or more waveform indicators indicating the target waveform for the PDSCH based on the reported CSI;
- One or more CMRs;
- One or more IMRs;
- A rank restriction indicator indicating the candidate number of layers for CSI feedback;
- A set of indicator(s) for CQI table indication, where each indicator may indicate a CQI table for a codebook or codebook subset;
- A number of reported CSIs.

In some aspects, the network entity 120 may transmit the CSI report configuration via control signaling by RRC signaling, e.g., *RRCReconfiguration* or *CSI-ReportConfig*. In some aspects, the network entity 120 may configure multiple CSI report sub-configurations in a CSI report configuration, e.g., *CSI-ReportConfig*. For example, the network entity 120 may configure one or more of the parameters above in one in one CSI report sub-configuration, and one or more other parameters in a different CSI report sub-configuration. Thus, the network entity 120 may configure at least one of the parameters including codebook, codebook subset, power backoff or power offset indicator, waveform indicator, CMR, IMR, and CQI table indicator in each CSI report sub-configuration. In some aspects, one or more of the parameters may be predefined (e.g., number of reported CSIs is 1) or the same as another parameter. For example, the number of reported CSIs may be the same as the number of configured codebooks or codebook subsets.

[0065] In some aspects, the network entity 120 may include, in the CSI report configuration, power backoff or power offset indicators for CQIs corresponding to different modulation orders. For example, the network entity 120 may configure a higher power backoff or power offset for a CQI with a higher modulation order. In some aspects, the power backoff or power offset for the CQIs corresponding to different modulation orders may be predefined.

[0066] In some aspects, the network entity 120 may include, in the CSI report configuration, an indication of common CMR(s) for all the configured codebooks or codebook subsets. In some other aspects, the network entity 120 may transmit a CSI report configuration indicating separate CMRs for different configured codebooks or codebook subsets. In such aspects, the network entity 120 may configure the CMRs for different codebooks or codebook subsets with the same number of ports, bandwidth, subcarriers, periodicity, and/or transmission configuration indication (TCI) state for quasi-co-location (QCL) indication. In such aspects, the UE 110 may therefore not expect the CMRs for different codebooks or codebook subsets to be configured with a different number of ports, different bandwidth, different subcarriers, different periodicity, and/or different TCI state. In some other aspects, the UE capability information may, as described above with respect to operation 402, indicate that the UE 110 supports CMRs for different codebooks or codebook

subsets being configured with a different number of ports, different bandwidth, different subcarriers, different periodicity, and/or different TCI state.

[0067] In some aspects, the network entity 120 may configure, in the CSI report configuration, the waveform indicator by configuring the codebook type. For example, different types of codebooks may be predefined for different waveforms. The network entity 120 can include, in the CSI report configuration, a codebook type which will then also indicate the waveform corresponding to the codebook type.

[0068] In some other implementations, the network entity 120 may refrain from including, in the CSI report configuration, the codebooks corresponding to different waveforms in a CSI report configuration. Thus, in such implementations, the UE 110 may not expect the network entity 120 to configure the codebooks corresponding to different waveforms in a CSI report configuration.

[0069] In some implementations, the network entity 120 includes, in the CSI report configuration, the same number of horizontal antenna ports and vertical antenna ports for the configured codebook(s). In some implementations, the network entity may include, in the CSI report configuration, orthogonal codebooks or codebook subsets for different waveforms and/or different power backoff or power offsets.

[0070] In some implementations, the network entity 120 includes, in the CSI report configuration, a common CQI table for CQI measurement and report for configured codebooks or codebook subsets. In some other implementations, the network entity 120 includes, in the CSI report configuration, an indication of separate CQI tables for CQI measurement and report for each configured codebook or codebook subset. In some aspects, the candidate CQI tables may be similar to those defined in 3GPP Technical Specification (TS) 38.214.

[0071] At operation 406, the network entity 120 may trigger the UE 110 to provide a CSI report in accordance with the CSI report configuration provided to the UE 110 at operation 404. For example, the network entity 120 may trigger a semi-persistent CSI report or an aperiodic CSI report. In some aspects, the network entity 120 network entity may transmit MAC CE or DCI activating or triggering the CSI report. In some aspects, the network entity 120 may provide one or more of CSI report configuration parameters described above with respect to operation 404 by the MAC CE or DCI triggering the CSI report. For example, the network entity may provide parameters such as waveform indicator or number of reported CSIs by MAC CE or DCI.

[0072] At operation 408, the network entity 120 may transmit the CMR configured in the CSI report configuration at operation 404. In some aspects, the network entity 120 may transmit an IMR in addition to the CMR if an IMR is included in the CSI report configuration received at operation 404.

[0073] At operation 410, the UE 110 measures the CSIs for some or all of the codebooks or codebook subsets configured in the CSI report configuration based on the CMR (and optionally, the IMR).

[0074] At operation 412, the UE 110 may select, based on the CSI measurements obtained at operation 410, a codebook or codebook subset from among the codebooks and/or codebook subsets configured in the CSI report configuration. In some aspects, the UE 110 selects the codebook or codebook subset that is associated with the highest spectrum efficiency (SE). As an example, the UE 110 may indicate in the UE capability information that the UE 110 is capable of selecting a codebook or codebook subset. The network entity 120 may configure the UE 110 to perform such selection in the CSI report configuration.

[0075] At operation 414, the UE 110 may transmit a CSI report corresponding to a configured CSI report interval or as triggered CSI at operation 406. In some aspects, the CSI report provides CSI with respect to the codebook or codebook entity selected at operation 412, and in accordance with the CSI report configuration received at operation 404.

[0076] **Figure 4B** is a sequence diagram illustrating example operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks where the UE provides multiple CSIs to the network entity. Although not illustrated for the sake of illustration clarity, various acknowledgements for messages illustrated in Figure 4B may be implemented to ensure reliable operations for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks.

[0077] The operations of communication process 420 are similar to those of communication process 400 described above with respect to Figure 4A. A difference is that instead of the UE 110 selecting a codebook or codebook set for reporting CSI feedback, the UE 110 reports CSI feedback for multiple codebooks or codebook subsets. Thus, in some aspects, operations 402-412 of Figure 4B are the same as, or substantially similar to, operations 410-412 described above with respect to Figure 4A.

[0078] At operation 416, the UE 110 transmits a CSI report to network entity 120. In some aspects, the CSI report includes CSIs for some or all of the codebooks and/or codebook subsets configured in the CSI report configuration received at operation 404. The different CSIs in the CSI report may correspond to different codebooks and/or codebook subsets in the CSI report.

[0079] **Figure 5** is a flow chart diagram illustrating example UE operations of a method for providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. The example operations of method 500 may be performed, for example, by UE 110 of Figures 1, 2, 4A, and 4B.

[0080] At block 502, and as described above with respect to Figures 4A and 4B, operation 402, the UE may transmit UE capability information to a network entity. In some aspects, the UE 110 may transmit UE capability information including at least one of: a first indicator indicating support for providing CSI feedback based on one or more codebook entities and power relationship indicators corresponding to the one or more codebook entities; a maximum number of codebook entities with different power relationship indicators; a maximum number of reported CSIs for the at least one CSI report; a number of CSI processing units (CPUs) for the at least one CSI report; or a second indicator indicating a minimum processing delay for the at least one CSI report. For example, the UE 110 may report UE capability information indicating whether the UE 110 supports CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks, and information related to such support.

[0081] At block 504, and as described with respect to Figures 4A and 4B, operation 404, the UE 110 may receive at least one CSI report configuration that includes multiple codebook entities, where the different codebooks or codebook subsets corresponding to different power backoff or power offsets. In some aspects, the UE 110 may receive at least one CSI report configuration including: a plurality of codebook entities (e.g., codebooks or codebooks subsets), one or more power relationship indicators (e.g., power backoff or power offset indicators) indicating a power relationship between a PDSCH and a CSI-RS for each codebook entity of the plurality of codebook entities, and one or more CMRs associated with the CSI-RS.

[0082] In some other aspects, the at least one CSI report configuration further includes at least one of: at least one waveform indicator indicating a target waveform for the PDSCH based on the reported CSI; at least one IMR; a rank restriction indicator indicating a candidate number of layers for CSI feedback; a first CQI table indicator indicating a common or separate CQI table for the plurality of codebook entities; a second CQI table indicator indicating a separate CQI table for each of the plurality of codebook entities; an indicator indicating a number of reported CSIs; a configuration of power relationship indicators for CQIs corresponding to different modulation orders; one or more common CMRs for the plurality of codebook entities; or one or more separate CMRs for the plurality of codebook entities.

[0083] In some aspects, the target waveform includes at least one of: a CP-OFDM waveform, a DFT-s-OFDM waveform, or a SC-FDMA waveform.

[0084] At block 506, and as described with respect to Figures 4A and 4B, operation 406, the UE 110 may receive an indication (e.g., a “trigger”) that the UE 110 is to provide a CSI report in accordance with the CSI report configuration received by the UE 110 at block 504. In addition to receiving the indication to provide the CSI report, the UE 110 may receive one or more of CSI report configuration parameters described above by the MAC CE or DCI activating or triggering

the CSI report. For example, the UE may receive parameters such as waveform indicator or number of reported CSIs by MAC CE or DCI.

[0085] At block 508 and as described with respect to Figures 4A and 4B, operation 408, the UE 110 may receive, from the network entity, the CMR configured in the CSI report configuration. In some aspects, the UE 110 may receive the one or more CMRs associated with the CSI-RS. In some aspects, the UE 110 may receive an IMR in addition to the CMR if an IMR is included in the CSI report configuration. In some aspects, the UE 110 may receive a plurality of CMRs, each of the plurality of CMRs having a same value for at least one of: a number of antenna ports; a bandwidth; a configuration of subcarriers; a periodicity; or a transmission configuration indication (TCI) state.

[0086] At block 510 and as described with respect to Figures 4A and 4B, operation 410, the UE 110 measures the CSIs for some or all of the codebooks or codebook subsets configured in the CSI report configuration based on the CMR (and optionally, the IMR). In some aspects, the UE 110 may calculate a CSI for the at least one CSI report based on at least one of: one of the plurality of codebook entities; a power relationship indicator for one of the plurality of codebook entities; a target waveform for one of the plurality of codebook entities; or a rank restriction for one of the plurality of codebook entities.

[0087] In some aspects, at block 512 and as described with respect to Figure 4A, operation 412, the UE 110 may optionally select a codebook or codebook subset from among the codebooks and/or codebook subsets configured in the CSI report configuration, where the selection of a codebook or codebook subset may be based on the CSI measurements obtained at block 510. In some aspects, the UE 110 selects the codebook or codebook subset that is associated with the highest SE.

[0088] At block 518, and as described above with respect to Figure 4A, operation 414 and Figure 4B, operation 416, the UE 110 transmits the CSI report to the network entity. In some aspects, the UE 110 may transmit at least one CSI report based on the at least one CSI report configuration and the one or more CMRs. In some aspects, the UE 110 transmits a CSI report with information regarding the codebook or codebook entity optionally selected by the UE at block 512. In some aspects, the UE 110 transmits a CSI report that includes CSIs for some or all of the codebooks and/or codebook subsets configured in the CSI report configuration.

[0089] In some aspects, the UE 110 may transmit the at least one CSI report with at least one of: a subset of measured CSIs in the at least one CSI report; a first indicator indicating a number of reported CSIs; a second indicator indicating a codebook entity of the plurality of codebook entities for each reported CSI; all the measured CSIs in the at least one CSI report; an RI for each CSI in the at least one CSI report; a PMI for each CSI in the at least one CSI report; a CQI for each

CSI in the at least one CSI report; a LI for each CSI in the at least one CSI report; a common RI for all reported CSIs; or at least one of a common RI, common PMI, or common LI based on one of the plurality of codebook entities and the CQI for each CSI in the at least one CSI report.

[0090] In some other aspects, the UE 110 may refrain from transmitting the CSI report when a number of occupied CPUs in a component carrier (CC) or across CCs exceeds a maximum number of CPUs. In still other aspects, the UE 110 may refrain from transmitting the CSI report when a scheduling offset for the CSI report is smaller than a minimum processing delay.

[0091] **Figure 6** is a flow chart diagram illustrating example network entity operations of a method for receiving CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. The example operations of method 600 may be performed, for example, by the network entity 120 of Figures 1, 2, 4A, and 4B.

[0092] At block 602, and as described above with respect to Figures 4A and 4B, operation 402, the network entity may receive UE capability information from a UE. For example, the network entity may receive UE capability information indicating whether the UE supports providing CSI feedback based on one or more codebooks and power backoff values corresponding to the codebooks. In some aspects, the network entity 120 may receive UE capability information including similar UE capabilities as described with respect to Figure 5, operation 502.

[0093] At block 604, and as described with respect to Figures 4A and 4B, operation 404, the network entity may transmit, to the UE, at least one CSI report configuration that includes multiple codebook entities, where the different codebooks or codebook subsets corresponding to different power backoff or power offsets. The network entity may include, in the CSI report configuration, a CMR and optionally an IMR. In some aspects, the network entity may transmit at least one CSI report configuration including: a plurality of codebook entities (e.g., codebooks or codebooks subsets), one or more power relationship indicators (e.g., power backoff or power offset indicators) indicating a power relationship between a PDSCH and a CSI-RS for each codebook entity of the plurality of codebook entities, and one or more CMRs associated with the CSI-RS. In some other aspects, the at least one CSI report configuration further includes similar parameters as described with respect to Figure 5, operation 504.

[0094] At block 606, and as described with respect to Figures 4A and 4B, operation 406, the network entity may transmit an indication (e.g., a “trigger”) that the UE is to provide a CSI report in accordance with the CSI report configuration provided to the UE at block 604. In addition to transmitting the indication that the UE is to provide the CSI report, the network entity may transmit one or more CSI report configuration parameters described above in the MAC CE or DCI used to trigger the CSI report. For example, the network entity may transmit parameters such as a waveform indicator or a number of CSIs to be reported.

[0095] At block 608 and as described with respect to Figures 4A and 4B, operation 408, the network entity may transmit, to the UE, the CMR configured in the CSI report configuration. In some aspects, the network entity may transmit the one or more CMRs associated with the CSI-RS. In some aspects, the network entity may transmit an IMR in addition to the CMR if an IMR is included in the CSI report configuration. In some aspects, the network entity 120 may transmit a plurality of CMRs, each of the plurality of CMRs having a same value for at least one of: a number of antenna ports; a bandwidth; a configuration of subcarriers; a periodicity; or a TCI state.

[0096] At block 618, and as described above with respect to Figure 4A, operation 414 and Figure 4B, operation 416, the network entity receives the CSI report from the UE. In some aspects, the network entity may receive at least one CSI report based on the at least one CSI report configuration and the one or more CMRs. In some aspects, the network entity receives a CSI report with information regarding a codebook or codebook entity that was selected by the UE. In some aspects, the network entity receives a CSI report that includes CSI feedback for some or all of the codebooks and/or codebook subsets configured in the CSI report configuration. The network entity may select the appropriate codebook or codebook subset based on the CSI feedback. In some aspects, the network entity 120 may receive the at least one CSI report with similar CSI components as described with respect to Figure 5, operation 518.

[0097] Figures 7-13 provide examples of CSI feedback that may be provided by a UE in various scenarios involving different CSI report configurations, codebooks, and codebook subsets. The examples provided in Figures 7-13 are but a few of the many different possible combinations of CSI report configurations, codebooks, and codebook offsets.

[0098] **Figure 7** is a diagram illustrating an example of CSI feedback with waveform and power backoff aware codebooks. In some aspects, a network entity provides a UE with a set of codebooks 704 with a power backoff or power offset indicator for each configured codebook. In the example shown in Figure 7, the network entity has configured three codebooks 704A-704C. Each of the codebooks 704A-704C may produce different measured CSIs 706A-706C respectively, based on the waveforms and CMR(s) associated with the respective codebooks. In this example, the network entity has configured the power backoff or power offset indicator for each codebook 704A-704C. For example, codebook 704A includes power backoff/offset indicator 1 indicating a 0dB backoff, codebook 704B includes a power backoff/offset indicator 2 indicating a 3dB backoff or offset, and codebook 704C has a power backoff/offset indicator 3 indicating a 6dB power backoff or offset. In some other aspects, the network entity may configure N codebooks and N power backoff or power offset indicators, and the power backoff indicators or offsets may be mapped one-to-one with codebooks. In some aspects, each codebook 704 may

specify one type of precoder, although different codebooks can specify different types of precoders from one another.

[0099] In some aspects, for codebooks that specify codebooks having a Type2 precoder, the network entity may provide to the UE a codebook 704 specifying common or separate power backoff or power offset indicators, where one antenna port may be mapped to a different number of layers in each codebook. For instance, the network entity may provide separate power backoff or power offset indicators for the Type2 precoders. As an example, one antenna port may be mapped to two layers, another antenna port may be mapped to three layers, a further antenna port may be mapped to four layers, and so on. Further, a layer may be mapped to one or more than one antenna ports.

[0100] In some aspects, the network entity may configure a common or separate waveform indication for each codebook 704. In the example shown in Figure 7, codebooks 704A and 704B have a common waveform indication of DFT-s-OFDM and codebook 704C has a separate waveform indication of CP-OFDM. This can facilitate compatibility with UE implementations that may apply different receivers to receive PDSCHs having different waveforms.

[0101] In some aspects, the network entity may configure a common rank restriction indicator for each codebook 704. In some other aspects, the network entity may configure separate rank restriction indicators for each codebook 704. In still other aspects, the network entity may configure separate rank restriction indicators for different waveforms.

[0102] In some aspects, the network may configure the parameters of a codebook in a CSI sub-configuration in the CSI report configuration.

[0103] **Figure 8** is a diagram illustrating an example of CSI feedback with waveform and power backoff aware codebook subsets. In some aspects, the network entity provides, to the UE, a codebook 802 having a set of codebook subsets 804, and a power backoff or power offset indicator for each of the configured codebook subsets 804. In the example shown in Figure 8, the codebook 802 includes three codebook subsets 804A-804C. Each of the codebook subsets 804A-804C may produce different measured CSIs 706A-706C respectively, based on the CMR(s) and waveforms associated with the respective codebook subsets. In some aspects, the network entity configures the power backoff or power offset indicator in the configuration of each codebook subset 804. In this example, the network entity has configured the power backoff or power offset indicator in each codebook subset 804A-804C. For example, codebook subset 804A includes power backoff/offset indicator 1 indicating a 0dB backoff, codebook subset 804B includes a power backoff/offset indicator 2 indicating a 3dB backoff or offset, and codebook subset 804C has a power backoff/offset indicator 3 indicating a 6dB power backoff or offset. In some other aspects, the network entity configures N codebook subsets and N power backoff or power offset indicators

that may be one-to-one mapped with codebook subsets 804. In some implementations, each codebook subset 804 may specify only one type of precoder.

[0104] In some aspects, for codebook subsets 804 having a Type2 precoder, the network entity may provide to the UE codebook subsets 804 that have a common or separate power backoff or power offset indicators for the precoders, where one antenna port may be mapped to a different number of layers. For instance, the network entity may provide separate power backoff or power offset indicators for the precoders. As an example, one antenna port may be mapped to two layers, another antenna port may be mapped to three layers, a further antenna port may be mapped to four layers, and so on.

[0105] In some aspects, the network entity may configure a common or separate waveform indication for each codebook subset 804. In the example shown in Figure 8, codebook subsets 804A and 804B have a common waveform indication of DFT-s-OFDM and codebook subset 804C has a separate waveform indication of CP-OFDM. This can facilitate compatibility with UE implementations that may apply different receivers to different waveforms. For example, the UE can apply a receiver corresponding to a waveform when measuring CQI of the waveform.

[0106] In some aspects, the network entity configures a common rank restriction indicator for the codebook subsets 804. In some other aspects, the network entity configures separate rank restriction indicators for different waveforms. In yet other aspects, the network entity configures separate rank restriction indicators for different codebook subsets 804. In some aspects, the codebook subsets for CP-OFDM waveforms may be the same as the codebook subsets with Type2 precoders for DFT-s-OFDM waveforms.

[0107] **Figure 9** is a diagram illustrating an example of CSI feedback with a waveform specific codebook and power backoff aware codebook subsets. In some aspects, the network entity configures a set of codebooks 902A and 902B, where each codebook corresponds to a different waveform, and configures a set of codebook subsets 904A-904C for at least one of the configured codebooks. Additionally, the network entity configures a power backoff or power offset indicator for each configured codebook subset. In the example shown in Figure 9, the network entity has configured a first codebook 902A with codebook subsets 904A and 904B that share the same waveform indication (e.g., DFT-s-OFDM). Additionally, the network entity has configured codebook 902B with a codebook subset 904C having a different waveform indication (e.g., CP-OFDM) from codebook subsets 904A and 904B. In some aspects, the network entity configures the power backoff or power offset indicator in the configuration of each codebook subset. In some other aspects, the network entity configures N codebook subsets and N power backoff or power offset indicators, which may be mapped one-to-one with the codebook subsets. In some aspects, each codebook subset may specify only one type of precoder. Each of the codebook subsets 904A-

904C may produce different measured CSIs 706A-706C respectively, based on the CMR(s) and waveforms associated with the respective codebook subsets.

[0108] In some aspects, for codebook subsets with Type2 precoders, the network entity may configure the UE with codebook subsets having common or separate power backoff or power offset indicators, where each antenna port may be mapped to a different number of layers from other antenna ports. For instance, the network entity may provide separate power backoff or power offset indicators for the precoders. As an example, one antenna port may be mapped to two layers, another antenna port may be mapped to three layers, a further antenna port may be mapped to four layers, and so on.

[0109] In some aspects, the network entity may configure codebook subsets having a common rank restriction indicator. In some other aspects, the network entity may configure codebook subsets having separate rank restriction indicators for different waveforms. In still other aspects, the network entity may configure separate rank restriction indicators for different codebook subsets. In some aspects, the codebook subsets indicating CP-OFDM waveforms may be configured the same as or similar to codebook subsets indicating Type2 precoders for DFT-s-OFDM waveforms.

[0110] Figures 10-13 illustrate various example CSI reports that may be generated by a UE and transmitted to a network entity. The various CSI reports are based on codebooks 704A-704C of Figure 7 and the measured CSIs associated with waveforms associated with the codebooks.

[0111] **Figure 10** is a diagram illustrating an example 1000 of a UE selected codebook for CSI feedback. In some aspects, the UE transmits a CSI report 1002 based on a CSI report configuration received from the network entity. The CSI report 1002 may include at least one CSI based on one of the configured codebooks or codebook subsets and its corresponding power backoff or power offset. In the example illustrated in Figure 10, the UE has selected codebook 704B and its associated measured CSI 706B for reporting. CSI report 1002 includes an indicator indicating codebook 704B, and at least one of an RI, PMI, CQI, or LI from the measured CSI 706B.

[0112] In some aspects, the network entity may configure the number of reported CSIs. In some other aspects, the UE reports an indicator indicating the number of reported CSIs. The network entity may configure the maximum number of reported CSIs. In some other aspects, the number of reported CSIs may be predefined, e.g., one ("1").

[0113] In some aspects, when reporting multiple CSIs, the UE the UE may report an indicator indicating whether the CSI is based on the UE selected codebook or codebook subset. In cases where the UE reports the CSI on PUSCH or long PUCCH (e.g., a PUCCH with more than 4 symbols), the UE may report the selection indicator in CSI part 1. Alternatively, the UE may report the selection indicator in CSI part 2. The CSI part 1 and part 2 are defined in 3GPP TS

38.212. In some other aspects, the UE may report a first indicator indicating the UE selected codebook and a second indicator indicating the UE selected codebook subsets for the UE selected codebook. The UE may further report at least one of the RI, PMI, CQI, and LI of the measured CSI corresponding to the UE selected codebook or codebook subset (e.g., CSI 706B).

[0114] In some aspects, the UE may report the selection indicator indicating the UE selected codebook or codebook subset for the whole bandwidth associated with the CSI measurement. In some other aspects, the UE may report the selection indicator indicating the UE selected codebook or codebook subset for the whole bandwidth associated with each sub-band associated with the CSI measurement.

[0115] In some aspects, if the network entity configures separate CMRs or CMR sets for different codebooks or codebook subsets, the UE reports the CMR index or CMR set index indicating the selected codebook or codebook subset.

[0116] In some aspects, the UE may select a CSI for reporting based on the measured spectrum efficiency (SE). For example, the UE may report the CSI with highest SE. If the SE for some CSIs are the same, the UE may report the CSI with highest power backoff for network energy saving.

[0117] **Figures 11, 12, and 13** illustrate various example configurations of CSI reports, including example reports with separate CSI values for each CSI and example reports with common CSI values for some of the reported CSIs. In some aspects, the network entity may configure whether the UE reports common or separate CSI values. For example, the network entity may configure whether the UE reports common or separate RI, PMI, and/or LI for each CSI.

[0118] **Figure 11** is a diagram illustrating an example CSI report 1100 with separate CSIs for configured codebooks. In some aspects, the UE transmits the CSI report for the configured CSI report configuration including CSIs for all configured codebooks and their corresponding power backoff or power offset, where each CSI is based on one of the configured codebooks or codebook subsets and its corresponding power backoff or power offset. In the example shown in Figure 11, the CSI report 1102 includes measurements from each of the CSIs 1106A-1106C associated with the configured codebooks 704A-704C. The network entity can select a waveform and precoder corresponding to a selected CSI of the reported CSIs.

[0119] In some aspects, the UE may report at least one of the RI, PMI, CQI, and LI for each CSI based on the corresponding codebook or codebook subset and the power backoff or power offset for the CSI. In the example shown in Figure 11, the UE reports separate RI, PMI, and/or CQI for each CSI in CSI report 1102.

[0120] **Figure 12** is a diagram illustrating an example CSI report 1200 with a common RI for configured codebooks. In some other aspects, the UE may report a common RI for all the CSIs, and separate PMI, CQI, and/or LI for each reported CSI. In the example shown in Figure 12, the

measured RI for each of CSIs 1206 is the same, e.g., one ("1"). The CSI report 1202 includes a single common RI for the reported CSIs, and individual PMI and/or CQI for each reported CSI.

[0121] **Figure 13** is a diagram illustrating an example CSI report 1300 with RI or PMI for configured codebooks. In some aspects, the UE may report RI, PMI, and/or LI for one of a CSI corresponding to one codebook or codebook subset and report separate CQIs for each reported CSI. In the example shown in Figure 13, the CSI report 1302 includes separate CQIs for codebooks 704A and 704B based on measured CSIs 1306A and 1306B respectively. The CSI report 1302 includes RI, PMI, and/or CQI for codebook 704C based on measured CSI 1306C. The separately reported codebook or codebook subset may be predefined, e.g., the codebook or codebook subset for Type2 precoders or precoders for a CP-OFDM waveform. Additionally, the codebook or codebook subset may be configured by the network entity. Further, the codebook or codebook subset may be reported by the UE in addition to the CSI values. In some aspects, the UE may measure the CQI based on the reported RI and a UE selected precoder from a corresponding codebook for each CSI.

[0122] When implementing the techniques described herein, there may be UE complexity and reporting time considerations. For example, it may be advantageous to reduce UE complexity in some cases. Further, it may be advantageous to minimize reporting time in some cases.

[0123] In some aspects, UE complexity can be affected by CSI processing units (CPUs). In some aspects, network entity and the UE determine the number of CPUs for a CSI report based on the number of configured codebooks or codebook subsets (N) and/or the CSI resources configured as CMR (K). In some aspects, the network entity and UE may determine the number of CPUs as $NK+M$, where M indicates additional CPUs for CSI processing (e.g., CSI comparison for the CSIs from the configured codebooks or codebook subsets). In some other aspects, the network entity and UE may determine the number of CPUs as $\text{ceil}(RNK)+M$, where R is in the range of (0, 1), and the value may be predefined or reported by the UE as part of the UE capability information. In some aspects, M may be predefined, e.g., $M=0$. In some aspects, M may be reported as part of the UE capability information.

[0124] In some aspects, if the number of occupied CPUs for the CSI report in a component carrier (CC) or across all configured CCs exceeds a maximum number of CPUs the UE reported in the UE capability information, the UE may report outdated CSI(s) for the CSI report or may refrain from transmitting the CSI report.

[0125] In some aspects, the network entity and UE may determine the minimum processing delay Z and Z' for the CSI report based on the number of configured codebooks or codebook subsets (N) and/or the number of CSI resources configured as CMR (K), where Z indicates the minimum offset between the last symbol of the PDCCH scheduling the CSI report and the first

symbol of the PUSCH or PUCCH with the CSI report, and Z' indicates the minimum between the last symbol of the last CMR/IMR and the first symbol of the PUSCH or PUCCH with the CSI report.

[0126] For example, in some aspects, the network entity and the UE may determine the minimum processing delay as $Z=Z_xNK$ and $Z'=Z_x'NK$, where Z_x and Z_x' are Z_2 and Z_2' or Z_3 and Z_3' as defined in 3GPP TS 38.214. In some other aspects, the network entity and UE determines the minimum processing delay as $Z=Z_xN$ and $Z'=Z_x'N$. In still other aspects, the network entity and the UE may determine the minimum processing delay as $Z=Z_x+r$ and $Z'=Z_x'+r$, where r may be predefined or reported by the UE via UE capability information. In yet further aspects, the network entity and UE may determine the minimum processing delay as $Z=Z_xN+r$ and $Z'=Z_x'N+r$. If the scheduling offset for the CSI report is smaller than the minimum processing delay, the UE may report an outdated CSI or may refrain from transmitting the CSI report.

[0127] It is noted that throughout this disclosure, an expression of “X/Y” may include meaning of “X or Y”. It is noted that throughout this disclosure, an expression of “X/Y” may include meaning of “X and Y”. It is noted that throughout this disclosure, an expression of “X/Y” may include meaning of “X and/or Y”. It is noted that throughout this disclosure, an expression of “(A) B” or “B (A)” may include concept of “only B”. It is noted that throughout this disclosure, an expression of “(A) B” or “B (A)” may include concept of “A+B” or “B+A”.

[0128] It is noted that some or all of the foregoing or the following implementations can be jointly combined or formed to be a new or another one implementation.

[0129] It is noted that the foregoing or the following techniques can be used to solve at least (but not limited to) the issue(s) or scenario(s) mentioned in this disclosure.

[0130] The following additional considerations may apply to the foregoing and the following discussions.

[0131] It is noted that any two or more than two of the foregoing or the following paragraphs, (sub)-bullets, points, actions, or claims described in each method/technique/implementation may be combined logically, reasonably, and properly to form a specific method.

[0132] It is noted that any sentence, paragraph, (sub)-bullet, point, action, or claim described in each of the foregoing or the following technique(s)/implementation(s)/concept(s) may be implemented independently and separately to form a specific method. Dependency, such as “based on”, “more specifically”, “where” or etc., in technique(s)/implementation(s)/concept(s) mentioned in this disclosure is just one possible implementation which would not restrict the specific method.

[0133] Certain techniques are described in this disclosure as including logic or a number of components or modules. Modules may be software modules (such as code stored on non-transitory

machine-readable medium) or hardware modules. A hardware module is a tangible unit capable of performing certain operations and may be configured or arranged in a certain manner. A hardware module can comprise dedicated circuitry or logic that is permanently configured (such as a special-purpose processor, such as a field programmable gate array (FPGA) or an application-specific integrated circuit (ASIC)) to perform certain operations. A hardware module may also comprise programmable logic or circuitry (for example, as encompassed within a general-purpose processor or other programmable processor) that is temporarily configured by software to perform certain operations. The decision to implement a hardware module in dedicated and permanently configured circuitry, or in temporarily configured circuitry (for example, configured by software) may be driven by cost and time considerations.

[0134] Figures 1, 2, 3A, 3B, 4A, 4B, and 5-13 and the operations described herein are examples meant to aid in understanding example implementations and should not be used to limit the potential implementations or limit the scope of the claims. Some implementations might include additional operations, fewer operations, operations in parallel or in a different order, and some operations differently.

[0135] As used herein, the terms “component” and “module” are intended to be broadly construed as hardware, firmware, or a combination of hardware and software. As used herein, a processor is implemented in hardware, firmware, or a combination of hardware and software. As used herein, the phrase “based on” is intended to be broadly construed to mean “based at least in part on.”

[0136] Some aspects are described herein in connection with thresholds. As used herein, satisfying a threshold may refer to a value being greater than the threshold, greater than or equal to the threshold, less than the threshold, less than or equal to the threshold, equal to the threshold, not equal to the threshold, or the like.

[0137] As used herein, a phrase referring to “at least one of” or “one or more of” a list of items refers to any combination of those items, including single members. For example, “at least one of: a, b, or c” is intended to cover the possibilities of: a only, b only, c only, a combination of a and b, a combination of a and c, a combination of b and c, and a combination of a and b and c.

[0138] In this disclosure, the term “can” indicates a capability, or alternatively indicates a possible implementation option. The term “may” indicates a permission or a possible implementation option.

[0139] The various illustrative components, logic, logical blocks, modules, circuits, operations and algorithm processes described in connection with the implementations disclosed herein may be implemented as electronic hardware, firmware, software, or combinations of hardware, firmware or software, including the structures disclosed in this specification and the structural

equivalents thereof. The interchangeability of hardware, firmware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and processes described above. Whether such functionality is implemented in hardware, firmware or software depends upon the particular application and design constraints imposed on the overall system.

[0140] The hardware and data processing apparatus used to implement the various illustrative components, logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, or any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, for example, a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular processes, operations and methods may be performed by circuitry that is specific to a given function.

[0141] As described above, in some aspects implementations of the subject matter described in this specification can be implemented as software. For example, various functions of components disclosed herein, or various blocks or steps of a method, operation, process or algorithm disclosed herein can be implemented as one or more modules of one or more computer programs. Such computer programs can include non-transitory processor- or computer-executable instructions encoded on one or more tangible processor- or computer-readable storage media for execution by, or to control the operation of, data processing apparatus including the components of the devices described herein. By way of example, and not limitation, such storage media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store program code in the form of instructions or data structures. Combinations of the above should also be included within the scope of storage media. When implemented in software, the techniques can be provided as part of the operating system, a library used by multiple applications, a particular software application, etc. The software can be executed by one or more general-purpose processors or one or more special-purpose processors.

[0142] As used herein, the terms “user device”, “user equipment” (for example, UE 110), “wireless communication device”, “mobile communication device”, “communication device”, or “mobile device” refer to any one or all of cellular telephones, smartphones, portable computing

devices, personal or mobile multi-media players, laptop computers, tablet computers, smartbooks, Internet-of-Things (IoT) devices, palm-top computers, wireless electronic mail receivers, multimedia Internet enabled cellular telephones, wireless gaming controllers, display sub-systems, driver assistance systems, vehicle controllers, vehicle system controllers, vehicle communication system, infotainment systems, vehicle telematics systems or subsystems, vehicle display systems or subsystems, vehicle data controllers, point-of-sale (POS) terminals, health monitoring devices, drones, cameras, media-streaming dongles or another personal media devices, wearable devices such as smartwatches, wireless hotspots, femtocells, broadband routers or other types of routers, and similar electronic devices which include a programmable processor and memory and circuitry configured to perform operations as described herein. Further, the user device in some cases may be embedded in an electronic system such as the head unit of a vehicle or an advanced driver assistance system (ADAS). Still further, a mobile-internet device (MID). Depending on the type, the user device can include one or more general-purpose processors, a computer-readable memory, a user interface, one or more network interfaces, one or more sensors, etc.

[0143] Various modifications to the implementations described in this disclosure may be readily apparent to persons having ordinary skill in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

[0144] Additionally, various features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. As such, although features may be described above as acting in particular combinations, and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0145] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one or more example processes in the form of a flowchart or flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the

illustrated operations. In some circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

[0146] The foregoing disclosure provides illustration and description but is not intended to be exhaustive or to limit the aspects to the precise form disclosed. Modifications and variations may be made in light of the above disclosure or may be acquired from practice of the aspects. While the aspects of the disclosure have been described in terms of various examples, any combination of aspects from any of the examples is also within the scope of the disclosure. The examples in this disclosure are provided for pedagogical purposes.

CLAIMS

What is claimed is:

1. A method for wireless communications by a user equipment (UE) (110), comprising:
receiving (404, 504), from a network entity (120), at least one channel state information (CSI) report configuration (219), the at least one CSI report configuration including:
 - a plurality of codebook entities (220),
 - one or more power relationship indicators indicating a power relationship between a physical downlink shared channel (PDSCH) and a CSI reference signal (CSI-RS) for each codebook entity of the plurality of codebook entities, and
 - one or more channel measurement resources (CMRs) associated with the CSI-RS;receiving (408, 508), from the network entity, the one or more CMRs; and
transmitting (412, 512), to the network entity, at least one CSI report based on the at least one CSI report configuration and the one or more CMRs.
2. The method of claim 1, further comprising transmitting (402, 502) UE capability information including at least one of:
 - a first indicator indicating support for providing CSI feedback based on one or more codebook entities and power relationship indicators corresponding to the one or more codebook entities;
 - a maximum number of codebook entities with different power relationship indicators;
 - a maximum number of reported CSIs for the at least one CSI report;
 - a number of CSI processing units (CPUs) for the at least one CSI report; or
 - a second indicator indicating a minimum processing delay for the at least one CSI report.
3. The method of any one of claims 1-2, wherein the at least one CSI report configuration further includes at least one of:
 - at least one waveform indicator indicating a target waveform for the PDSCH based on the reported CSI;

- at least one interference measurement resource (IMR);
 - a rank restriction indicator indicating a candidate number of layers for CSI feedback;
 - a first channel quality indicator (CQI) table indicator indicating a common or separate CQI table for the plurality of codebook entities;
 - a second CQI table indicator indicating a separate CQI table for each of the plurality of codebook entities;
 - an indicator indicating a number of reported CSIs;
 - a configuration of power relationship indicators for channel quality indicators (CQIs) corresponding to different modulation orders;
 - one or more common CMRs for the plurality of codebook entities; or
 - one or more separate CMRs for the plurality of codebook entities.
4. The method of claim 3, wherein the target waveform comprises at least one of:
- a cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) waveform,
 - a discrete Fourier transform spread orthogonal frequency division multiplexing (DFT-s-OFDM) waveform, or
 - a single-carrier frequency division multiple access (SC-FDMA) waveform.
5. The method of any one of claims 1-4, wherein receiving the one or more CMRs comprises receiving a plurality of CMRs, each of the plurality of CMRs having a same value for at least one of:
- a number of antenna ports;
 - a bandwidth;
 - a configuration of subcarriers;
 - a periodicity; or
 - a transmission configuration indication (TCI) state.
6. The method of any one of claims 1-5, further comprising calculating a CSI for the at least one CSI report based on at least one of:
- one of the plurality of codebook entities;
 - a power relationship indicator for one of the plurality of codebook entities;
 - a target waveform for one of the plurality of codebook entities; or
 - a rank restriction for one of the plurality of codebook entities.

7. The method of any one of claims 1-6, wherein the transmitting comprises transmitting at least one of:
 - a subset of measured CSIs in the at least one CSI report;
 - a first indicator indicating a number of reported CSIs;
 - a second indicator indicating a codebook entity of the plurality of codebook entities for each reported CSI;
 - all the measured CSIs in the at least one CSI report;
 - a rank indicator (RI) for each CSI in the at least one CSI report;
 - a precoder matrix indicator (PMI) for each CSI in the at least one CSI report;
 - a channel quality indicator (CQI) for each CSI in the at least one CSI report;
 - a layer indicator (LI) for each CSI in the at least one CSI report;
 - a common RI for all reported CSIs; or
 - at least one of a common RI, common PMI, or common LI based on one of the plurality of codebook entities and the CQI for each CSI in the at least one CSI report.
8. The method of claim 7, further comprising calculating a CQI for each CSI based on an RI corresponding to the CSI and a codebook entity of the plurality of codebook entities corresponding to the CSI.
9. The method of any one of claims 1-8, further comprising:
 - refraining from transmitting the CSI report when:
 - a number of occupied CPUs in a component carrier (CC) or across CCs exceeds a maximum number of CPUs, or
 - a scheduling offset for the CSI report is smaller than a minimum processing delay.
10. The method of any of claims 1-9, further comprising determining either or both a number of CPUs or a minimum scheduling offset based on at least one of:
 - a number of the plurality of codebook entities; or
 - a number of the one or more CMRs.

11. A method for wireless communications by a network entity (120), comprising:
 - transmitting (404, 604), to a user equipment (UE) (110), at least one channel state information (CSI) report configuration (219), the at least one CSI report configuration including:
 - a plurality of codebook entities (320),
 - one or more power relationship indicators indicating a power relationship between a physical downlink shared channel (PDSCH) and a CSI reference signal (CSI-RS) for each codebook entity of plurality of codebook entities, and
 - one or more channel measurement resources (CMRs) associated with the CSI-RS;
 - transmitting (408, 608), to the UE, the one or more CMRs; and
 - receiving (412, 414, 612), from the UE, at least one CSI report based on the at least one CSI report configuration and the one or more CMRs.
12. The method of claim 11, further comprising receiving (402, 602), from the UE, UE capability information including at least one of:
 - a first indicator indicating support for providing CSI feedback based on one or more codebook entities and power relationship indicators corresponding to the one or more codebook entities;
 - a maximum number of codebook entities with different power relationship indicators;
 - a maximum number of codebook entities with different power relationship indicators;
 - a maximum number of reported CSIs for the at least one CSI report;
 - a number of CSI processing units (CPUs) for the at least one CSI report; or
 - a second indicator indicating a minimum processing delay for the at least one CSI report.
13. The method of any one of claims 11-12, wherein the at least CSI report configuration further includes at least one of:
 - at least one waveform indicator indicating a target waveform for the PDSCH based on the reported CSI;
 - at least one interference measurement resource (IMR);
 - a rank restriction indicator indicating a candidate number of layers for CSI feedback;

- a channel quality indicator (CQI) table indicator indicating a common or separate CQI tables for the plurality of codebook entities;
 - a first indicator indicating a number of reported CSIs;
 - a second indicator indicating a maximum number of reported CSIs;
 - a configuration of power relationship indicators for channel quality indicators (CQIs) corresponding to different modulation orders;
 - one or more common CMRs for the plurality of codebook entities; or
 - one or more separate CMRs for the plurality of codebook entities.
14. The method of any one of claims 11-13, wherein the receiving comprises receiving, from the UE, at least one of:
- a subset of measured CSIs in the at least one CSI report;
 - a first indicator indicating a number of reported CSIs;
 - a second indicator indicating a codebook entity of the plurality of codebook entities for each reported CSI;
 - all the measured CSIs in the at least one CSI report;
 - a rank indicator (RI) for each CSI in the at least one CSI report;
 - a precoder matrix indicator (PMI) for each CSI in the at least one CSI report;
 - a channel quality indicator (CQI) for each CSI in the at least one CSI report;
 - a layer indicator (LI) for each CSI in the at least one CSI report;
 - a common RI for all reported CSIs; or
 - at least one of a common RI, common PMI, or common LI based on one of the plurality of codebook entities and the CQI for each CSI in the at least one CSI report.
15. The method of any one of claims 1-14, wherein the plurality of codebook entities comprises a plurality of codebooks or codebook subsets, and wherein the one or more power relationship indicators comprise one or more power backoff indicators or power offset indicators.
16. An apparatus, comprising:
- a communication unit; and
 - a processing system configured to control the communication unit to implement any one of the methods of claims 1-15.

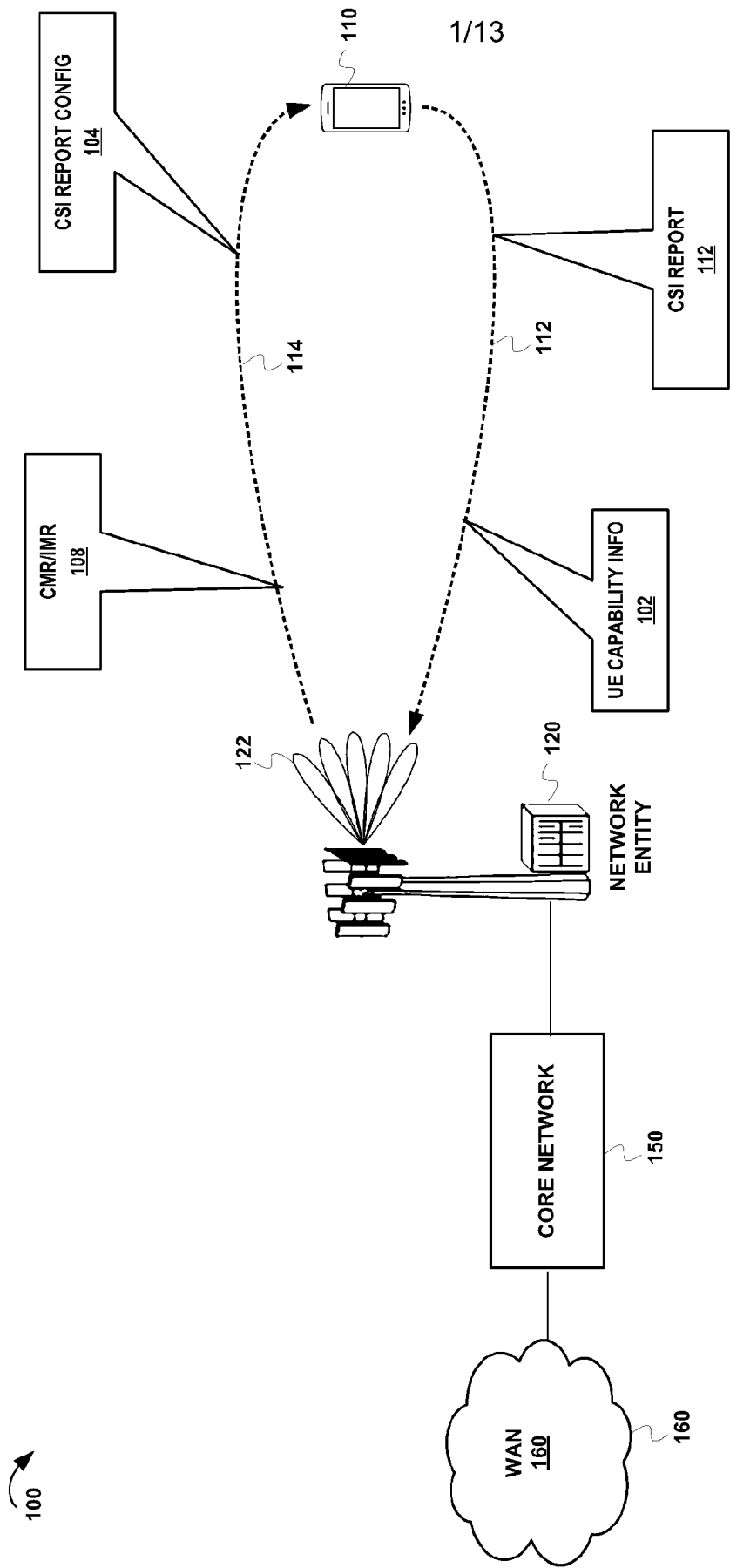


FIGURE 1

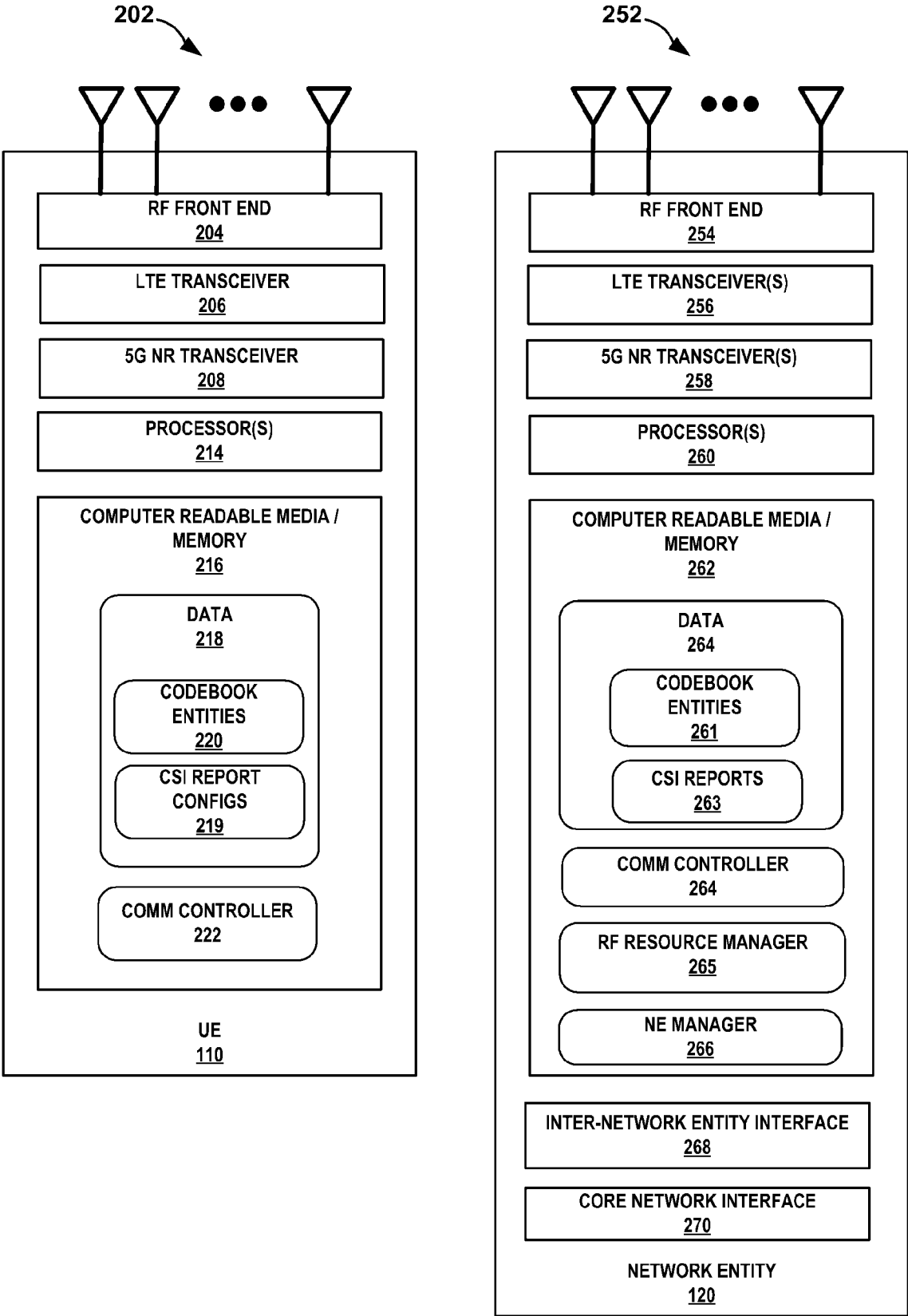


FIGURE 2

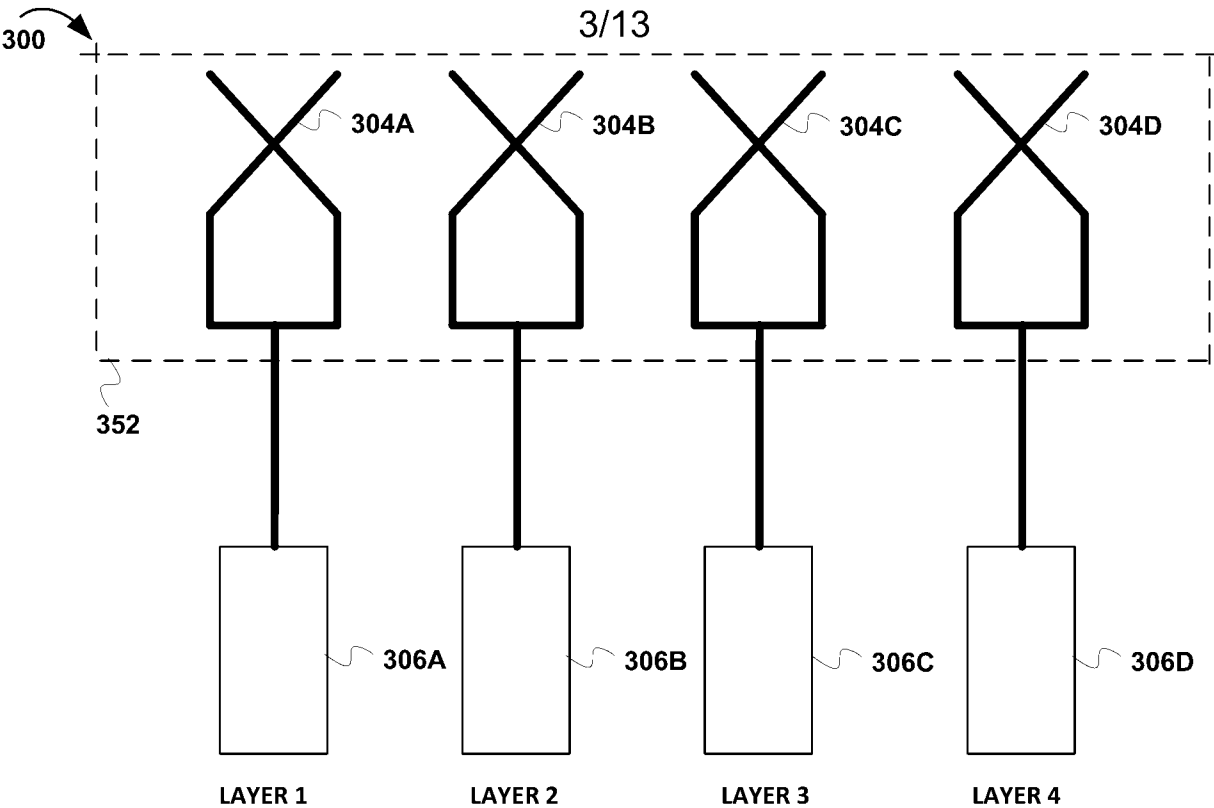


FIGURE 3A

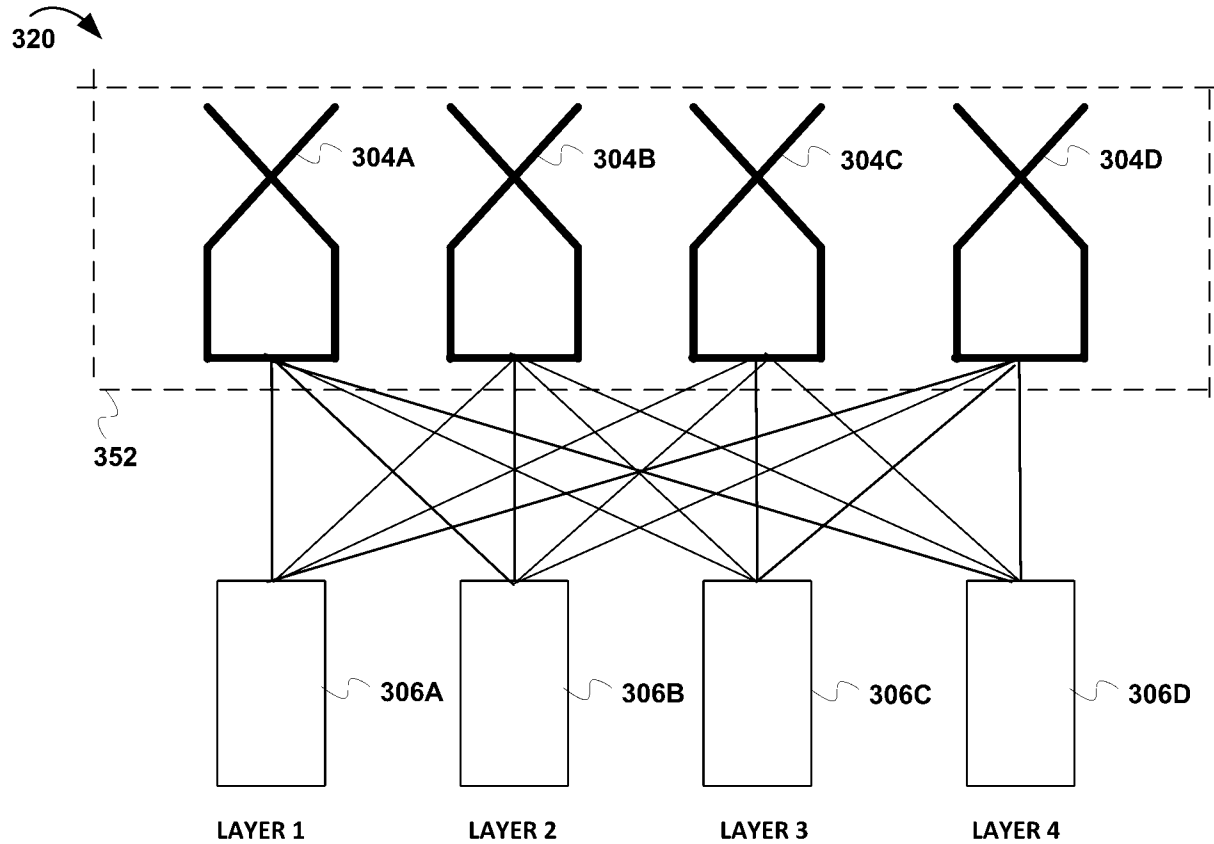


FIGURE 3B

4/13

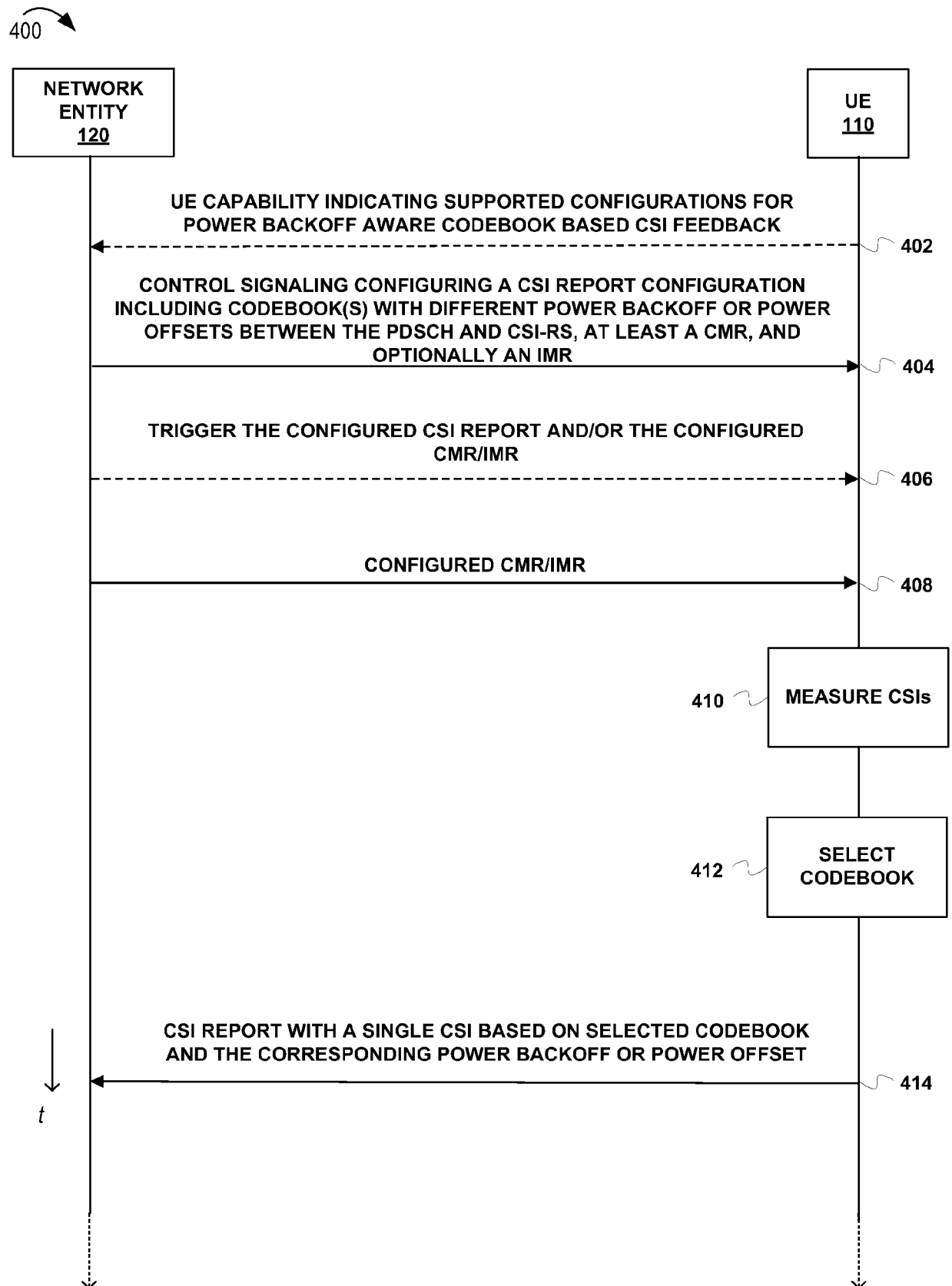


FIGURE 4A

5/13

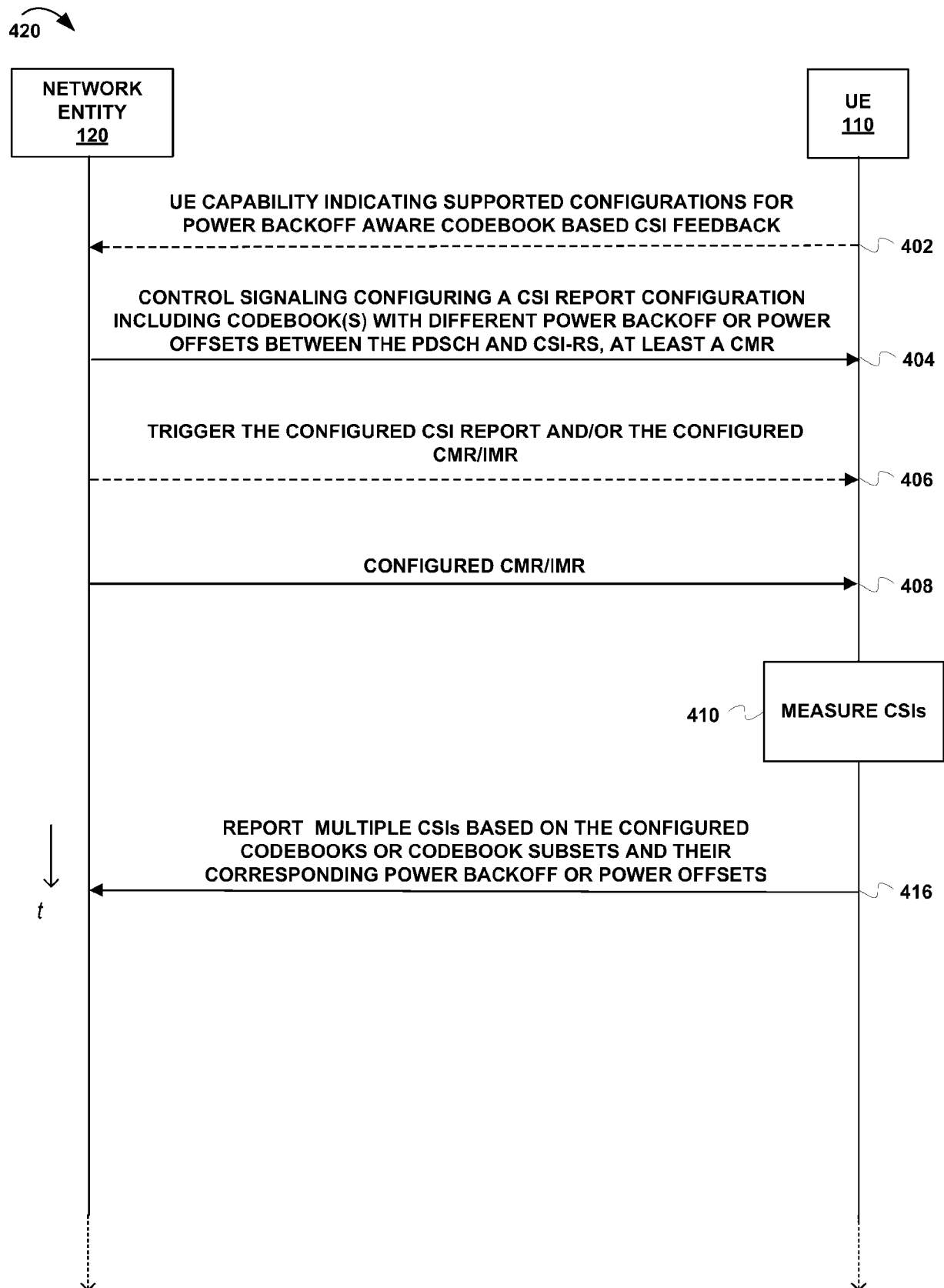


FIGURE 4B

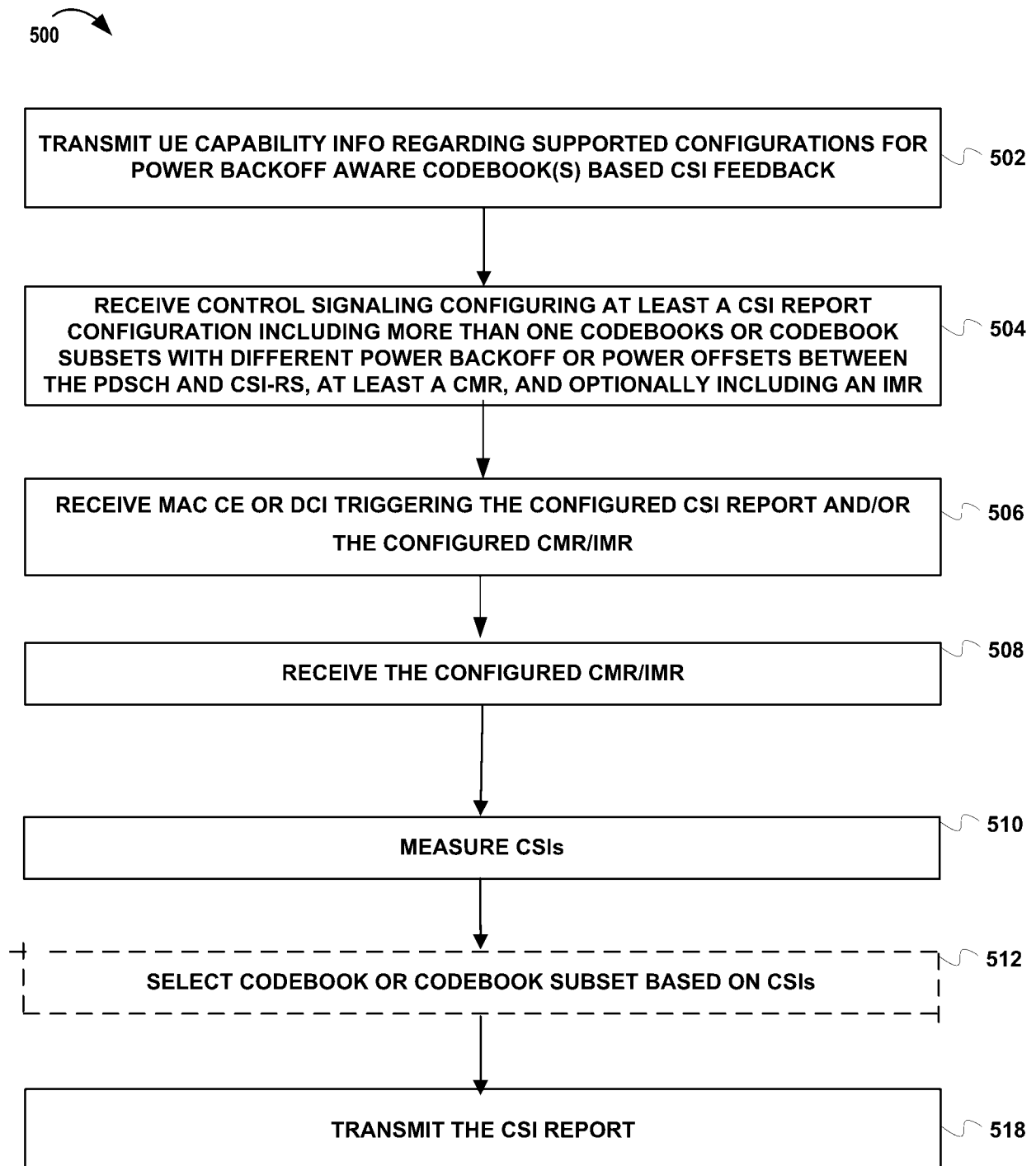
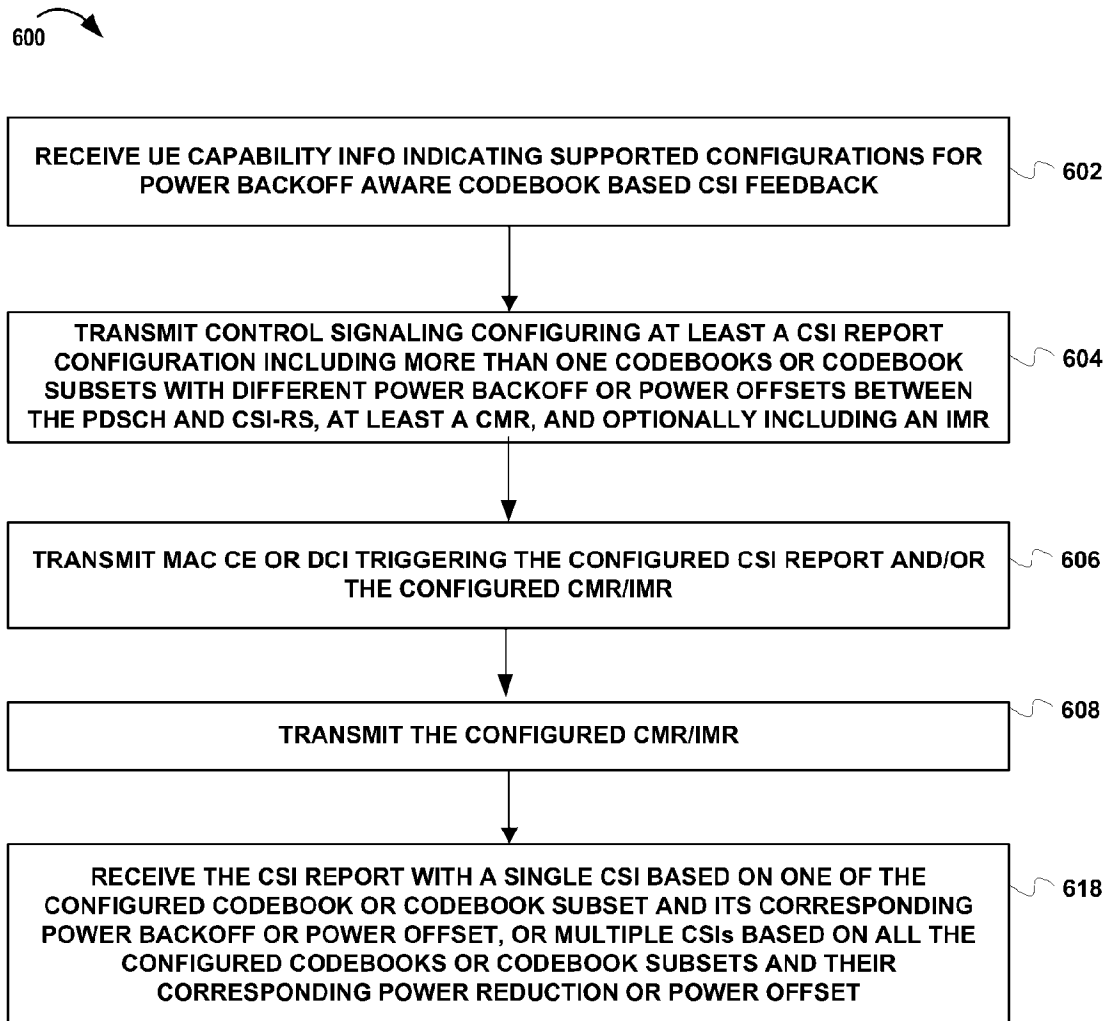


FIGURE 5

7/13

**FIGURE 6**

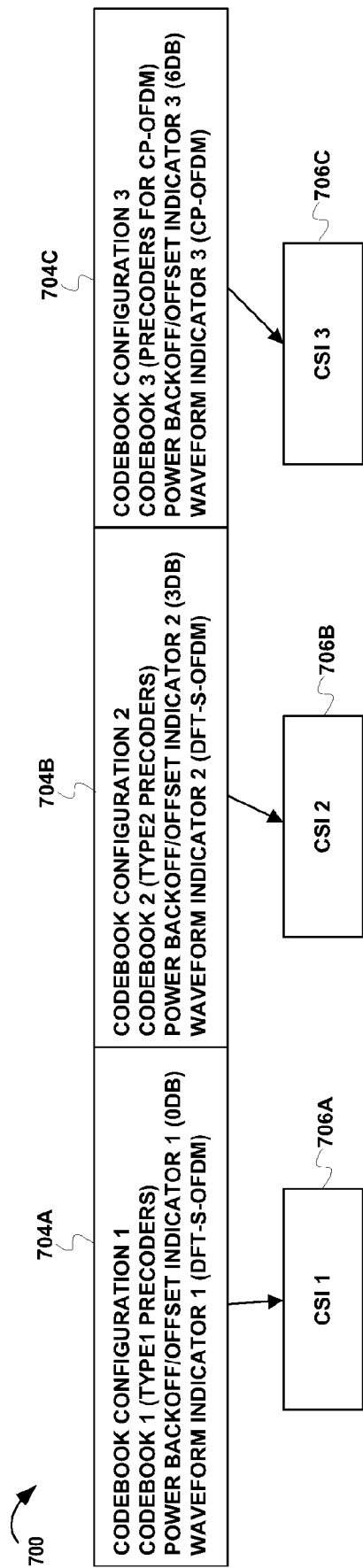


FIGURE 7

8/13

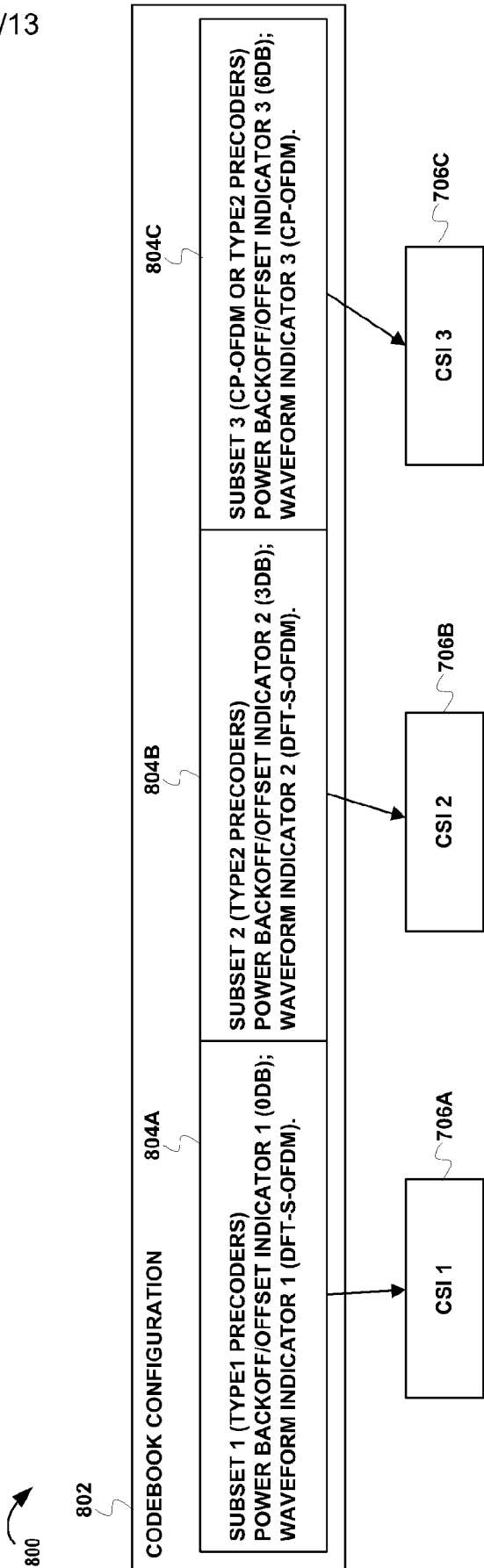


FIGURE 8

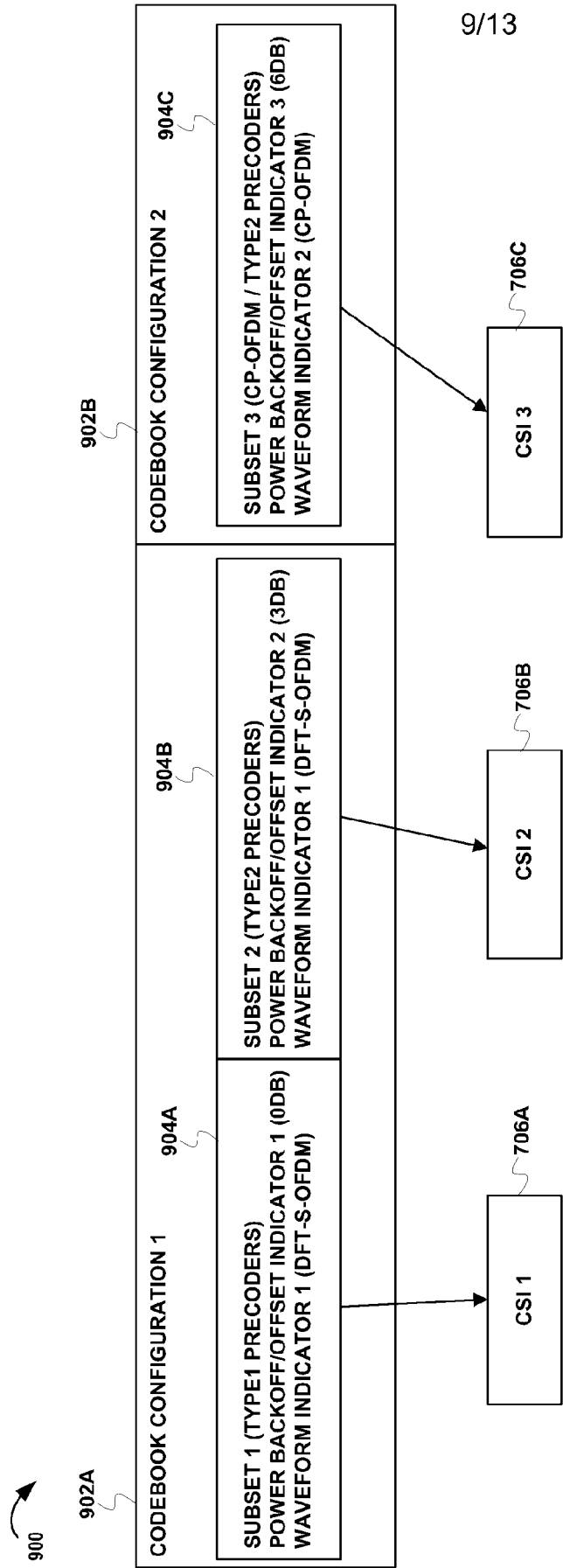


FIGURE 9

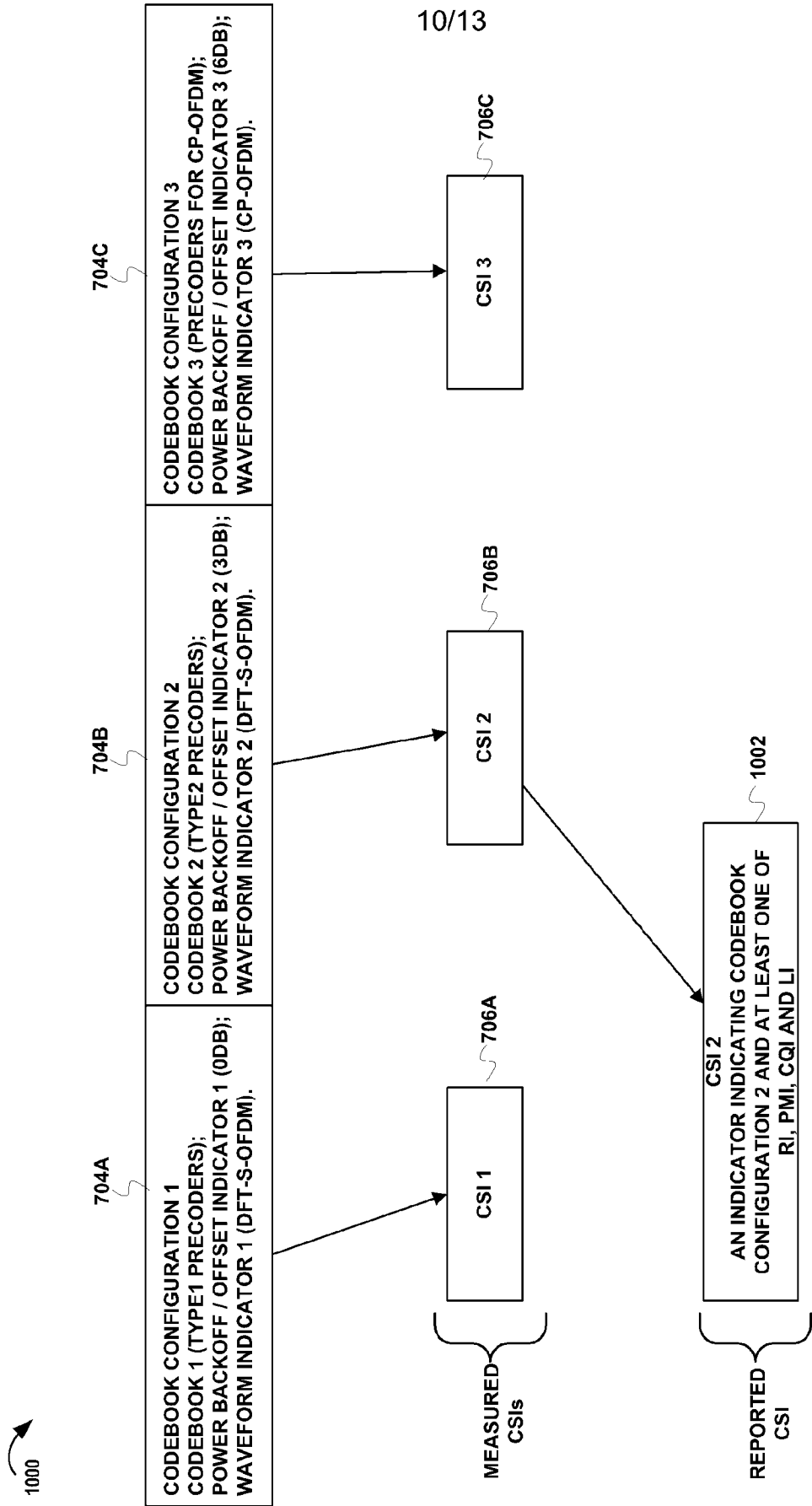


FIGURE 10

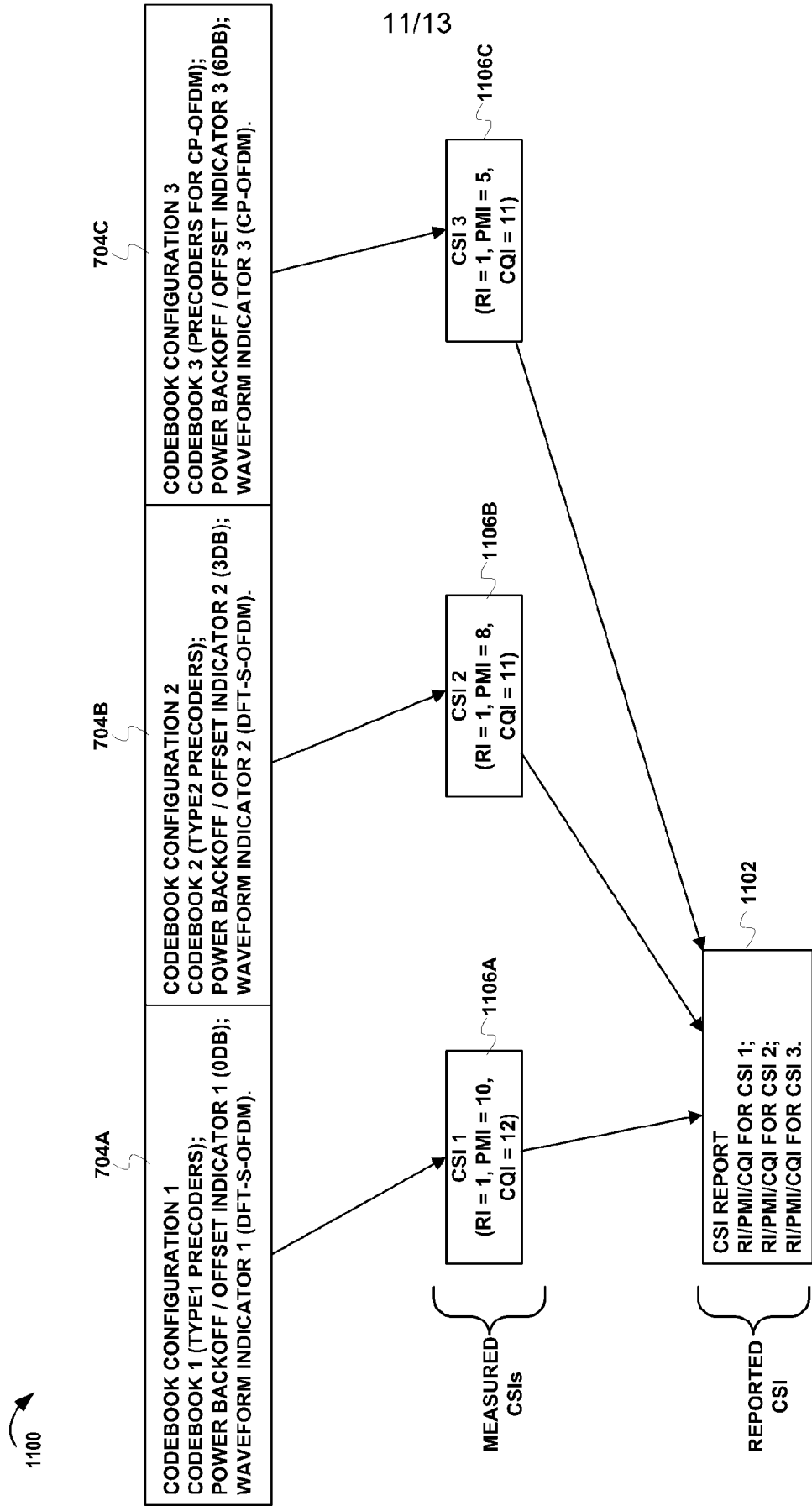


FIGURE 11

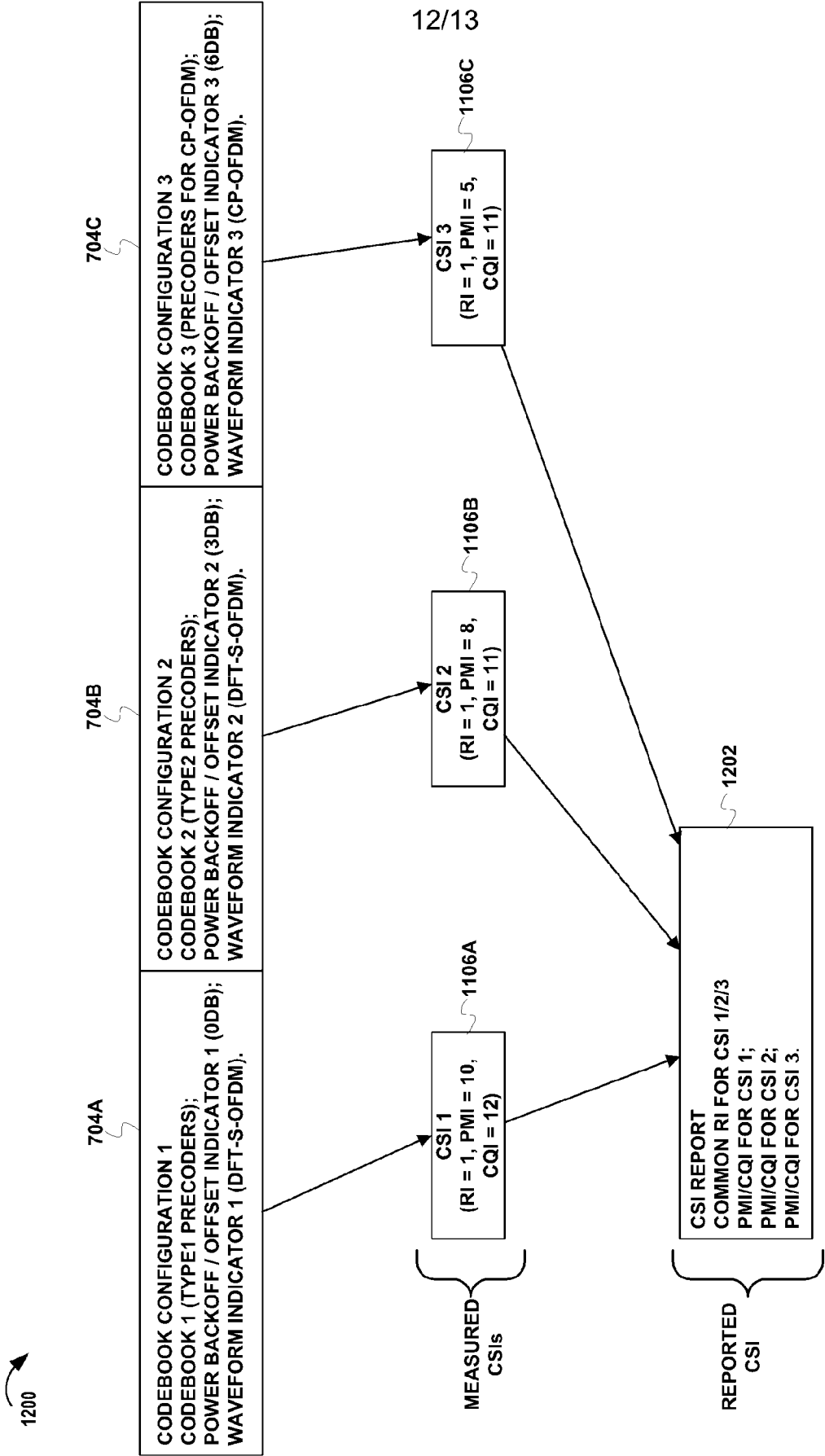


FIGURE 12

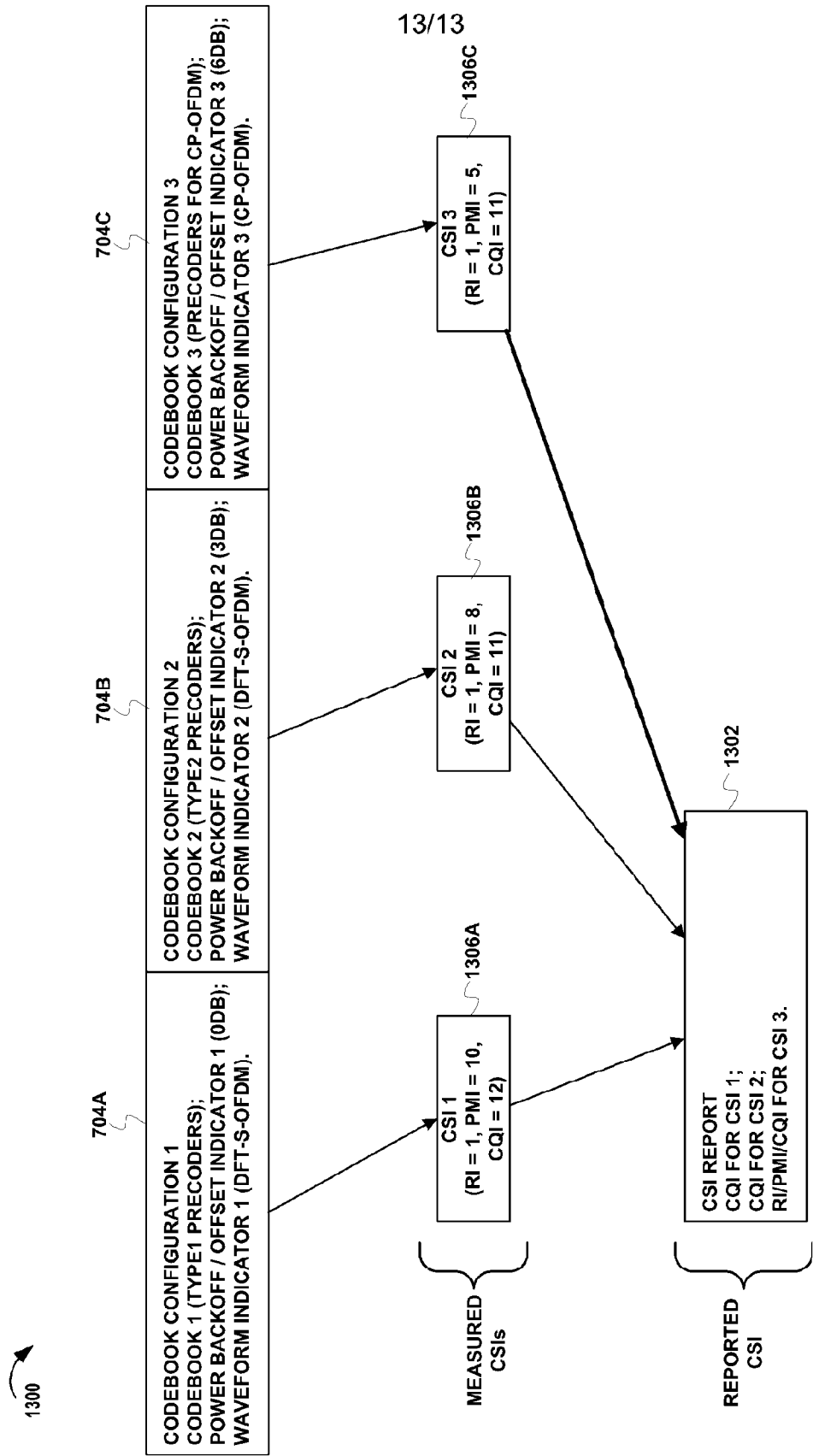


FIGURE 13

INTERNATIONAL SEARCH REPORT

International application No

PCT/CN2023/112573

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04B7/0456 H04B7/06 H04L5/00 H04W72/23
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B H04W H04L

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MODERATOR (HUAWEI): "Final FL summary for SD and PD adaptation for R18 NES", 3GPP DRAFT; R1-2306034, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE / vol. RAN WG1, no. Incheon, Korea; 20230522 - 20230526 26 May 2023 (2023-05-26), XP052493721, Retrieved from the Internet: URL:https://ftp.3gpp.org/Meetings_3GPP_SYN C/RAN1/Inbox/R1-2306034.zip [retrieved on 2023-05-26]	1-3,5-16
Y	Sections 2, 3, 4, 5, 6 and 11 ----- -/--	4

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

5 February 2024

Date of mailing of the international search report

13/02/2024

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Ganis, Alexander

INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2022/024042 A1 (ERICSSON TELEFON AB L M [SE]) 3 February 2022 (2022-02-03) paragraphs [0003], [0122] - [0123] -----	4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/CN2023/112573

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CN 116325623 A	23-06-2023
		EP 4189844 A1	07-06-2023
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		WO 2022024042 A1	03-02-2022
