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(71) Applicant: **QUALCOMM INCORPORATED** [US/US]; Attn: International IP Administration, 5775 Morehouse Drive, San Diego, California 92121-1714 (US).

(72) Inventors; and
(71) Applicants *(for US only)*: **YUAN, Fang** [CN/CN]; 5775 Morehouse Drive, San Diego, California 92121-1714 (US). **NAM, Wooseok** [KR/US]; 5775 Morehouse Drive, San Diego, California 92121-1714 (US). **ZHOU, Yan** [CN/US]; 5775 Morehouse Drive, San Diego, California 92121-1714 (US). **ZHENG, Ruiming** [CN/CN]; 5775 Morehouse Drive, San Diego, California 92121-1714 (US). **LUO, Tao** [US/US]; 5775 Morehouse Drive, San Diego, California 92121-1714 (US).

(74) Agent: **NTD PATENT & TRADEMARK AGENCY LTD.**; 10th Floor, Tower C, Beijing Global Trade Center, 36 North Third Ring Road East, Dongcheng District, Beijing 100013 (CN).

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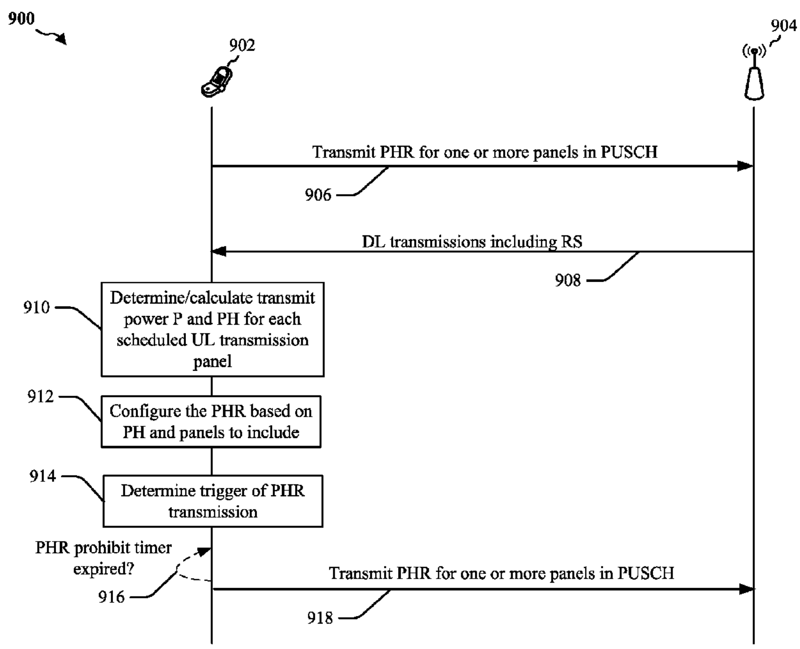

FIG. 9

(57) Abstract: Aspects relate to technologies and techniques for power headroom report (PHR) determination and triggering for multi-panel uplink transmissions. Apparatus and methods provide the determination of a respective transmission power value for each panel in a multi-panel uplink transmission. A power headroom value is calculated for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value. The power headroom value for at least one panel is transmitted in a power headroom report on an uplink channel. Also, triggering of transmission of the PHR may be accomplished by determining a change in a path loss metric based on at least a path loss change for at least one panel over a time period, or a path loss change for two different panels over the time period.

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PHR TRIGGER AND REPORT FOR MULTI-PANEL UPLINK TRANSMISSION

BACKGROUND

Technical Field

[0001] The present disclosure relates generally to communication systems, and more particularly, to a power headroom report (PHR) trigger and report for a multi-panel uplink transmission.

Introduction

[0002] Wireless communication systems are widely deployed to provide various telecommunication services such as telephony, video, data, messaging, and broadcasts. Typical wireless communication systems may employ multiple-access technologies capable of supporting communication with multiple users by sharing available system resources. Examples of such multiple-access technologies include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems, single-carrier frequency division multiple access (SC-FDMA) systems, and time division synchronous code division multiple access (TD-SCDMA) systems.

[0003] These multiple access technologies have been adopted in various telecommunication standards to provide a common protocol that enables different wireless devices to communicate on a municipal, national, regional, and even global level. An example telecommunication standard is 5G New Radio (NR). 5G NR is part of a continuous mobile broadband evolution promulgated by Third Generation Partnership Project (3GPP) to meet new requirements associated with latency, reliability, security, scalability (e.g., with Internet of Things (IoT)), and other requirements. 5G NR includes services associated with enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra reliable low latency communications (URLLC). Some aspects of 5G NR may be based on the 4G Long Term Evolution (LTE) standard. There exists a need for further improvements in 5G NR technology. These improvements may also be applicable to other multi-access technologies and the telecommunication standards that employ these technologies.

SUMMARY

[0004] The following presents a simplified summary of one or more aspects in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated aspects, and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present some concepts of one or more aspects in a simplified form as a prelude to the more detailed description that is presented later.

[0005] In an aspect of the disclosure, a method, a computer-readable medium, and an apparatus are provided. The apparatus determines, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission. The apparatus also calculates a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value. Further, the apparatus transmits the power headroom value for at least one panel in a power headroom report on an uplink channel.

[0006] To the accomplishment of the foregoing and related ends, the one or more aspects comprise the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative features of the one or more aspects. These features are indicative, however, of but a few of the various ways in which the principles of various aspects may be employed, and this description is intended to include all such aspects and their equivalents.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a diagram illustrating an example of a wireless communications system and an access network.

[0008] FIGs. 2A, 2B, 2C, and 2D are diagrams illustrating examples of a first 5G/NR frame, DL channels within a 5G/NR subframe, a second 5G/NR frame, and UL channels within a 5G/NR subframe, respectively.

[0009] FIG. 3 is a diagram illustrating an example of a base station and user equipment (UE) in an access network.

[0010] FIG. 4 illustrates exemplary plots of multi-panel transmissions over time for various multiplexing schemes according to some aspects.

[0011] FIG. 5 illustrates an example of a power headroom report (PHR) using a MAC-CE format according to aspects of the present disclosure.

[0012] FIG. 6 illustrates another example of a power headroom report (PHR) using a MAC-CE format according to some aspects.

[0013] FIGs. 7A, 7B, and 7C illustrate examples of timing diagrams of PHR triggering according to some aspects.

[0014] FIGs. 8A, 8B, 8C, and 8D illustrate examples of timing diagrams of PHR triggering according to some aspects.

[0015] FIG. 9 is a call flow diagram illustrating various processes for wireless communication according to some aspects.

[0016] FIG. 10 is a flowchart of a method of wireless communication.

[0017] FIG. 11 is a flowchart of a method of wireless communication.

[0018] FIG. 12 is a conceptual data flow diagram illustrating the data flow between different means/components in an example apparatus.

[0019] FIG. 13 is a diagram illustrating an example of a hardware implementation for an apparatus employing a processing system.

DETAILED DESCRIPTION

[0020] The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

[0021] Several aspects of telecommunication systems will now be presented with reference to various apparatus and methods. These apparatus and methods will be described in the following detailed description and illustrated in the accompanying drawings by various blocks, components, circuits, processes, algorithms, etc. (collectively referred to as "elements"). These elements may be implemented using electronic hardware, computer software, or any combination thereof. Whether such elements are implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system.

[0022] By way of example, an element, or any portion of an element, or any combination of elements may be implemented as a "processing system" that includes one or more processors. Examples of processors include microprocessors, microcontrollers, graphics processing units (GPUs), central processing units (CPUs), application processors, digital signal processors (DSPs), reduced instruction set computing (RISC) processors, systems on a chip (SoC), baseband processors, field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. One or more processors in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software components, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise.

[0023] Accordingly, in one or more example embodiments, the functions described may be implemented in hardware, software, or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise a random-access memory (RAM), a read-only memory (ROM), an electrically erasable programmable ROM (EEPROM), optical disk storage, magnetic disk storage, other magnetic storage devices, combinations of the aforementioned types of computer-readable media, or any other medium that can be used to store computer executable code in the form of instructions or data structures that can be accessed by a computer.

[0024] FIG. 1 is a diagram illustrating an example of a wireless communications system and an access network 100. The wireless communications system (also referred to as a wireless wide area network (WWAN)) includes base stations 102, UEs 104, an Evolved Packet Core (EPC) 160, and another core network 190 (e.g., a 5G Core (5GC)). The base stations 102 may include macrocells (high power cellular base station) and/or small cells (low power cellular base station). The macrocells include base stations. The small cells include femtocells, picocells, and microcells.

[0025] The base stations 102 configured for 4G LTE (collectively referred to as Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN)) may interface with the EPC 160 through backhaul links 132 (e.g., S1 interface). The base stations 102 configured for 5G NR (collectively referred to as Next Generation RAN (NG-RAN)) may interface with core network 190 through backhaul links 184. In addition to other functions, the base stations 102 may perform one or more of the following functions: transfer of user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (e.g., handover, dual connectivity), inter-cell interference coordination, connection setup and release, load balancing, distribution for non-access stratum (NAS) messages, NAS node selection, synchronization, radio access network (RAN) sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations 102 may communicate directly or indirectly (e.g., through the EPC 160 or core network 190) with each other over backhaul links 134 (e.g., X2 interface). The backhaul links 134 may be wired or wireless.

[0026] The base stations 102 may wirelessly communicate with the UEs 104. Each of the base stations 102 may provide communication coverage for a respective geographic coverage area 110. There may be overlapping geographic coverage areas 110. For example, the small cell 102' may have a coverage area 110' that overlaps the coverage area 110 of one or more macro base stations 102. A network that includes both small cell and macrocells may be known as a heterogeneous network. A heterogeneous network may also include Home Evolved Node Bs (eNBs) (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG). The communication links 120 between the base stations 102 and the UEs 104 may include uplink (UL) (also referred to as reverse link) transmissions from a

UE 104 to a base station 102 and/or downlink (DL) (also referred to as forward link) transmissions from a base station 102 to a UE 104. The communication links 120 may use multiple-input and multiple-output (MIMO) antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. The communication links may be through one or more carriers. The base stations 102/UEs 104 may use spectrum up to Y MHz (e.g., 5, 10, 15, 20, 100, 400, etc. MHz) bandwidth per carrier allocated in a carrier aggregation of up to a total of Yx MHz (x component carriers) used for transmission in each direction. The carriers may or may not be adjacent to each other. Allocation of carriers may be asymmetric with respect to DL and UL (e.g., more or fewer carriers may be allocated for DL than for UL). The component carriers may include a primary component carrier and one or more secondary component carriers. A primary component carrier may be referred to as a primary cell (PCell) and a secondary component carrier may be referred to as a secondary cell (SCell).

[0027] Certain UEs 104 may communicate with each other using device-to-device (D2D) communication link 158. The D2D communication link 158 may use the DL/UL WWAN spectrum. The D2D communication link 158 may use one or more sidelink channels, such as a physical sidelink broadcast channel (PSBCH), a physical sidelink discovery channel (PSDCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH). D2D communication may be through a variety of wireless D2D communications systems, such as for example, FlashLinQ, WiMedia, Bluetooth, ZigBee, Wi-Fi based on the IEEE 802.11 standard, LTE, or NR.

[0028] The wireless communications system may further include a Wi-Fi access point (AP) 150 in communication with Wi-Fi stations (STAs) 152 via communication links 154 in a 5 GHz unlicensed frequency spectrum. When communicating in an unlicensed frequency spectrum, the STAs 152/AP 150 may perform a clear channel assessment (CCA) prior to communicating in order to determine whether the channel is available.

[0029] The small cell 102' may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell 102' may employ NR and use the same 5 GHz unlicensed frequency spectrum as used by the Wi-Fi AP 150. The small cell 102', employing NR in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network.

[0030] A base station 102, whether a small cell 102' or a large cell (e.g., macro base station), may include an eNB, gNodeB (gNB), or another type of base station. Some base stations, such as gNB 180 may operate in a traditional sub 6 GHz spectrum, in millimeter wave (mmW) frequencies, and/or near mmW frequencies in communication with the UE 104. When the gNB 180 operates in mmW or near mmW frequencies, the gNB 180 may be referred to as an mmW base station. Extremely high frequency (EHF) is part of the RF in the electromagnetic spectrum. EHF has a range of 30 GHz to 300 GHz and a wavelength between 1 millimeter and 10 millimeters. Radio waves in the band may be referred to as a millimeter wave. Near mmW may extend down to a frequency of 3 GHz with a wavelength of 100 millimeters. The super high frequency (SHF) band extends between 3 GHz and 30 GHz, also referred to as centimeter wave. Communications using the mmW/near mmW radio frequency band (e.g., 3 GHz – 300 GHz) has extremely high path loss and a short range. The mmW base station 180 may utilize beamforming 182 with the UE 104 to compensate for the extremely high path loss and short range.

[0031] The base station 180 may transmit a beamformed signal to the UE 104 in one or more transmit directions 182'. The UE 104 may receive the beamformed signal from the base station 180 in one or more receive directions 182''. The UE 104 may also transmit a beamformed signal to the base station 180 in one or more transmit directions. The base station 180 may receive the beamformed signal from the UE 104 in one or more receive directions. The base station 180/UE 104 may perform beam training to determine the best receive and transmit directions for each of the base station 180/UE 104. The transmit and receive directions for the base station 180 may or may not be the same. The transmit and receive directions for the UE 104 may or may not be the same.

[0032] The EPC 160 may include a Mobility Management Entity (MME) 162, other MMEs 164, a Serving Gateway 166, a Multimedia Broadcast Multicast Service (MBMS) Gateway 168, a Broadcast Multicast Service Center (BM-SC) 170, and a Packet Data Network (PDN) Gateway 172. The MME 162 may be in communication with a Home Subscriber Server (HSS) 174. The MME 162 is the control node that processes the signaling between the UEs 104 and the EPC 160. Generally, the MME 162 provides bearer and connection management. All user Internet protocol (IP) packets are transferred through the Serving Gateway 166, which itself is connected to the PDN Gateway 172. The PDN Gateway 172 provides UE IP address allocation as well as other functions. The PDN Gateway 172 and the BM-SC 170 are connected to the IP Services 176. The IP Services 176 may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, and/or other IP services. The BM-SC 170 may provide functions for MBMS user service provisioning and delivery. The BM-SC 170 may serve as an entry point for content provider MBMS transmission, may be used to authorize and initiate MBMS Bearer Services within a public land mobile network (PLMN), and may be used to schedule MBMS transmissions. The MBMS Gateway 168 may be used to distribute MBMS traffic to the base stations 102 belonging to a Multicast Broadcast Single Frequency Network (MBSFN) area broadcasting a particular service, and may be responsible for session management (start/stop) and for collecting eMBMS related charging information.

[0033] The core network 190 may include a Access and Mobility Management Function (AMF) 192, other AMFs 193, a Session Management Function (SMF) 194, and a User Plane Function (UPF) 195. The AMF 192 may be in communication with a Unified Data Management (UDM) 196. The AMF 192 is the control node that processes the signaling between the UEs 104 and the core network 190. Generally, the AMF 192 provides QoS flow and session management. All user Internet protocol (IP) packets are transferred through the UPF 195. The UPF 195 provides UE IP address allocation as well as other functions. The UPF 195 is connected to the IP Services 197. The IP Services 197 may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, and/or other IP services.

[0034] The base station may also be referred to as a gNB, Node B, evolved Node B (eNB), an access point, a base transceiver station, a radio base station, a radio transceiver, a transceiver function, a basic service set (BSS), an extended service set (ESS), a transmit reception point (TRP), or some other suitable terminology. The base station 102 provides an access point to the EPC 160 or core network 190 for a UE 104. Examples of UEs 104 include a cellular phone, a smart phone, a session initiation protocol (SIP) phone, a laptop, a personal digital assistant (PDA), a satellite radio, a global positioning system, a multimedia device, a video device, a digital audio player (e.g., MP3 player), a camera, a game console, a tablet, a smart device, a wearable device, a vehicle, an electric meter, a gas pump, a large or small kitchen appliance, a healthcare device, an implant, a sensor/actuator, a display, or any other similar functioning device. Some of the UEs 104 may be referred to as

IoT devices (e.g., parking meter, gas pump, toaster, vehicles, heart monitor, etc.). The UE 104 may also be referred to as a station, a mobile station, a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal, a mobile terminal, a wireless terminal, a remote terminal, a handset, a user agent, a mobile client, a client, or some other suitable terminology.

[0035] Referring again to FIG. 1, in some aspects, the UE 104 may be configured to generate a power headroom report (PHR) generation including reporting the power headroom per each panel in a multi-panel transmission on the uplink (UL) as shown at 198. Furthermore, in other aspects, the UE 104 may be configured to initiate or trigger the transmission of the PHR based on path loss metric changes as also indicated at 198. Of further note, although the following description may be focused on 5G NR, the concepts described herein may be applicable to other similar areas, such as LTE, LTE-A, CDMA, GSM, and other wireless technologies.

[0036] FIG. 2A is a diagram 200 illustrating an example of a first subframe within a 5G/NR frame structure. FIG. 2B is a diagram 230 illustrating an example of DL channels within a 5G/NR subframe. FIG. 2C is a diagram 250 illustrating an example of a second subframe within a 5G/NR frame structure. FIG. 2D is a diagram 280 illustrating an example of UL channels within a 5G/NR subframe. The 5G/NR frame structure may be FDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for either DL or UL, or may be TDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for both DL and UL. In the examples provided by FIGs. 2A, 2C, the 5G/NR frame structure is assumed to be TDD, with subframe 4 being configured with slot format 28 (with mostly DL), where D is DL, U is UL, and X is flexible for use between DL/UL, and subframe 3 being configured with slot format 34 (with mostly UL). While subframes 3, 4 are shown with slot formats 34, 28, respectively, any particular subframe may be configured with any of the various available slot formats 0-61. Slot formats 0, 1 are all DL, UL, respectively. Other slot formats 2-61 include a mix of DL, UL, and flexible symbols. UEs are configured with the slot format (dynamically through DL control information (DCI), or semi-statically/statically through radio resource control (RRC) signaling) through a received slot format indicator (SFI). Note that the description *infra* applies also to a 5G/NR frame structure that is TDD.

[0037] Other wireless communication technologies may have a different frame structure and/or different channels. A frame (10 ms) may be divided into 10 equally sized subframes (1 ms). Each subframe may include one or more time slots. Subframes may also include mini-slots, which may include 7, 4, or 2 symbols. Each slot may include 7 or 14 symbols, depending on the slot configuration. For slot configuration 0, each slot may include 14 symbols, and for slot configuration 1, each slot may include 7 symbols. The symbols on DL may be cyclic prefix (CP) OFDM (CP-OFDM) symbols. The symbols on UL may be CP-OFDM symbols (for high throughput scenarios) or discrete Fourier transform (DFT) spread OFDM (DFT-s-OFDM) symbols (also referred to as single carrier frequency-division multiple access (SC-FDMA) symbols) (for power limited scenarios; limited to a single stream transmission). The number of slots within a subframe is based on the slot configuration and the numerology. For slot configuration 0, different numerologies μ 0 to 5 allow for 1, 2, 4, 8, 16, and 32 slots, respectively, per subframe. For slot configuration 1, different numerologies 0 to 2 allow for 2, 4, and 8 slots, respectively, per subframe. Accordingly, for slot configuration 0 and numerology μ, there are 14 symbols/slot and 2^{μ} slots/subframe. The subcarrier spacing and symbol length/duration are a function of the numerology. The subcarrier spacing may be equal to $2^{\mu} * 15\ kKz$, where μ is the numerology 0 to 5. As such, the numerology μ=0 has a subcarrier spacing of 15 kHz and the numerology μ=5 has a subcarrier spacing of 480 kHz. The symbol length/duration is inversely related to the subcarrier spacing. FIGs. 2A-2D provide an example of slot configuration 0 with 14 symbols per slot and numerology μ=0 with 1 slot per subframe. The subcarrier spacing is 15 kHz and symbol duration is approximately 66.7 μs.

[0038] A resource grid may be used to represent the frame structure. Each time slot includes a resource block (RB) (also referred to as physical RBs (PRBs)) that extends 12 consecutive subcarriers. The resource grid is divided into multiple resource elements (REs). The number of bits carried by each RE depends on the modulation scheme.

[0039] As illustrated in FIG. 2A, some of the REs carry reference (pilot) signals (RS) for the UE. The RS may include demodulation RS (DM-RS) (indicated as R_x for one particular configuration, where 100x is the port number, but other DM-RS configurations are possible) and channel state information reference signals (CSI-RS) for channel estimation at the UE. The RS may also include beam measurement RS (BRS), beam refinement RS (BRRS), and phase tracking RS (PT-RS).

[0040] FIG. 2B illustrates an example of various DL channels within a subframe of a frame. The physical downlink control channel (PDCCH) carries DCI within one or more control channel elements (CCEs), each CCE including nine RE groups (REGs), each REG including four consecutive REs in an OFDM symbol. A primary synchronization signal (PSS) may be within symbol 2 of particular subframes of a frame. The PSS is used by a UE 104 to determine subframe/symbol timing and a physical layer identity. A secondary synchronization signal (SSS) may be within symbol 4 of particular subframes of a frame. The SSS is used by a UE to determine a physical layer cell identity group number and radio frame timing. Based on the physical layer identity and the physical layer cell identity group number, the UE can determine a physical cell identifier (PCI). Based on the PCI, the UE can determine the locations of the aforementioned DM-RS. The physical broadcast channel (PBCH), which carries a master information block (MIB), may be logically grouped with the PSS and SSS to form a synchronization signal (SS)/PBCH block. The MIB provides a number of RBs in the system bandwidth and a system frame number (SFN). The physical downlink shared channel (PDSCH) carries user data, broadcast system information not transmitted through the PBCH such as system information blocks (SIBs), and paging messages.

[0041] As illustrated in FIG. 2C, some of the REs carry DM-RS (indicated as R for one particular configuration, but other DM-RS configurations are possible) for channel estimation at the base station. The UE may transmit DM-RS for the physical uplink control channel (PUCCH) and DM-RS for the physical uplink shared channel (PUSCH). The PUSCH DM-RS may be transmitted in the first one or two symbols of the PUSCH. The PUCCH DM-RS may be transmitted in different configurations depending on whether short or long PUCCHs are transmitted and depending on the particular PUCCH format used. Although not shown, the UE may transmit sounding reference signals (SRS). The SRS may be used by a base station for channel quality estimation to enable frequency-dependent scheduling on the UL.

[0042] FIG. 2D illustrates an example of various UL channels within a subframe of a frame. The PUCCH may be located as indicated in one configuration. The PUCCH carries uplink control information (UCI), such as scheduling requests, a channel quality indicator (CQI), a precoding matrix indicator (PMI), a rank indicator (RI), and HARQ ACK/NACK feedback. The PUSCH carries data, and may additionally be used to carry a buffer status report (BSR), a power headroom report (PHR), and/or UCI.

[0043] FIG. 3 is a block diagram of a base station 310 in communication with a UE 350 in an access network. In the DL, IP packets from the EPC 160 may be provided to a controller/processor 375. The controller/processor 375 implements layer 3 and layer 2 functionality. Layer 3 includes a radio resource control (RRC) layer, and layer 2 includes a service data adaptation protocol (SDAP) layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The controller/processor 375 provides RRC layer functionality associated with broadcasting of system information (e.g., MIB, SIBs), RRC connection control (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer packet data units (PDUs), error correction through ARQ, concatenation, segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

[0044] The transmit (TX) processor 316 and the receive (RX) processor 370 implement layer 1 functionality associated with various signal processing functions. Layer 1, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The TX processor 316 handles mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may then be split into parallel streams. Each stream may then be mapped to an OFDM subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an Inverse Fast Fourier Transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator 374 may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE 350. Each spatial stream may then be provided to a different antenna 320 via a separate transmitter 318TX. Each transmitter 318TX may modulate an RF carrier with a respective spatial stream for transmission.

[0045] At the UE 350, each receiver 354RX receives a signal through its respective antenna 352. Each receiver 354RX recovers information modulated onto an RF carrier and provides the information to the receive (RX) processor 356. The TX processor 368 and the RX processor 356 implement layer 1 functionality associated with various signal processing functions. The RX processor 356 may perform spatial processing on the information to recover any spatial streams destined for the UE 350. If multiple spatial streams are destined for the UE 350, they may be combined by the RX processor 356 into a single OFDM symbol stream. The RX processor 356 then converts the OFDM symbol stream from the time-domain to the frequency domain using a Fast Fourier Transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station 310. These soft decisions may be based on channel estimates computed by the channel estimator 358. The soft decisions are then decoded and deinterleaved to recover the data and control signals that were originally transmitted by the base station 310 on the physical channel. The data and control signals are then provided to the controller/processor 359, which implements layer 3 and layer 2 functionality.

[0046] The controller/processor 359 can be associated with a memory 360 that stores program codes and data. The memory 360 may be referred to as a computer-readable medium. In the UL, the controller/processor 359 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the EPC 160. The controller/processor 359 is also responsible for error detection using an ACK and/or NACK protocol to support HARQ operations.

[0047] Similar to the functionality described in connection with the DL transmission by the base station 310, the controller/processor 359 provides RRC layer functionality associated with system information (e.g., MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto TBs, demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

[0048] Channel estimates derived by a channel estimator 358 from a reference signal or feedback transmitted by the base station 310 may be used by the TX processor 368 to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the TX processor 368 may be provided to different antenna 352 via separate transmitters 354TX. Each transmitter 354TX may modulate an RF carrier with a respective spatial stream for transmission.

[0049] The UL transmission is processed at the base station 310 in a manner similar to that described in connection with the receiver function at the UE 350. Each receiver 318RX receives a signal through its respective antenna 320. Each receiver 318RX recovers information modulated onto an RF carrier and provides the information to a RX processor 370.

[0050] The controller/processor 375 can be associated with a memory 376 that stores program codes and data. The memory 376 may be referred to as a computer-readable medium. In the UL, the controller/processor 375 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE 350. IP packets from the controller/processor 375 may be provided to the EPC 160. The controller/processor 375 is also responsible for error detection using an ACK and/or NACK protocol to support HARQ operations. At least one of the TX processor 368, the RX processor 356, and the controller/processor 359 may be configured to perform aspects in connection with 198 of FIG. 1.

[0051] In multiple input and multiple output (MIMO) wireless systems, wireless devices such as UEs may employ multiple panel transmission schemes (e.g., multi-panel transmissions from multiple antenna panels) including spatial multiplexing, joint transmission, and time diversity. FIG. 4 illustrates exemplary plots 400 of multi-panel transmissions over time for various multiplexing schemes according to some aspects. As shown, a first panel transmission 402 with horizontal line shading is for an uplink transmission of a channel such as the physical uplink shared channel PUSCH (also designated PUSCH 1 to indicate the first panel transmission for the PUSCH), but the disclosure is not limited to such and this diagram is applicable for PUCCH as another example. A second panel transmission 404 with diagonal line shading is also for the uplink transmission of the channel such as PUSCH (also designated PUSCH 2 to indicate the second panel transmission for the PUSCH). It is noted that in aspects, these panels 402 and 404 may also or alternatively be identified with a respective transmitted precoding matrix indicator (TPMI), such as TPMI1 and TPMI2, respectively. In other aspects, the panels 402 and 404 may be identified with a sounding resource signal (SRS) resource indicator (SRI), such as SRI1 and SRI2, respectively. In still further aspects, the panels 402 and 404 may be identified by a UL transmission configuration indicator (TCI), such as UL TCI1 and UL TCI2, respectively. In still other aspects, a panel can also be identified as an antenna port group. In some aspects, the PUSCH1 and PUSCH2 can be scheduled by a single downlink control information (DCI). In some other aspects, the PUSCH1 and PUSCH2 can be scheduled by two DCIs, where each DCI schedules a respective PUSCH, and the two DCIs may be received in two control resource sets (CORESETs) of different CORESET pool indexes. Correspondingly, a panel may be identified by a CORESET pool index.

[0052] In a first example 406, a spatial division multiplexing (SDM) scheme is shown. Here, on the UL, a UE such as UE 104 transmits with multiple panels in different spatial layers (the difference is spatial layers being shown in the "z" axis); namely panel 1 408 in layer 1 and panel 2 410 in layer 2. These panels are transmitted simultaneously in time as well as on the same frequencies or subcarriers, but are spatially multiplexed, such as through beam forming antennas.

[0053] In another example 412, a time division multiplexing (TDM) scheme is illustrated wherein multiple panels 414 and 416 are utilized for UL transmissions by the UE at different times. As may be seen in example 412, the panels 414 and 416 may utilize the same frequencies or subcarriers as the panels are time division multiplexed.

[0054] In still another example 418, a frequency division multiplexing (FDM) scheme is illustrated wherein multiple panels 420 and 422 are utilized for UL transmissions at the same time, but using different subcarriers or frequencies.

[0055] In order to assist a base station, such as base station 102, with scheduling and allocating uplink resources for different UEs, such as UE 104, each UE in a network is configured to report its available power headroom to a base station, where the reporting is typically configured as a power headroom report (PHR). In turn, a base station uses the PHR to determine how much uplink bandwidth per subframe the UE can use. This bandwidth allocation determination avoids scheduling uplink transmission resources to UEs that are unable to fully use them (e.g., UEs where the PH is small indicating less available power headroom).

[0056] In systems such as 5G NR, a UE utilizes a medium access control (MAC) control element (MAC-CE) to indicate the power headroom available in the UE as a PHR. Typically, the PHR is encoded in a MAC-CE having a plurality of 8 bit fields where 6 bits of each field are used to indicate the power head room values, which are the difference between a maximum UE transmit power and a current UE transmit power. Additionally, the MAC-CE is typically transmitted from a UE to the base station on the PUSCH channel.

[0057] A PHR can be configured to be sent periodically or when the downlink path loss changes by some specified threshold. For periodic reporting, a report is trigged by the expiration of a Periodic_PHR_Timer. Additionally, a phr-ProhibitTimer may be used in the case of threshold change reporting, where this timer specifies how long a PHR is prohibited from being transmitted.

[0058] Concerning the calculation of transmission power used for determining the power headroom, it is noted that for power control of the PUSCH in a single panel UL transmissions, an actual or real transmission power calculation of the PUSCH transmission power (P_{PUSCH}) may be based on the following relationship (equation 1):

$$P_{PUSCH}(i,j,q_d,l) = P_{o_{PUSCH},b,f,c}(j) + 10\log_{10}\left(2^{\mu} M_{RB,b,f,c}^{PUSCH}(i)\right) + \alpha_{b,f,c}(j) PL_{b,f,c}(q_d) + \Delta_{TF,b,f,c}(i) + f_{b,f,c}(i,l) \quad \text{(equation 1)}$$

where $P_{o_{PUSCH},b,f,c}$ is a target signal to interference plus noise ratio (SINR) set by an initial P_0 value, $M_{RB,b,f,c}^{PUSCH}(i)$ is the bandwidth of the PUSCH resource assignment expressed in a number of resource blocks for PUSCH transmission, $\alpha_{b,f,c}$ is a path loss compensation factor, $PL_{b,f,c}$ is a path loss reference signal (RS), $\Delta_{TF,f,c}$ is a modulation coding scheme (MCS) related adjustment, $f_{b,f,c}$ is a PUSCH power control adjustment state, l is a closed loop index, i is a transmission occasion index, j is a parameter set configuration index, q_d is a pathloss reference signal index, b is a bandwidth part index, f is a frequency band index, and c is a serving cell index.

[0059] Additionally, in cases where the PUSCH is not transmitted, the power can be calculated based on a reference format that is known to both the base station and the UE, which is also known as a virtual transmission power that allows power headroom calculation based on this assumed or virtual transmission. In this virtual transmission case, the PUSCH transmission power (P_{PUSCH}) may be determined according to the following relationship (equation 2):

$$P_{PUSCH}(i,j,q_d,l) = P_{o_{PUSCH},b,f,c}(j) + \alpha_{b,f,c}(j) PL_{b,f,c}(q_d) + f_{b,f,c}(i,l) \quad \text{(equation 2)}$$

where default or predetermined parameters are used for the values i,j,q_d, and l. For example, the values l and j may be set as $l=0$, and $j=0$.

[0060] It is noted here that various standards such as 5G NR have defined the PHR triggering and reporting conditions for single panel uplink transmissions. For multi-panel transmissions, however, the triggering and reporting conditions for PHR are not clear. Accordingly, the present disclosure provides various methods and apparatus that effectuate PHR triggering and reporting in multi-panel transmission environments.

[0061] In the case of power control for the PUSCH transmitted with multiple panels, an independent power transmission for each panel may be calculated according to some aspects. As used herein, the nomenclature for a particular UL panel is a k^{th} panel.

In particular aspects, it is assumed that there are two panels similar to the examples illustrated in FIG. 4, and the k values are 0 and 1 (k = 0, 1). For a real or actual power transmission, the per kth panel power ($P_{k,PUSCH}$) may be determined according to the following relationship (equation 3), which is similar to equation 1 above except for each kth panel:

$$P_{k,PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},k,b,f,c}(j) + 10\log_{10}\left(2^{\mu} M^{PUSCH}_{RB,k,b,f,c}(i)\right) + \alpha_{k,b,f,c,}(j) PL_{k,b,f,c}(q_d) + \Delta_{k,TF,b,f,c}(i) + f_{k,b,f,c}(i,l) \quad \text{(equation 3).}$$

Similar to equation 1 above, the value $P_{o_{PUSCH},k,b,f,c}$ is a target signal to interference plus noise ratio (SINR) set by an initial P0 value, $M^{PUSCH}_{RB,k,b,f,c}(i)$ is the bandwidth of the PUSCH resource assignment expressed in a number of resource blocks for the PUSCH transmission, $\alpha_{b,f,c}$ is a path loss compensation factor, $PL_{k,b,f,c}$ is a path loss RS, $\Delta_{k,TF,f,c}$ is a modulation coding scheme (MCS) related adjustment determined per PUSCH occasion, $f_{k,b,f,c}$ is a PUSCH power control adjustment state, l is a closed loop index, i is a transmission occasion index, j is a parameter set configuration index, q_d is a pathloss reference signal index, b is a bandwidth part index, f is a frequency band index, and c is a serving cell index. Of further note, in the cases of FDM or TDM, the bandwidth of the PUSCH resource assignment $M^{PUSCH}_{RB,k,b,f,c}(i)$ is determined per each PUSCH occasion.

[0062] In the case of virtual transmission, the transmit power $P_{k,PUSCH}$ per each kth panel may be determined according to the following relationship (equation 4):

$$P_{k,PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},k,b,f,c}(j) + \alpha_{k,b,f,c,}(j) PL_{k,b,f,c}(q_d) + f_{k,b,f,c}(i,l) \quad \text{(equation 4)}$$

where default or predetermined parameters are used for the i, j, q_d, and l values per each k^{th} panel.

[0063] In the case of power control for the PUCCH transmitted with multiple panels, again an independent power transmission for each panel may be calculated in aspects of the disclosure. For a real or actual power transmission, the per kth panel power ($P_{k,PUCCH}$) may be determined according to the following relationship (equation 5), for each k^{th} panel:

$$P_{k,PUCCH}(i, q_u, q_d, l) = P_{o_{PUCCH},k,b,f,c}(q_u) + 10\log_{10}\left(2^{\mu} M^{PUCCH}_{RB,k,b,f,c}(i)\right) + PL_{k,b,f,c}(q_d) + \Delta_{F_{k,PUCCH}}(F) + \Delta_{TF_{k,b,f,c}}(i) + g_{k,b,f,c}(i, l) \quad \text{(equation 5)}$$

where $P_{o_{PUCCH},k,b,f,c}$ is a target signal to interference plus noise ratio (SINR) set by an initial P0 value, $M^{PUCCH}_{RB,k,b,f,c}(i)$ is the bandwidth of the PUCCH resource assignment expressed in a number of resource blocks for the PUCCH transmission, $PL_{k,b,f,c}$ is a path loss RS, $\Delta_{k,PUCCH}$ and $\Delta_{k,TF,f,c}$ are PUCCH format related adjustment factors, $g_{k,b,f,c}$ is a PUCCH power control adjustment state, and l is a closed loop index.

[0064] In the case of virtual transmission, the transmit power $P_{k,PUCCH}$ per each k^{th} panel may be determined according to the following relationship (equation 6):

$$P_{k,PUCCH}(i, q_u, q_d, l) = P_{o_{PUCCH},k,b,f,c}(q_u) + PL_{k,b,f,c}(q_d) + g_{k,b,f,c}(i, l) \quad \text{(equation 6)}$$

where default or predetermined parameters are used for the i, q_u, q_d, and l values.

[0065] In the case of power control for the sounding reference signals (SRS) transmitted with multiple panels, an independent power transmission for each panel may be calculated in aspects of the disclosure. For a real or actual power transmission, the per kth panel power ($P_{k,SCS}$) may be determined according to the following relationship (equation 7), for each k^{th} panel:

$$P_{k,SRS}(i, q_s, l) = P_{o_{SRS},k,b,f,c}(q_s) + 10\log_{10}\left(2^{\mu} M^{SRS}_{RB,k,b,f,c}(i)\right) + \alpha_{k,b,f,c,}(q_s) PL_{k,b,f,c}(q_d) + h_{k,b,f,c}(i, l) \quad \text{(equation 7)}$$

where $P_{o_{SRS},k,b,f,c}$ is the target SINR set by a P_0 value, $M^{SRS}_{RB,k,b,f,c}(i)$ is the bandwidth of the SRS resource assignment expressed in the number of resource blocks for an SRS transmission, $PL_{k,b,f,c}$ is a path loss RS, $h_{k,b,f,c}$ is an SRS power control adjustment state, l is a closed loop index, i is a transmission occasion index, j is the parameter set configuration index, q_s is the SRS resource set, q_d is a pathloss reference signal index associated with the SRS resource set, b is a bandwidth part index, f is a frequency band index, and c is a serving cell index. For FDM or SDM transmissions, it is noted that $M^{SRS}_{RB,k,b,f,c}(i)$ is determined per SRS transmission occasion.

[0066] In the case of virtual transmission, the transmit power $P_{k,SCS}$ per each kth panel may be determined according to the following relationship (equation 8):

$$P_{k,SRS}(i,\ q_s,l) = P_{O_{PUSCH},k,b,f,c}(q_s) + \alpha_{k,b,f,c,}(q_s)PL_{kb,f,c}(q_d) + h_{k,b,f,c}(i,l) \quad \text{(equation 8)}$$

where default or predetermined parameters are used for the $i, q_s, and\ l$ values.

[0067] Turning then to the determinations of power headroom and PHRs for multi-panel uplink transmissions based on the above per panel power transmission calculations, it is noted that a per panel power headroom calculation may also be determined according to some aspects. As noted above, power headroom is determined by calculating the difference between a maximum UE transmit power and the calculated UE transmit power. Accordingly, a power headroom for each panel in a multi-panel uplink transmission may be determined using the kth panel power (e.g., $P_{k,PUSCH}$) and the maximum UE transmit power applicable to a particular panel k, which is represented as $P_{CMAX,f,c}(i, k)$. The power headroom for each type of channel ($PH_{type\ X,b,f,c}$), such as the PUSCH, PUCCH, and SRS channels as discussed above, and termed respectively as type 1, type 2, and type 3 (or generically as type X), may be determined according to the following relationships (equations 9, 10, and 11) for the PUSCH, PUCCH, and SRS, respectively:

$$PH_{type1,b,f,c}(i,j,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,PUSCH}(i,j,q_d,l) \quad \text{(equation 9)}$$

$$PH_{type2,b,f,c}(i,q_u,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,PUCCH}(i,q_u,q_d,l) \quad \text{(equation 10)}$$

$$PH_{type3,b,f,c}(i,q_s,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,SRS}(i,q_s,q_d,l) \quad \text{(equation 11)}$$

where the PH can be based on real transmissions or virtual transmissions as discussed earlier. Additionally, it is noted that the maximum transmit power $P_{CMAX,f,c}(i, k)$ may be configured as a power applicable to each panel (i.e., maximum power values unique to each panel), but may also be configured such that the maximum transmit power is the same for all panels in the multi-panel transmission. In an aspect, the PH calculations above are performed within a UE device, such as UE 104.

[0068] According to further aspects, the PHR reports that include the PH values calculated above for the multi-panel uplink transmissions may be configured in a number of different ways as will be explained below in connection with at least two examples illustrated in FIGs. 5 and 6. As discussed above, PHR reporting is typically accomplished using a MAC-CE on the PUSCH channel, although the examples herein are not necessarily limited to the PUSCH. The PHR examples of FIGs. 5 and 6 are illustrated in the context of MAC-CEs transmitted over the PUSCH, but another transmission channel on the uplink could be utilized.

[0069] FIG. 5 illustrates an example of a power headroom report (PHR) 500 using a MAC-CE format according to aspects of the present disclosure. In an aspect, the PHR 500 may be configured and transmitted by a UE (e.g., UE 104) to a base station (e.g., base station 102) over the data uplink channel PUSCH. The PHR 500 includes a number of 8 bit fields (i.e., octets) used to convey various information and values. A first field 502 includes seven component carrier (CC, or serving cell index) bits (C0 through C7). In this example, the PHR 500 includes a CC 504 (e.g., C4) that is configured as a multi-panel uplink CC. The bit in CC 504 may be configured to indicate that a power headroom values for multiple panels are contained in subsequent fields in the PHR 500.

[0070] In this example, CC 504 indicates that the presence of PH value fields for two panels, as well as the maximum power values for each panel of the UE, are conveyed in the PHR 500. The CC 504 indicates that fields 506, 508, 510, and 512 will be within the PHR for multiple panels. Correspondence between the CC and PH and power maximum fields is further illustrated by light gray shading of both the CC 504 and fields 506, 508, 510, and 512. In an example, the PHR may be configured such that when the bit value of CC 504 is of a certain state (e.g., "1"), this signals to the receiver (e.g., base station) that PH values for a multi-panel transmission is contained in the PHR 500.

[0071] As illustrated, fields 506 and 510 include the calculated PH values for the first panel (panel 0) and the second panel (panel 1) of the multi-panel transmission. In this example, the PH value information may be communicated by 6 bits in the field (e.g., bits 0 through 5), but other configurations may also be utilized. Additionally, each field or octet may include other information, such as in bits 6 and 7 as illustrated in the example of FIG. 5. In particular, a “P” bit as illustrated in fields 506 and 510 may be used to indicate whether the MAC entity applies power backoff due to power management. A “V” bit or value may be used to indicate whether the included PH value is based on a real transmission or a virtual reference format, as also may be seen in fields 506 and 510. In a particular aspect, it is noted that the type of PH (e.g., PUSCH, PUCCH, or SRS, which may be also designated as Type 1, Type 2, and Type 3, respectively) may be indicated using the “V” bit. For example, if the V field is set to “0”, this may be configured to indicate the presence of a field or octet containing the associated $P_{CMAX,f,c}$ value, such as indicated by fields 508 and 512. Alternatively, if the “V” bit is set to “1”, this may be used to indicate that an octet containing the associated $P_{CMAX,f,c}$ value is omitted in this PHR. It is noted that “R” bits illustrated in PHR 500 are reserved bits and are normally set to zero.

[0072] The illustrated PHR 500 may also be used to convey PH information for single panel uplink transmissions, as illustrated by CC 514 which is used to indicate the presence of corresponding fields 518 and 520 in the MAC-CE (i.e., PHR 500), which are also visually shown corresponding to one another by dark shading in FIG. 5. In this example, the CC 514 indicates the presence of field 518 including the PH data for the single panel transmission. Furthermore, the values of the “P” and “V” bits in field 518 may be used to indicate a type of PH (e.g., type 1, 2, or 3) and use of power backoff, as well as whether the maximum power value is indicated in field 520.

[0073] FIG. 6 illustrates another example of a power headroom report (PHR) 600 using a MAC-CE format according to further aspects of the present disclosure. The PHR 600 may be configured and transmitted by a UE (e.g., UE 104) to a base station (e.g., base station 102) over the data uplink channel PUSCH. As illustrated, the PHR 600 includes a number of 8 bit fields (i.e., octets) used to convey various information and values.

[0074] In this example, like the example of FIG. 5, PHR 600 includes a first component carrier field 602 including seven component carrier (CC) bits (C0 through C7), but also adds a second component carrier field 604 of additional or auxiliary component carriers (AC). In a multi-panel scenario, bits in field or octet 602 may be used to indicate that power headroom report is being reported for a first panel when multiple panels are configured in the cell or the only panel when a single panel is configured in the cell, and bits in field or octet 604 may be used to indicated that the power headroom report is being reported for a second panel when multiple panels are configured in a cell or reserved when a single panel is configured in a cell. Accordingly, two bits, such as a bit 606 in the CC field 602 (e.g., C4) and a bit 608 in the AC field 604 may be used to indicate the presence of PH values for panels, which provides further flexibility for either reporting two or more PH values for multiple panels or the reporting of just one PH of a panel among multiple panel PH values with one bit such as 609, as will be explained in more detail below.

[0075] For the scenario where reporting two PH values for respective first and second panels is desired, the bit values for 606 and 608 may be set to a same value (e.g., "1"), which then indicates to a receiver (e.g., a base station) that PH values for both panels are conveyed within PHR 600. In the illustrated example, bit 606 might indicate that field 610 containing the PH value for the first panel (i.e., panel 0), as well the maximum power value in field 612 (which may be dependent on the "V" bit in field 610), are included in PHR 600. Likewise, bit 608 might indicate that field 614 containing the PH value for the second panel (i.e., panel 1), as well the maximum power value in field 616 (which may be dependent on the "V" bit in field 614). It is noted that the "P", "V", and "R" fields shown have the same functionality as the example of FIG. 5; namely conveying type, maximum power field inclusion, and whether power backoff is applied.

[0076] Alternatively, by including two bits (i.e., CC bits and AC bits) in the PHR, it is also possible to report only one PH value for one of the panels of the multi-panel transmission. In the example of FIG. 6, the darker shading of bit 609 and corresponding shading of fields 622 and 624 illustrate this scenario. Here, it is assumed that the bit value of bit 7 (i.e., C6 or 626) may be one value such as "0", which indicates that no PH information is being conveyed for a first panel (e.g., panel 0), whereas bit 609 is of an opposite binary value (e.g., "1"), thereby indicating the PH information for the second panel (e.g., panel 1) is conveyed by PHR 500. Those skilled in the art will appreciate that this is exemplary and that alternatively the PH information for the first panel may be conveyed whereas the second panel PH information is not but reversing the values of bits 626 and 609 for that scenario. Of further note, in the scenario where only one panel's PH information is conveyed, it is noted that the "P", "V" and "R" values or bits shown in fields 622 and 624 have the same functionality as the example of FIG. 5; namely conveying type, maximum power field inclusion (i.e., the inclusion of information in field 624), and whether power backoff is applied.

[0077] According to further aspects, the present disclosure also provides methods and apparatus for deciding when to send the PHR (i.e., triggering of the PHR). According to some particular aspects, the PHR may be triggered if a path loss metric of the uplink or downlink transmissions to or from the base station, for example, has been changed. The path loss metric and when to trigger based on the metric change may be configured in a number of different ways as will be illustrated with reference to FIGs. 7A, 7B, and 7C. Of further note, when determining path loss the UE may calculate the path loss based on a reference signal (RS) configured by network (e.g., from the base station) and the measured RS signal power on at least one UE antenna port.

[0078] In one aspect the path loss metric change may be determined based on a change in the path loss over time in one or more panels. Stated differently, if a path loss occurs over time for any panel between one time and a subsequent time, a PHR will be triggered and sent by the UE over the uplink. For example, FIG. 7A illustrates a scenario 702 where the path loss changes within the same UE panel transmission. In this example, a path loss change δ within the same UE panel where k=0,1 may be determined according to the relationships $\delta_{00} = \mathrm{PLB0} - \mathrm{PLA0}$ or $\delta_{11} = \mathrm{PLB1} - \mathrm{PLA1}$ where the values A and B indicate a first time A as shown at 704 and a second, subsequent time B as shown at 706. Here to "00" subscript and "11" subscript for the change value δ denote path loss change among the same panel over time (e.g., path loss of panel 0 at time A to path loss of panel 0 at time B, path loss of panel 1 at time A to path loss of panel 1 at time B). In some aspects, time A may be the transmission time of the last transmission of PHR and the path loss reference signal in use at that time is used for determining the path loss metric. Time B may represent a present time and the corresponding current path loss reference signal is used for determining the path loss metric. In an aspect, this means that the path loss metric change for triggering the PHR can be any of the path loss change values δ_{00} or δ_{11}.

[0079] According to another aspect, the PHR may be triggered by an average of the path loss change within same UE panels k=0,1 (e.g., $(\delta_{00} + \delta_{11})/2$). According to an aspect, if the average of the path loss changes in value, the PHR may be triggered.

Alternatively, if the average changes by some predetermined amount, this could trigger the PHR reporting. In an aspect, this means that the path loss metric change for triggering the PHR can be the path loss change value $(\delta_{00} + \delta_{11})/2$.

[0080] In yet another aspect, the PHR may be triggered if any one of path losses occurs from time A to time B between either the same panels, as discussed above, or different panels. Generalized, this condition may be represented by the relationship, δ_{xy} = PLBx-PLAy for x, y = 0,1, which is across the UE panels (e.g., δ_{00} , δ_{11}, δ_{01} , δ_{10}). As an example, FIG. 7B illustrates a scenario 710 where a path loss change occurs between the path loss reference signal of panel 0 at time A and the path loss reference signal of panel 1 at time B, which would be represented by δ_{01} based on the relationship above. As another example, FIG. 7C illustrates a scenario 720 where a path loss change occurs between the path loss reference signal of panel 1 at time A and the path loss reference signal of panel 0 at time B, which would be represented by δ_{10} based on the relationship above. In an aspect, this means that the path loss metric change for triggering the PHR can be any of the path loss change values δ_{00}, δ_{11}, δ_{01}, or δ_{10}.

[0081] In other aspects, it is noted that the PHR may be triggered when the phr-ProhibitTimer expires (or has already expired) and the path loss metric has changed more than some predetermined amount (e.g., a phr-Tx-PowerFactorChange, which may be in units of dB) for at least one activated Serving Cell of any MAC entity which is used as a path loss reference since the last transmission of a PHR in the MAC entity when the MAC entity has UL resources for new transmission. In certain aspects, it is noted that the phr-ProhibitTimer and the phr-Tx_PowerFactorChange values, as example, may be configured in a UE through RRC messages from the network (e.g., via a base station DL signaling).

[0082] FIGs. 8A, 8B, 8C, and 8D illustrate other examples of timing diagrams for PHR triggering according to further aspects. The examples in FIGs. 8A, 8B, 8C, and 8D illustrate further conditions for which to determine when to trigger the PHR in cases of path loss change (i.e., the path loss metric) and when to apply triggering PHR based on the scheduling of panels from one time instance to another.

[0083] In FIG. 8A, shown at 805 (and also denoted as "Case A"), only one panel is scheduled (panel 0) at a first time (e.g., a time of the last PHR). Additionally, it is noted that an attendant power loss PL1 of panel 0 at that time is illustrated in this example. At a second time (e.g., a current time), two panels (panel 0 and panel 1) are scheduled and with attendant power loss PL2. In this example, there is a commonality of a same panel (i.e., panel 0) between the two time instances and, thus, the path loss change for just this panel may be utilized in determining the path loss metric.

[0084] In FIG. 8B, shown at 810 (and also denoted as “Case B”), similar to the example of 8A, there is a change in the number of scheduled panels from a time of a last PHR and a current time. In this case 810, two panels (panel 0 and panel 1) are scheduled at the pervious time of the last PHR, whereas at a current time only panel 0 is scheduled for transmission. Again in this example, there is commonality of a same panel (i.e., panel 0) scheduled in both time instance. Accordingly, the path loss change of this same panel may be used for determining the path loss metric change for triggering the sending of the PHR.

[0085] In FIG. 8C, shown at 815 (and also denoted as “Case D”), this scenario illustrates an example where both of two panels (panel 0 and panel 1) are scheduled at a first time instance (i.e., the time of the last PHR) and also at a second time instance (e.g., a current time). In this case, since there is again a commonality of at least one same panel (i.e., either panel 0 or panel 1) over the two time instances, only one panel path loss difference needs to be considered for the path loss metric of when to trigger a PHR for a panel. The path loss difference of one panel in two time instances may be considered for the path loss metric of when to trigger a PHR for a corresponding panel. This is further visually illustrated by dashed arrow 816 indicating that the path loss of panel 1 does not need to be considered for the path loss metric change that triggers the PHR of panel 0.

[0086] In FIG. 8D, shown at 820 (also denoted at “Case C”), this figure illustrates a scenario where the scheduled panels are different between the two time instances. In this case, a panel 0 is scheduled at a first time (i.e., a time of the last PHR) whereas panel 1 is scheduled at a second time (e.g., a current time). In this case, since there is no commonality or same panel scheduling between the two time instances, the path loss change between the two panels at two time instances would be used to determine the path loss metric change, which is similar to the scenarios illustrates by FIGs. 7B and 7C.

[0087] FIG. 9 is a signal flow diagram 900 illustrating various processes occurring over time for wireless communication according to some aspects. In this diagram 900, a

UE 902 may transmit a PHR for one or more panels to a base station 904 over a channel such as the data channel PUSCH and using a MAC-CE such as those illustrated in FIGs. 5 or 6 as shown by transmission 906. Transmission 906 is illustrated to show timing that may be used as a reference for triggering of subsequent PHR (e.g., triggering in block 914 and subsequent PHR transmission 918). Additionally, at a same time or some time after transmission 906 as illustrated in diagram 900, the base station 904 transmits various downlink transmissions 908 including reference signals (RSs) that may be utilized by the UE 902 to determine path loss changes.

[0088] Diagram 900 further illustrates that the UE 902 may determine the transmit power P and a PH for each panel that is scheduled for transmission on the UL as shown in block 910. In particular, the transmit power P may be determined for any of the types of channels, such as PUSCH, PUCCH, or SRS as examples, and also designated as Type 1, 2, or 3. Additionally, the determination is made per panel as discussed earlier. Furthermore, the PH for each panel may be determined based on the determined transmit power P and the known maximum power values (P_{MAX}) as also discussed before. The PH may be configured for the particular types of channels, as was discussed before.

[0089] Additionally, the UE 902 may include configuring the PHR based on the determined/calculated power headroom PH values for one or more of the multi-panel transmissions as shown at block 912. In an aspect, the PHR may be configured as a MAC-CE according to either of the examples of FIGs. 5 and 6. Additionally, the PHR may be configured at block 912 to report all the PH values for each of the available panels, or just a portion thereof such as was shown by the PHR configuration of FIG. 6. Furthermore, as discussed above the PHR may include the maximum power values (P_{MAX}) in some aspects, as well as an indication of the channel type to which the PH values pertain.

[0090] Still further, UE 902 may be configured to determine triggering of the PHR reporting to the base station 904 as shown by the process of block 914. The triggering may include determination of a change in a path loss metric as discussed before in connection with the examples of FIGs. 7A, 7B, and 7C, and 8A, 8B, 8C, and 8D. In particular, the triggering may occur when a change in the path loss occurs between first and second time instances. In an aspect, the first time instance may be the previous transmission of a PHR such as shown at PHR transmission 906.

In another aspect, the second time period may be a current time occurring after the DL transmission 908. Additionally, the DL transmissions may include reference signals that the UE 902 uses to determine the path loss for each panel. In yet further aspects, the processes in block 914 may include triggering based on a change per same panels over a time period (e.g., FIG. 7A or FIGs. 8A, 8B, or 8C) and further that the determination may also be based on a path loss difference of one panel at a first time and a second panel at a second time (e.g., FIGs. 7B, 7C, and 8D).

[0091] In another aspect, the UE 902 may also be configured with a phr-ProhibitTimer as discussed earlier. Accordingly, the UE 902 may also determine whether the timer is expired at shown at alternative loop back 916. When the timer expires and the trigger condition as determined at block 914 indicates reporting of the PHR, the UE 904 transmits the PHR as shown by transmission 918 from the UE 902 to the base station 904.

[0092] FIG. 10 is a flowchart 1000 of a method of wireless communication. The method may be performed by a UE (e.g., the UE 104 or 350, UE 902, apparatus 1202/1202'; the processing system 1314, which may include the memory 360 and which may be the entire UE 104 or 350 or a component of the UE 350, such as the TX processor 368, the RX processor 356, and/or the controller/processor 359).

[0093] At 1002, the UE determines a respective transmission power value for each panel in a multi-panel uplink transmission. This determination may be accomplished based on the various equations 3-8 discussed above, according to an aspect. Additionally, it is noted the processes of block 1002 may implemented in a processor such as controller/processor 359 or transmit processor 368, or a combination thereof as examples.

[0094] Furthermore, the method of diagram 1000 may include calculating a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value as shown at block 1004. In an aspect, the processes of block 1004 may include performing PH calculations according to the various equations 9-11 discussed above. Further, the processes of block 1004 may be implemented in a processor such as controller/processor 359 or transmit processor 368, or a combination thereof as examples.

[0095] Finally, at 1006, the UE transmits the power headroom value for at least one panel of the multi-panel uplink transmission in a power headroom report (PHR) on an uplink channel. In some aspects, it is noted that the PHR transmitted at block 1006 may be configured

[0096] FIG. 11 is a flowchart 1100 of another method of wireless communication according to some aspect. The method may be performed by a UE (e.g., the UE 104 or 350, UE 902, apparatus 1202/1202'; the processing system 1314, which may include the memory 360 and which may be the entire UE 104 or 350 or a component of the UE 350, such as the TX processor 368, the RX processor 356, and/or the controller/processor 359).

[0097] At 1102, a UE may configure a power headroom report (PHR) that includes power headroom information for at least one panel of a multi-panel uplink transmission scheduled for the UE. Of note, the processes of block 1102 may be based on calculation of the per panel transmit powers as discussed in connection with equations 3-8 and the power headroom calculations discussed in connection with equations 9-11. The PHR configuration may also be configured by a UE in accordance with the examples of FIGs. 5 and 6, and may report all PH values per panel as shown in FIG. 5, or at least on panel as shown in the example of FIG. 6 where the PHR is configured to report at least one PH for a particular panel.

[0098] At 1104, a UE may initiate or trigger the transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period. The processes at block 1104 may be implemented by a UE receiving reference signals (RSs) on the DL from a base station and determining path loss values based on the RSs in a receiver, receiver processor such as processor 356 or a controller/processor 359, or combinations thereof, as examples. According to yet further aspects, the processes of block 1104 may include a determination of a change in the path loss metric according to examples of FIGs. 7A, 7B, or 7C and FIGs. 8A, 8B, 8C, or 8D. This may include determining a path loss metric change for only one panel if at least one panel is common across the predetermined time period (i.e., the same panel is scheduled at a first time and a subsequent second time), or for at least two UE panels that are the same over the time period (i.e., same panel 0 and same panel 1). Additionally, the metric may include determining a path loss change occurring between different panels over the predetermined time period as illustrated by FIGs. 7B, 7C, or 8D, as examples.

[0099] FIG. 12 is a conceptual data flow diagram 1200 illustrating the data flow between different means/components in an example apparatus 1202. The apparatus 1202 may be a UE in one example. The apparatus includes a reception component 1204 that receives downlink transmissions for a base station 1250 or similar network node The received DL transmissions 1206 may include reference signals (RSs) that are decoding and passed to a path loss measurement/determination component 1208 that is configured determine or measure path loss metric information 1210 to a PHR triggering component 1212. The PHR triggering component 1212 is configured to determine path loss metric changes based on the various algorithms and methods discussed in connection with FIGs. 7A-7C and 8A-8D. The PHR triggering component, in turn, may issue a PHR trigger signal to a PHR determination component 1216 and/or transmission component 1218 when transmission of the PHR is warranted according to the various conditions discussed herein.

[00100] The PHR determination component 1216 is configured for determining various transmit power and power headroom values for each panel in a multi-panel uplink transmission. The PHR determination component 1216 is further configured to receive various information or parameters from the reception component 1204 including transmit power information received from the base station 1250 as well as other parameters that may be used to calculate the transmit power such as with equations 3-8 discussed above. Additionally, the PHR component 1216 may configure to the PHR according to either of the examples of FIGs. 5 and 6 discussed above. Once configured, the PHR may be sent from the PHR determination component 1216 to the transmission component 128 that, in turn, transmits UL transmission 1220 to the base station 1250 including the PHR in some instances when triggered.

[00101] The apparatus 1202 may include additional components that perform each of the blocks of the algorithm in the aforementioned flowcharts of FIGs. 10 or 11. As such, each block in the aforementioned flowcharts of FIGs. 10 or 11 may be performed by a component and the apparatus may include one or more of those components. The components may be one or more hardware components specifically configured to carry out the stated processes/algorithm, implemented by a processor configured to perform the stated processes/algorithm, stored within a computer-readable medium for implementation by a processor, or some combination thereof.

[00102] FIG. 13 is a diagram 1300 illustrating an example of a hardware implementation for an apparatus 1202' employing a processing system 1314. The processing system 1314 may be implemented with a bus architecture, represented generally by the bus 1324. The bus 1324 may include any number of interconnecting buses and bridges depending on the specific application of the processing system 1314 and the overall design constraints. The bus 1324 links together various circuits including one or more processors and/or hardware components, represented by the processor 1304, the components 1204, 1208, 1212, 1216, 1218, and the computer-readable medium/memory 1306. The bus 1324 may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further.

[00103] The processing system 1314 may be coupled to a transceiver 1310. The transceiver 1310 is coupled to one or more antennas 1320. The transceiver 1310 provides a means for communicating with various other apparatus over a transmission medium. The transceiver 1310 receives a signal from the one or more antennas 1320, extracts information from the received signal, and provides the extracted information to the processing system 1314, specifically the reception component 1204. In addition, the transceiver 1310 receives information from the processing system 1314, specifically the transmission component 1218, and based on the received information, generates a signal to be applied to the one or more antennas 1320. The processing system 1314 includes a processor 1304 coupled to a computer-readable medium/memory 1306. The processor 1304 is responsible for general processing, including the execution of software stored on the computer-readable medium/memory 1306. The software, when executed by the processor 1304, causes the processing system 1314 to perform the various functions described supra for any particular apparatus. The computer-readable medium/memory 1306 may also be used for storing data that is manipulated by the processor 1304 when executing software. The processing system 1314 further includes at least one of the components 1204, 1208, 1212, 1216 and 1218. The components may be software components running in the processor 1304, resident/stored in the computer readable medium/memory 1306, one or more hardware components coupled to the processor 1304, or some combination thereof.

[00104] In one configuration, the apparatus 1202/1202' for wireless communication includes means for means for determining, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission, means

for calculating a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value; and means for transmitting the power headroom value for at least one panel in a power headroom report on an uplink channel.

[00105] The aforementioned means may be one or more of the aforementioned components of the apparatus 1202 and/or the processing system 1314 of the apparatus 1202' configured to perform the functions recited by the aforementioned means. As described supra, the processing system 1314 may include the TX Processor 368, the RX Processor 356, and the controller/processor 359. As such, in one configuration, the aforementioned means may be the TX Processor 368, the RX Processor 356, and the controller/processor 359 configured to perform the functions recited by the aforementioned means.

[00106] Further disclosure is included in the Appendix.

[00107] It is understood that the specific order or hierarchy of blocks in the processes/flowcharts disclosed is an illustration of example approaches. Based upon design preferences, it is understood that the specific order or hierarchy of blocks in the processes/flowcharts may be rearranged. Further, some blocks may be combined or omitted. The accompanying method claims present elements of the various blocks in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

[00108] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any aspect described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects. Unless specifically stated otherwise, the term "some" refers to one or more. Combinations such as "at least one of A, B, or C," "one or more of A, B, or C," "at least one of A, B, and C," "one or more of A, B, and C," and "A, B, C, or any combination

thereof" include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as "at least one of A, B, or C," "one or more of A, B, or C," "at least one of A, B, and C," "one or more of A, B, and C," and "A, B, C, or any combination thereof" may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, where any such combinations may contain one or more member or members of A, B, or C. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. The words "module," "mechanism," "element," "device," and the like may not be a substitute for the word "means." As such, no claim element is to be construed as a means plus function unless the element is expressly recited using the phrase "means for."

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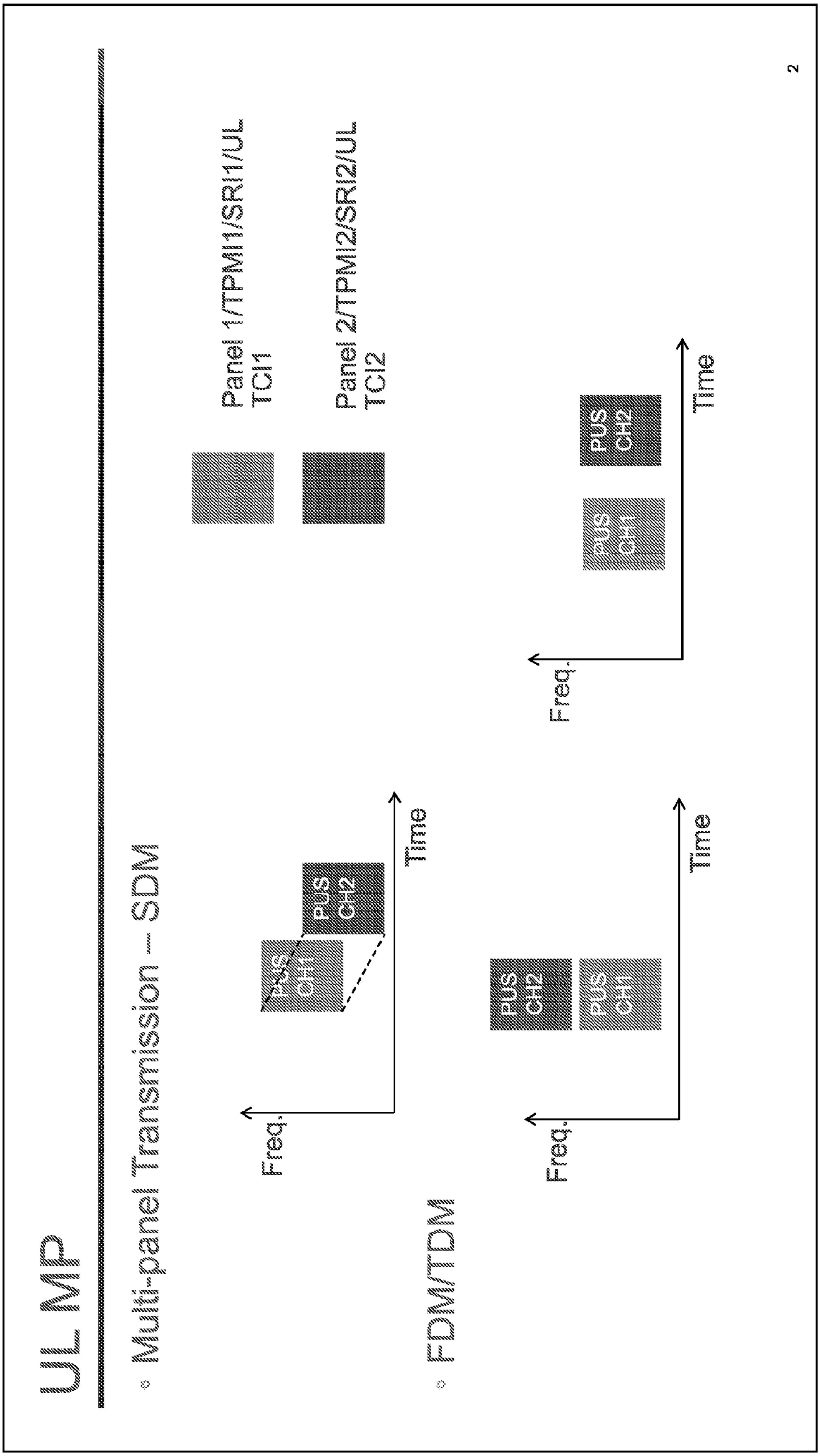
QCOM-4241WO1 (204997WO1)

TITLE:

PHR TRIGGER AND REPORT FOR MULTI-PANEL UPLINK TRANSMISSION

1


UL MP
Multi-panel Transmission – SDM
FDM/TDM
Panel 1/TPMI1/SRI1/UL TCI1
Panel 2/TPMI2/SRI2/UL TCI2
PUS CH1
PUS CH2
Freq.
Time
2

Power Control For PUSCH in NR Rel-15

- Power control for PUSCH
  - ✓ Option1: Real transmission: $P_{PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},b,f,c}(j) + 10\log_{10}\left(2^{\mu}\mathrm{M}_{RB,b,f,c}^{PUSCH}(i)\right) + \alpha_{b,f,c,}(j)PL_{b,f,c}(q_d) + \boldsymbol{\Delta_{TF,b,f,c}(i)} + f_{b,f,c}(i,l)$
    - $P_{O_{PUSCH},b,f,c}$ is the target SINR set by P0 value
    - $\mathrm{M}_{RB,b,f,c}^{PUSCH}(i)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for PUSCH transmission
    - $\alpha_{b,f,c,}$ is path loss compensation factor
    - $PL_{b,f,c}$ is path loss RS
    - $\boldsymbol{\Delta_{TF,f,c}}$ is MCS related adjustment
    - $f_{b,f,c}$ is the PUSCH power control adjustment state
  - ✓ Option2: Virtual transmission: $P_{PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},b,f,c}(j) + \alpha_{b,f,c,}(j)PL_{b,f,c}(q_d) + f_{b,f,c}(i,l)$, where default parameters are used for i,j,q_d,l

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Power Control For PUSCH in Multi-panel Uplink Transmission

- Independent transmit power for PUSCH with UL panel k, k=0,1
  - ✓ Option1: Real transmission:
    $P_{k,PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},k,b,f,c}(j) + 10\log_{10}\left(2^{\mu} M_{RB,k,b,f,c}^{PUSCH}(i)\right) + \alpha_{k,b,f,c,}(j) PL_{k,b,f,c}(q_d) + \boldsymbol{\Delta_{k,TF,b,f,c}(i)} + f_{k,b,f,c}(i,l)$
    - $P_{O_{PUSCH},k,b,f,c}$ is the target SINR set by P0 value
    - $M_{RB,k,b,f,c}^{PUSCH}(i)$ is the bandwidth of the PUSCH resource assignment expressed in number of resource blocks for PUSCH transmission
      - For FDM/TDM, $M_{RB,k,b,f,c}^{PUSCH}(i)$ is determined per PUSCH occasion
    - $\alpha_{k,b,f,c,}$ is path loss compensation factor
    - $PL_{k,b,f,c}$ is path loss RS
    - $\boldsymbol{\Delta_{k,TF,b,f,c}}$ is MCS related adjustment determined per PUSCH occasion
    - $f_{k,b,f,c}$ is the PUSCH power control adjustment state, and l is close loop index
  - ✓ Option2:Virtual transmission: $P_{k,PUSCH}(i,j,q_d,l) = P_{O_{PUSCH},k,b,f,c}(j) + \alpha_{k,b,f,c,}(j) PL_{k,b,f,c}(q_d) + f_{k,b,f,c}(i,l)$, where default parameters are used for i, j, q_d, l

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Power Control For PUCCH in Multi-panel Uplink Transmission

- Independent transmit power for PUCCH with UL panel, k=0,1
  - Option1: real transmission $P_{k,PUCCH}(i, q_u, q_d, l) = P_{o_{PUCCH},k,b,f,c}(q_u) + 10\log_{10}\left(2^{\mu} M_{RB,k,b,f,c}^{PUCCH}(i)\right) + PL_{k,b,f,c}(q_d) + \Delta_{F_{k,PUCCH}}(F) + \Delta_{TF_{k,b,f,c}}(i) + g_{k,b,f,c}(i, l)$
    - $P_{o_{PUCCH},k,b,f,c}$ is the target SINR set by P0 value
    - $M_{RB,k,b,f,c}^{PUCCH}(i)$ is the bandwidth of the PUCCH resource assignment expressed in number of resource blocks for PUCCH transmission
      - For FDM/SDM, $M_{RB,k,b,f,c}^{PUCCH}(i)$ is determined per PUCCH occasion
    - $PL_{k,b,f,c}$ is path loss RS
    - $\Delta_{F_{k,PUCCH}}$ *and* $\Delta_{k,TF,f,c}$ is PUCCH format related adjustment
    - $g_{k,b,f,c}$ is the PUCCH power control adjustment state, and l is close loop index
  - Option2: virtual transmission $P_{k,PUCCH}(i, q_u, q_d, l) = P_{o_{PUCCH},k,b,f,c}(q_u) + PL_{k,b,f,c}(q_d) + g_{k,b,f,c}(i, l)\}$ where default parameters are used for i, q_u, q_d, l

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Power Control For SRS in Multi-panel Uplink Transmission

- Independent power control for SRS by UL panel k=0,1
  - Option1: real transmission $P_{k.SRS}(i, q_s, l) = P_{o_{SRS},k,b,f,c}(q_s) + 10\log_{10}\left(2^{\mu} M_{RB,k,b,f,c}^{SRS}(i)\right) + \alpha_{k,b,f,c,}(q_s) PL_{k,b,f,c}(q_d) + h_{k,b,f,c}(i, l)$
    - $P_{o_{SRS},k,b,f,c}$ is the target SINR set by P0 value
    - $M_{RB,k,b,f,c}^{SRS}(i)$ is the bandwidth of the SRS resource assignment expressed in number of resource blocks for SRS transmission
      - For FDM/SDM, $M_{RB,k,b,f,c}^{SRS}(i)$ is determined per SRS occasion
    - $PL_{k,b,f,c}$ is path loss RS
    - $h_{k,b,f,c}$ is the SRS power control adjustment state, and l is close loop index
  - ✓ Option2: virtual transmission $P_{k,SRS}(i, q_s, l) = P_{o_{PUSCH},k,b,f,c}(q_s) + \alpha_{k,b,f,c,}(q_s) PL_{kb,f,c}(q_d) + h_{k,b,f,c}(i, l)$ where default parameters are used for i, q_s, l

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Power Headroom Report in Multi-panel Uplink Transmission

- Proposal1: – Support per panel power headroom calculation at UE as below
  - Type1- per panel PH for PUSCH

$$PH_{type1,b,f,c}(i,j,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,PUSCH}(i,j,q_d,l)$$

  - Type2- per panel PH for PUCCH

$$PH_{type2,b,f,c}(i,q_u,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,PUCCH}(i,q_u,q_d,l)$$

  - Type3-per panel PH for SRS

$$PH_{type3,b,f,c}(i,q_s,q_d,l,k) = P_{CMAX,f,c}(i,k) - P_{k,SRS}(i,q_s,q_d,l)$$

  - $P_{CMAX,f,c}(i,k)$ is the configured maximum transmit power applicable to panel k
    - Configured maximum transmit power may be same to all the panels
  - The PH can be real or virtual

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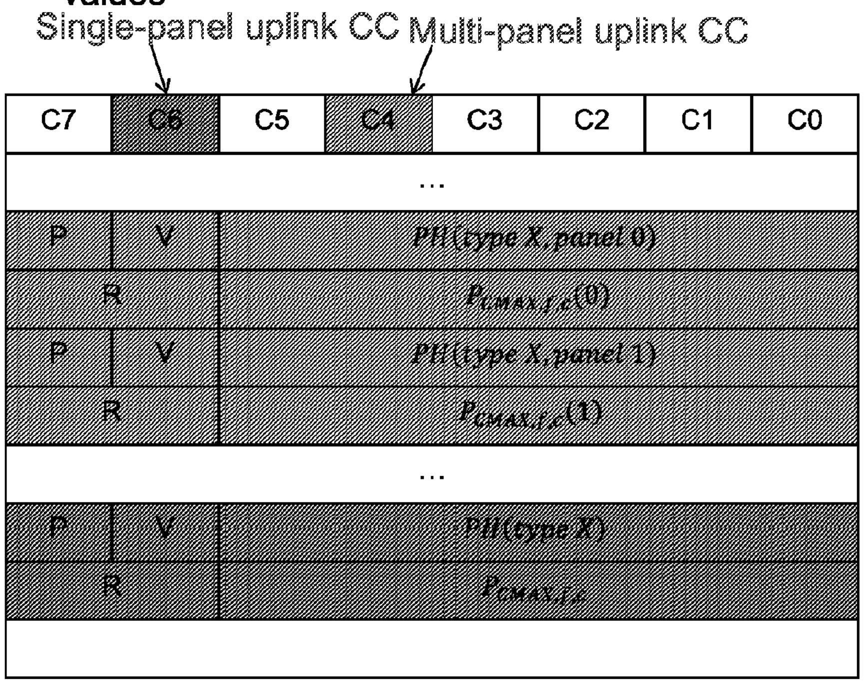
PHR Reporting For Multi-panel Uplink Transmission

Proposal2: Support per-panel power headroom report, where each CC have report up to two power headroom values



Example of MAC-CE on PUSCH

P: This field indicates whether the MAC entity applies power backoff due to power management

V: This field indicates if the PH value is based on a real transmission or a virtual reference format. Furthermore, for Type 1, Type 2, and Type 3 PH, the V field set to 0 indicates the presence of the octet containing the associated $P_{CMAX,f,c}$ field, and the V field set to 1 indicates that the octet containing the associated $P_{CMAX,f,c}$ field is omitted;

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PHR Reporting For Multi-panel Uplink Transmission

Proposal2A: Support per-panel power headroom report, where each CC have report up to two power headroom values

<table>
<tr><td>C7</td><td>C6</td><td>C5</td><td>C4</td><td>C3</td><td>C2</td><td>C1</td><td>C0</td></tr>
<tr><td>AC7</td><td>AC6</td><td>AC5</td><td>AC4</td><td>AC3</td><td>AC2</td><td>AC1</td><td>AC0</td></tr>
<tr><td colspan="8">…</td></tr>
<tr><td>P</td><td>V</td><td colspan="6">$PH(type\ X, panel\ 0)$</td></tr>
<tr><td colspan="2">R</td><td colspan="6">$P_{CMAX,f,c}(0)$</td></tr>
<tr><td>P</td><td>V</td><td colspan="6">$PH(type\ X, panel\ 1)$</td></tr>
<tr><td colspan="2">R</td><td colspan="6">$P_{CMAX,f,c}(1)$</td></tr>
<tr><td colspan="8">…</td></tr>
<tr><td>P</td><td>V</td><td colspan="6">$PH(type\ X, panel\ 1)$</td></tr>
<tr><td colspan="2">R</td><td colspan="6">$P_{CMAX,f,c}(1)$</td></tr>
<tr><td colspan="8"></td></tr>
</table>

C: this field indicate the PHR is reported for first panel in a cell

AC: this field indicate the PHR is reported for second panel in a cell

P: This field indicates whether the MAC entity applies power backoff due to power management

V: This field indicates if the PH value is based on a real transmission or a virtual reference format. Furthermore, for Type 1, Type 2, and Type 3 PH, the V field set to 0 indicates the presence of the octet containing the associated $P_{CMAX,f,c}$ field, and the V field set to 1 indicates that the octet containing the associated $P_{CMAX,f,c}$ field is omitted;

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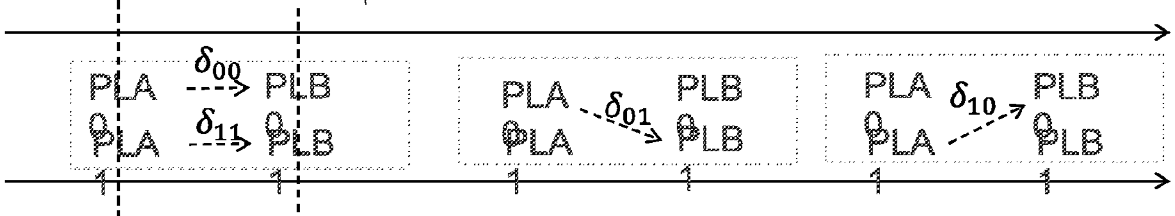
PHR Triggering For Multi-panel Uplink Transmission

- Proposal3: A Power Headroom Report (PHR) shall be triggered if the pathloss metric has been changed and the pathloss metric can be
  - ✓ One path loss change within the same UE panel k=0,1 ($\delta_{00} = PLB0 - PLA0$ or $\delta_{11} = PLB1 - PLA1$)
  - ✓ Both path loss changes within same UE panel k=0,1 (δ_{00} and δ_{11})
  - ✓ Average of path loss change within same UE panel k=0,1 ($(\delta_{00} + \delta_{11})/2$)
  - ✓ Any one of path loss {PLBx-PLAy} for x, y = 0,1 which is across UE panels (δ_{00} , δ_{11}, δ_{01} , δ_{10})
    - A is at the transmission time of the last transmission of PHR on the pathloss reference in use at that time
    - B is at present time on the current pathloss reference



- Example: A Power Headroom Report (PHR) shall be triggered when phr-ProhibitTimer expires or has expired and the pathloss metric has changed more than phr-Tx-PowerFactorChange dB for at least one activated Serving Cell of any MAC entity which is used as a pathloss reference since the last transmission of a PHR in this MAC entity when the MAC entity has UL resources for new transmission.

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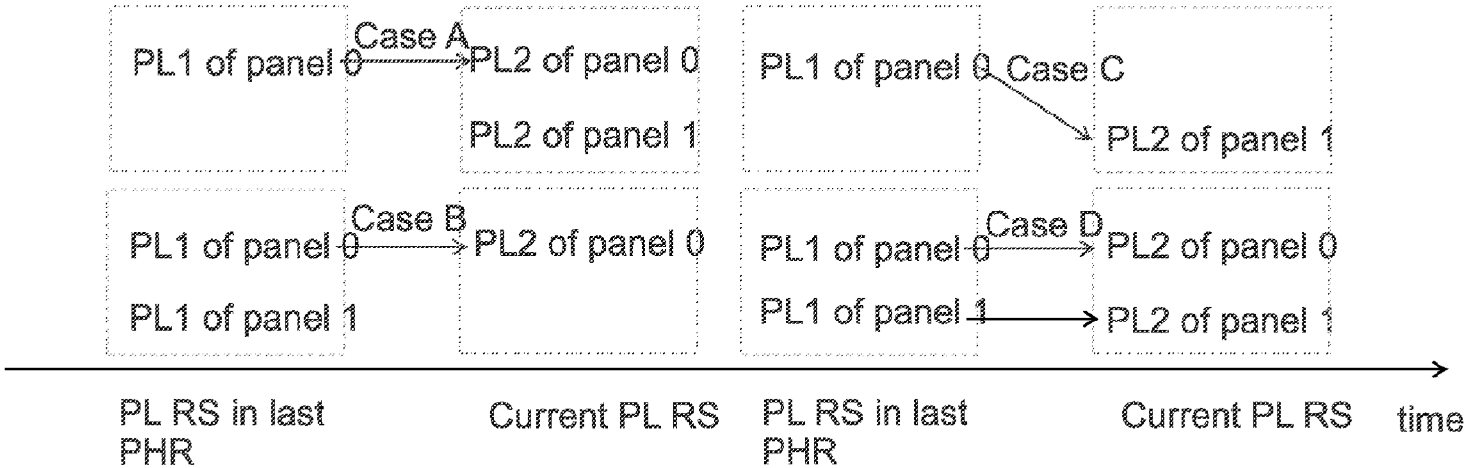
PHR Triggering For Multi-panel Uplink Transmission

- Proposal3B: The pathloss metric shall be
  - One of pathloss change of same panel in two time instance if there is, (Case A, B, D)
  - if not, the pathloss change in two time instance (Case C)



11

CLAIMS

WHAT IS CLAIMED IS:

1. A method of wireless communication, comprising:

determining, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission;

calculating a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value; and

transmitting the power headroom value for at least one panel of the multi-panel uplink transmission in a power headroom report on an uplink channel.

2. The method of claim 1, wherein calculating the power headroom value for each panel comprises determining a difference between the respective maximum transmit power value and the determined respective transmission power value.

3. The method of claim 1, wherein the power headroom value is calculated for a type of uplink transmission.

4. The method of claim 3, wherein the type of uplink transmission includes one of a physical uplink control channel (PUCCH) transmission, a physical uplink shared channel (PUSCH) transmission, or a sounding reference signal (SRS) transmission.

5. The method of claim 1, wherein the maximum transmit power value is preconfigured for each panel in the multi-panel uplink transmission.

6. The method of claim 5, wherein maximum transmit power value between at least two panels of the multi-panel uplink transmission are different.

7. The method of claim 1, wherein transmitting the power headroom value for each panel in the power headroom report further comprises:

configuring the power headroom report as a medium access control (MAC) control element (MAC-CE) including a plurality of fields, where each field in the plurality of fields is configured to transmit a respective power headroom value for a corresponding panel of the multi-panel uplink transmission.

8. The method of claim 1, wherein transmitting the power headroom value for each panel in the power headroom report further comprises:

configuring the power headroom report as a medium access control (MAC) control element (MAC-CE) including at least first and second component carrier (CC) fields wherein the first CC field indicates that a power headroom value for a first panel of the multi-panel uplink transmission is reported within the power headroom report and the second CC field indicates that a power headroom value for a second panel of the multi-panel uplink transmission is reported within the power headroom report.

9. The method of claim 1, wherein transmitting the power headroom value for each panel in the power headroom report further comprises:

configuring the power headroom report as a medium access control (MAC) control element (MAC-CE) including at least first and second component carrier (CC) fields wherein the first CC field indicates that a power headroom value for a first panel of the multi-panel uplink transmission is reported within the power headroom report and the second CC field indicates that a power headroom value for a second panel of the multi-panel uplink transmission is reported within the power headroom report.

10. The method claim 9, wherein the power headroom report may be configured to indicate the power headroom value for one of the first panel or the second panel by using a bit in either the first or second component carrier fields.

11. The method of claim 1, further comprising:

triggering the transmission of the PHR if a path loss metric changes for at least one panel of the multi-panel uplink transmissions.

12. The method of claim 11, wherein the change in the path loss metric comprises a path loss change with a same UE panel.

13. The method of claim 11, wherein the change in the path loss metric comprises path loss changes with each panel of at least two UE panels of the multi-panel uplink transmissions.

14. The method of claim 11, wherein the change in the path loss metric comprises a change in an average of path loss change over a predetermined time period for at least one panel of the multi-panel uplink transmissions.

15. The method of claim 14, wherein the predetermined time period is a time between a last transmission of a last PHR and a present time.

16. The method of claim 11, wherein the change in the path loss metric comprises a change between a first panel path loss at a first time and a second panel path loss at a second time.

17. The method of claim 1, wherein the uplink channel is a physical uplink shared channel (PUSCH).

18. An apparatus for wireless communication, comprising:

means for determining, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission;

means for calculating a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value; and

means for transmitting the power headroom value for at least one panel in a power headroom report on an uplink channel.

19. An apparatus for wireless communication, comprising:

a memory; and

at least one processor coupled to the memory and configured to:

determine, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission;

calculate a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value; and

transmit the power headroom value for at least one panel in a power headroom report on an uplink channel.

20. A computer-readable medium storing computer executable code, the code when executed by a processor causes the processor to:

determine, at a user equipment (UE), a respective transmission power value for each panel in a multi-panel uplink transmission;

calculate a power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value; and

transmit the power headroom value for at least one panel in a power headroom report on an uplink channel.

21. A method of wireless communication, comprising:

configuring in a UE a power headroom report (PHR) that includes power headroom information for at least one panel of a multi-panel uplink transmission scheduled for the UE; and

initiating transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period.

22. An apparatus for wireless communication, comprising:

means for configuring in a UE a power headroom report (PHR) that includes power headroom information for at least one panel of a multi-panel uplink transmission scheduled for the UE; and

means for initiating transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period.

23. An apparatus for wireless communication, comprising:

a memory; and

at least one processor coupled to the memory and configured to:

configure in a UE a power headroom report (PHR) that includes power headroom information for at least one panel of a multi-panel uplink transmission scheduled for the UE; and

initiate transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period.

24. A computer-readable medium storing computer executable code, the code when executed by a processor causes the processor to:

configure in a UE a power headroom report (PHR) that includes power headroom information for at least one panel of a multi-panel uplink transmission scheduled for the UE; and

initiate transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period.

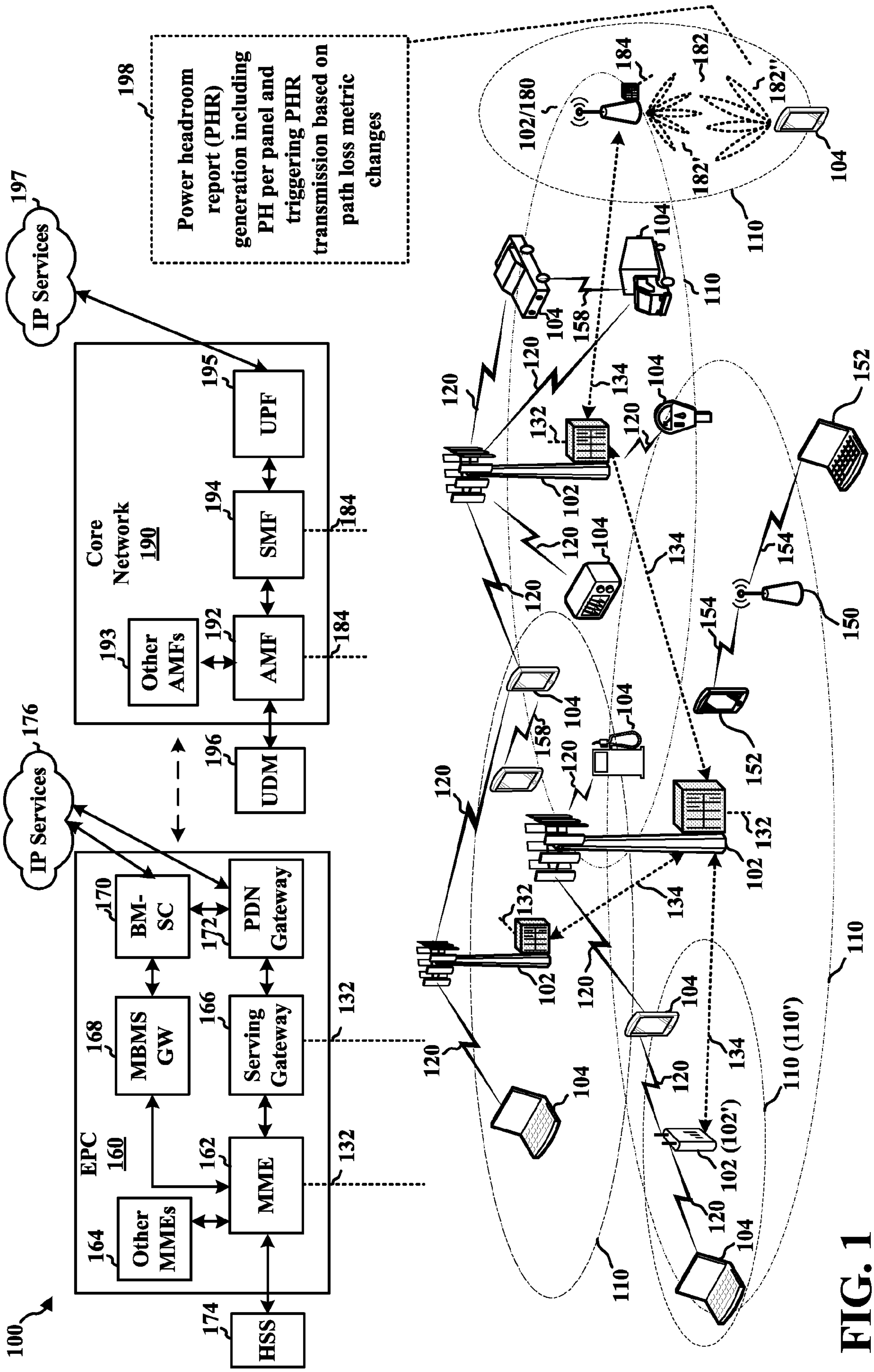

100
EPC
160
Other MMEs
164
MME
162
MBMS GW
168
Serving Gateway
166
BM-SC
170
PDN Gateway
172
HSS
174
IP Services
176
Core Network
190
Other AMFs
193
AMF
192
SMF
194
UPF
195
UDM
196
IP Services
197
198
Power headroom report (PHR) generation including PH per panel and triggering PHR transmission based on path loss metric changes
102/180
182
182'
182''
184
132
134
120
104
102
102 (102')
110
110 (110')
150
152
154
158

FIG. 1

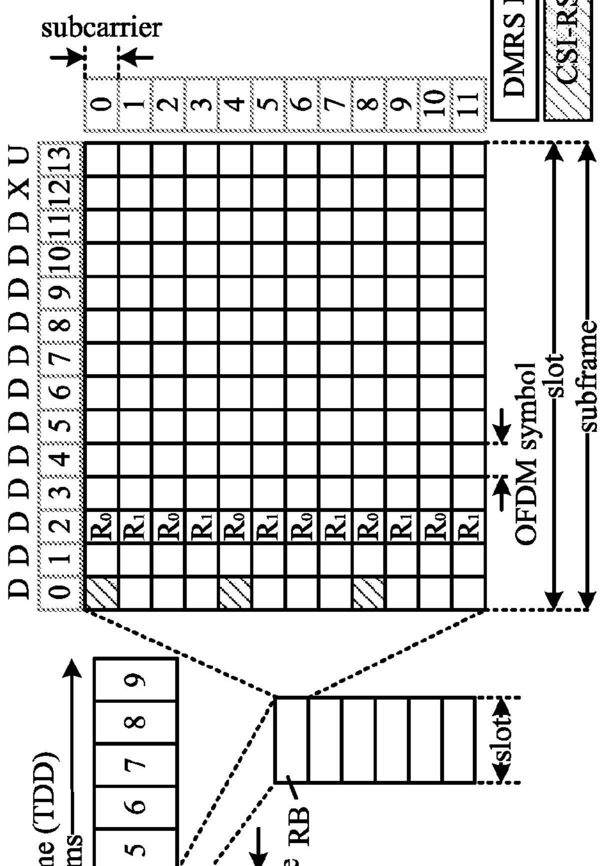


FIG. 2A

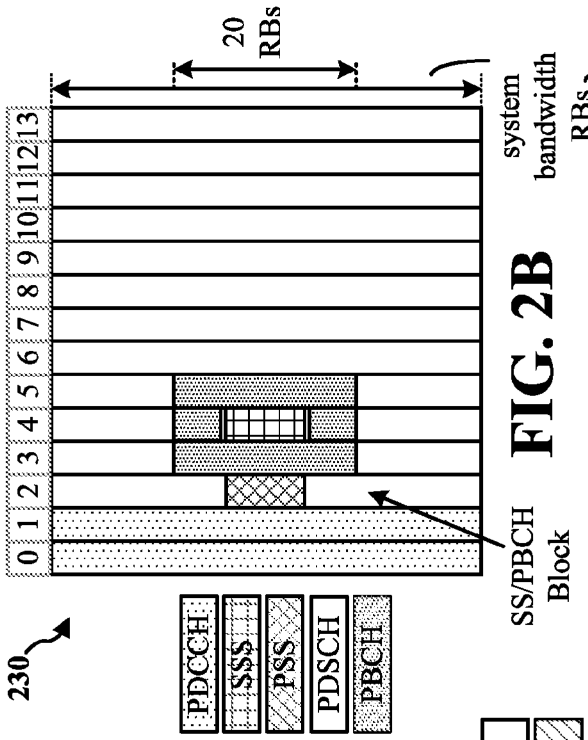


FIG. 2B

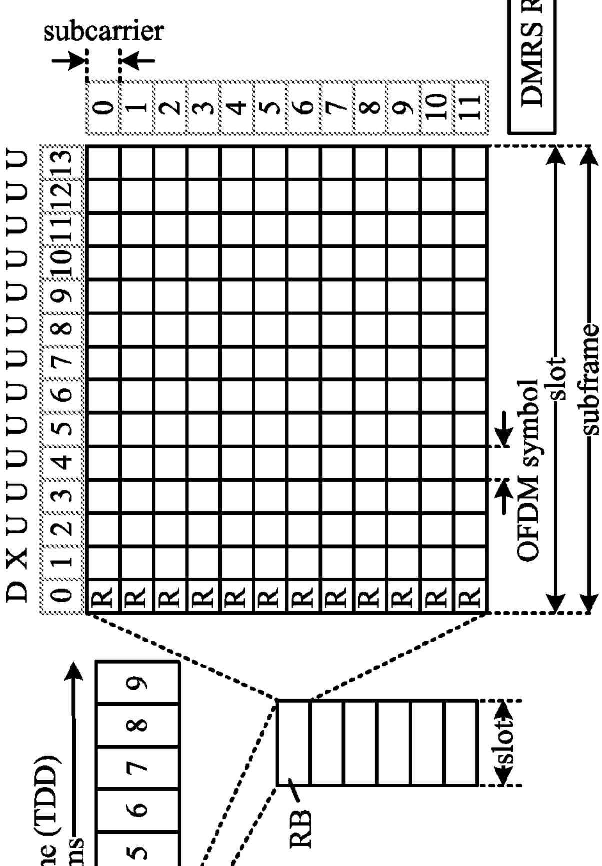


FIG. 2C

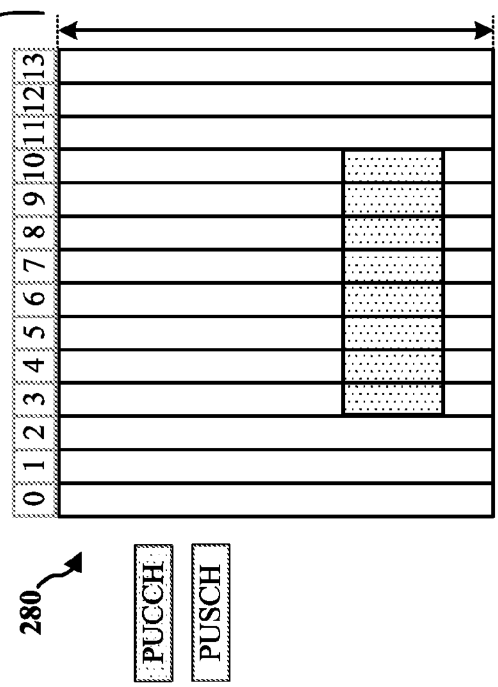


FIG. 2D

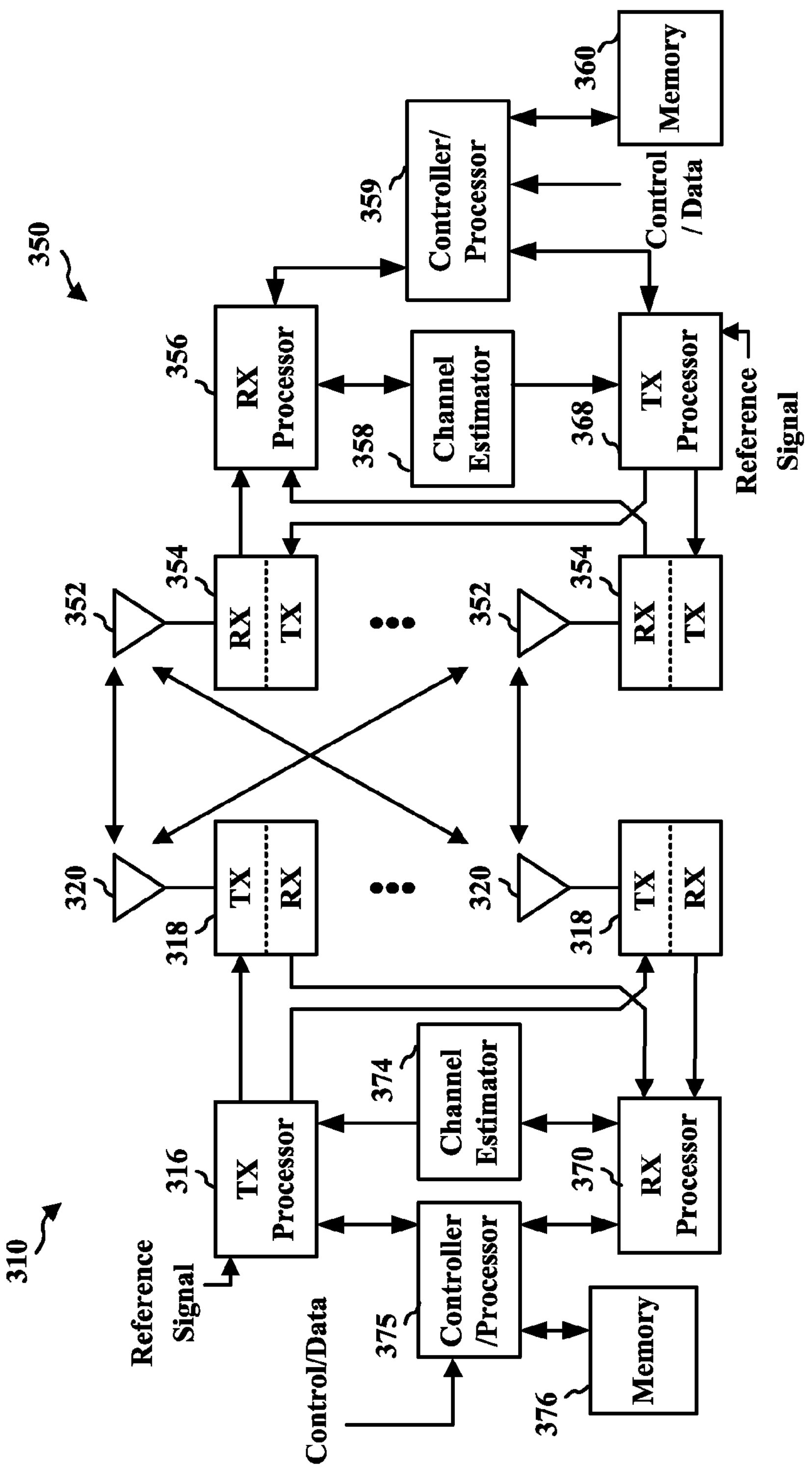

350
310
Reference Signal
316
TX Processor
Control/Data
375
Controller /Processor
376
Memory
374
Channel Estimator
370
RX Processor
318
TX
RX
320
352
354
356
RX Processor
358
Channel Estimator
368
TX Processor
Reference Signal
359
Controller/ Processor
Control / Data
360
Memory

FIG. 3

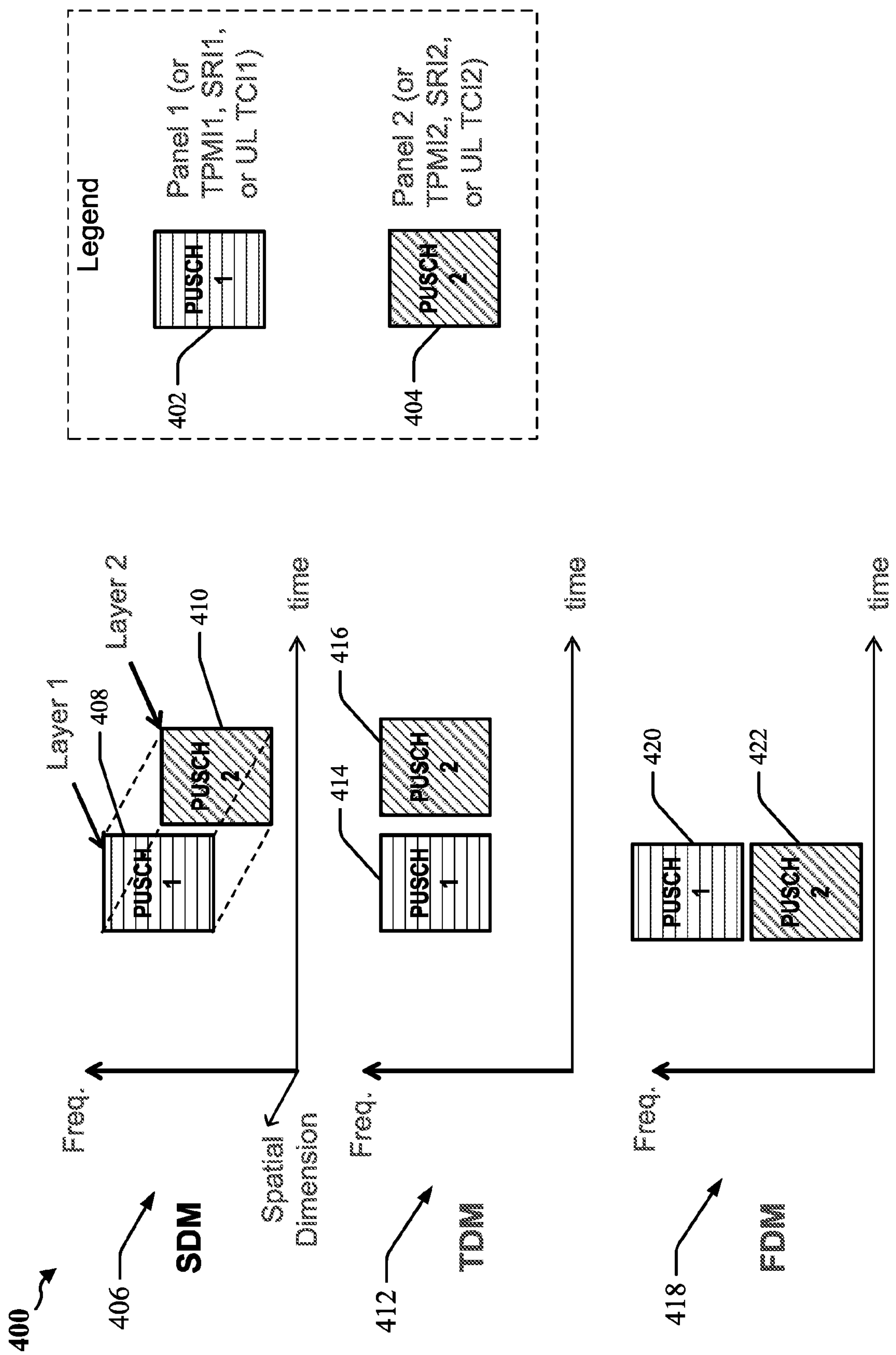

400
406
SDM
Freq.
Spatial Dimension
time
Layer 1
Layer 2
408
410
PUSCH 1
PUSCH 2
412
TDM
Freq.
time
414
416
PUSCH 1
PUSCH 2
418
FDM
Freq.
time
420
422
PUSCH 1
PUSCH 2
Legend
402
PUSCH 1
Panel 1 (or TPMI1, SRI1, or UL TCI1)
404
PUSCH 2
Panel 2 (or TPMI2, SRI2, or UL TCI2)

FIG. 4

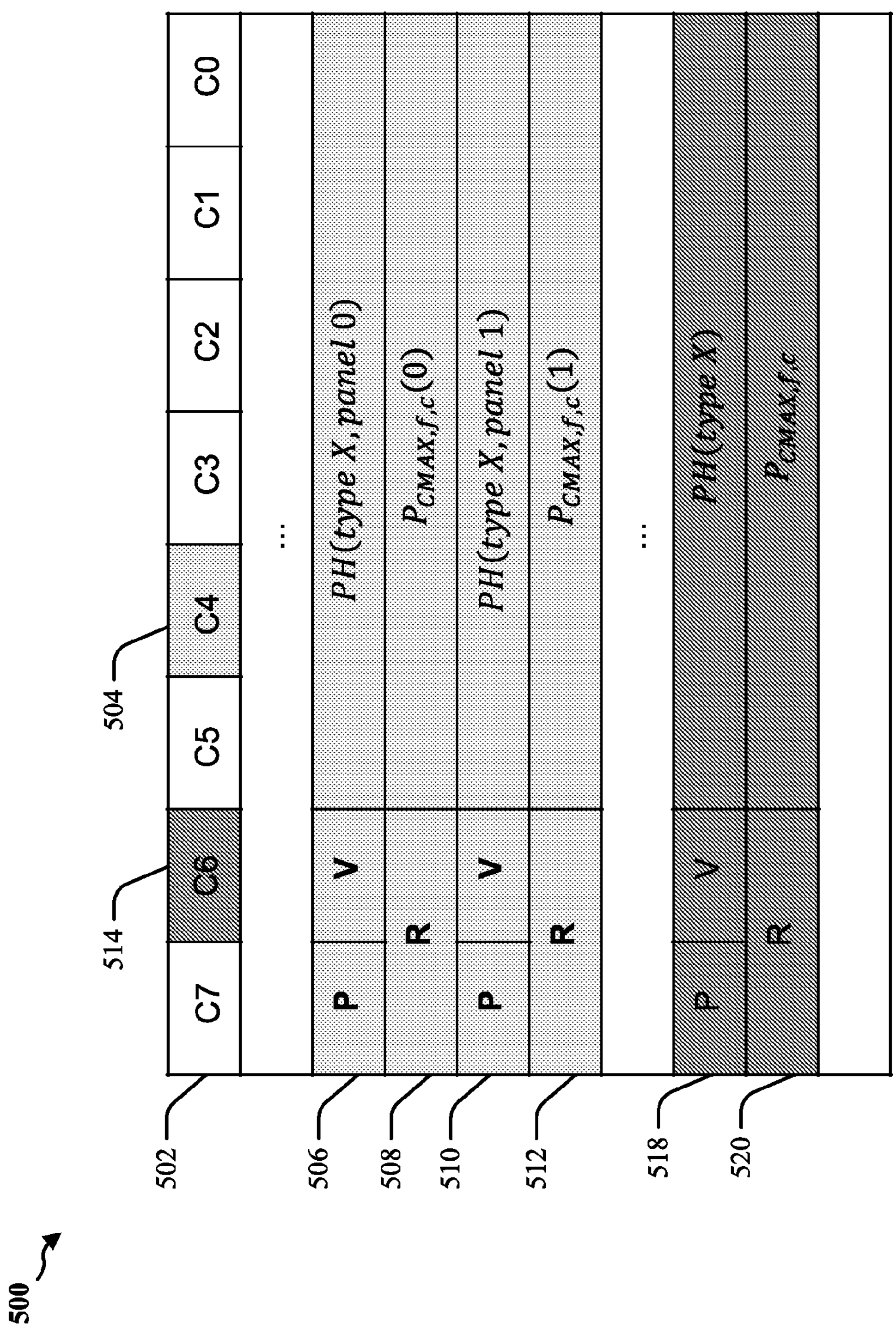

500
502
504
514
506
508
510
512
518
520
C7
C6
C5
C4
C3
C2
C1
C0
P
V
R
PH(type X, panel 0)
$P_{CMAX,f,c}(0)$
PH(type X, panel 1)
$P_{CMAX,f,c}(1)$
...
PH(type X)
$P_{CMAX,f,c}$

FIG. 5

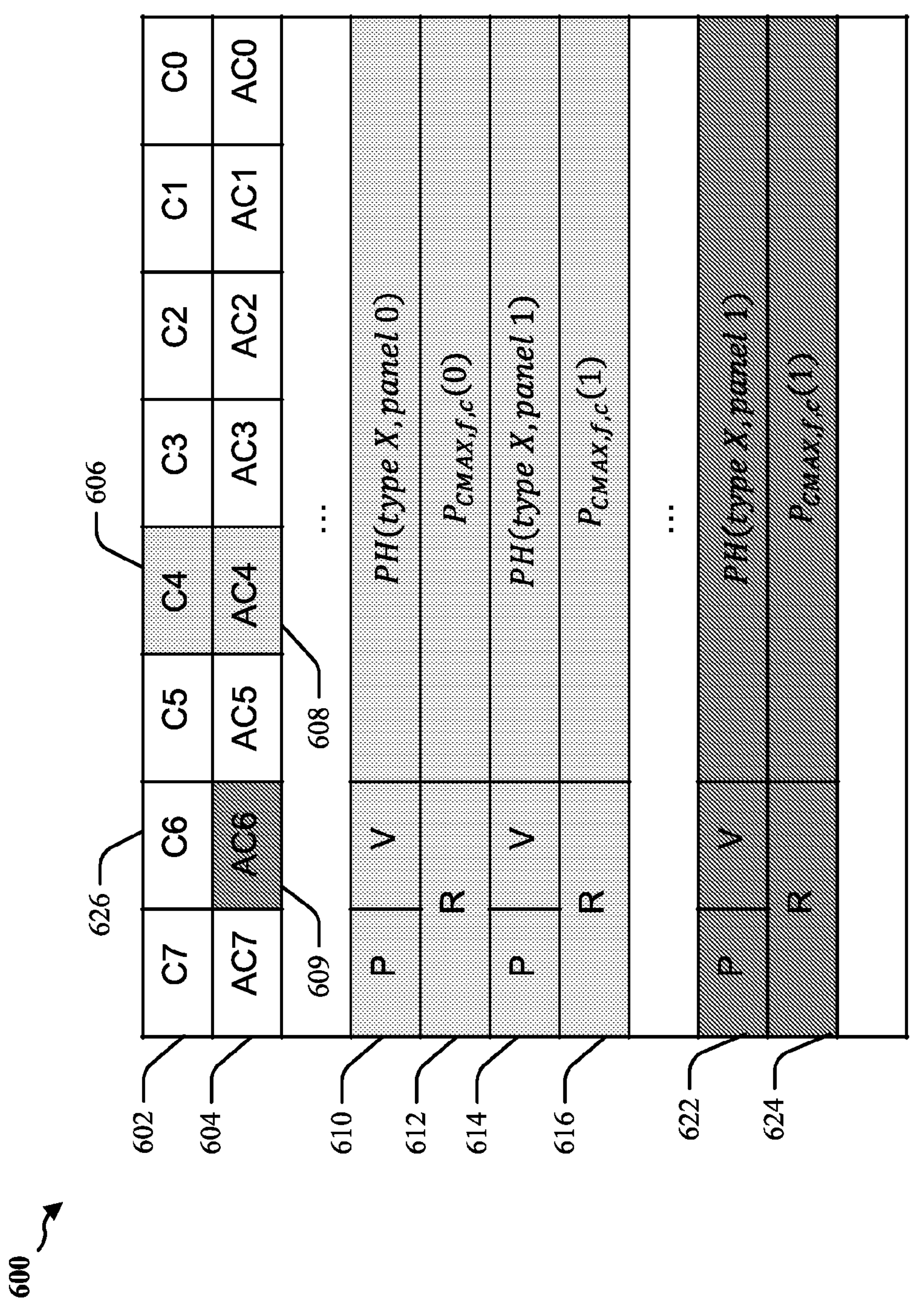

600
602
604
610
612
614
616
622
624
626
606
608
609
C7
C6
C5
C4
C3
C2
C1
C0
AC7
AC6
AC5
AC4
AC3
AC2
AC1
AC0
...
P
V
R
PH(type X, panel 0)
P_CMAX,f,c(0)
PH(type X, panel 1)
P_CMAX,f,c(1)

FIG. 6

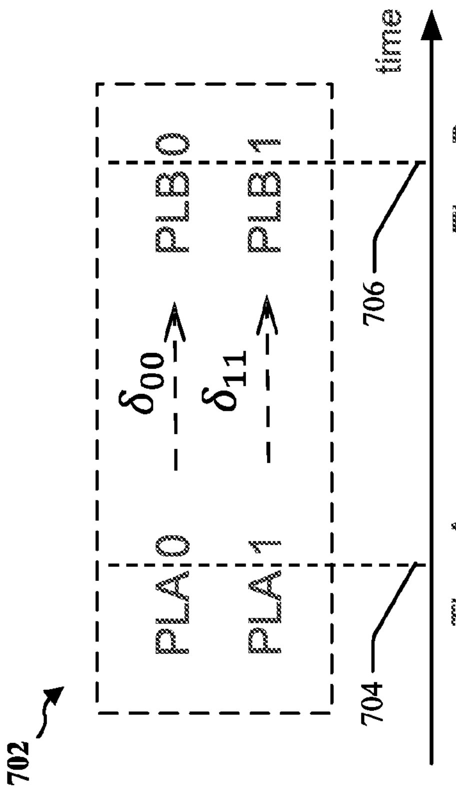


FIG. 7A

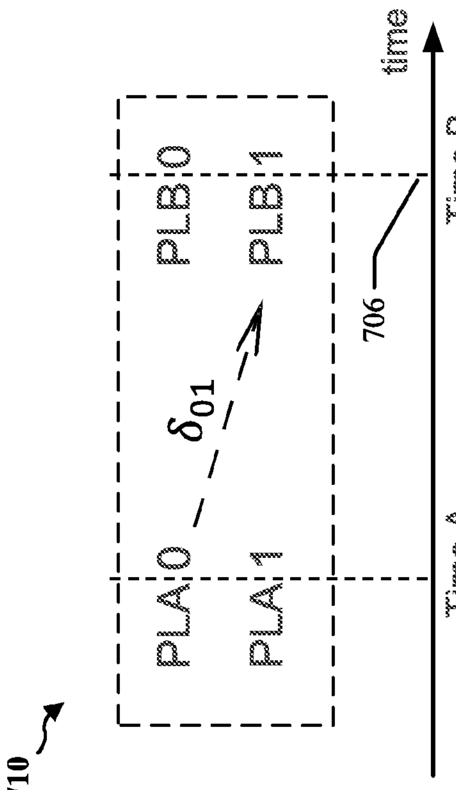


FIG. 7B

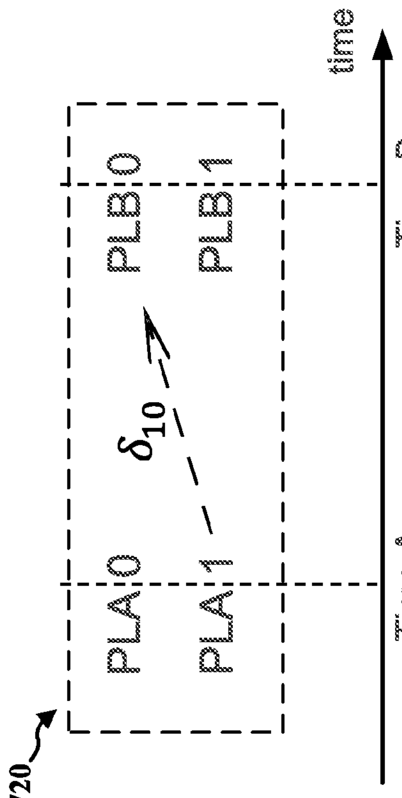


FIG. 7C

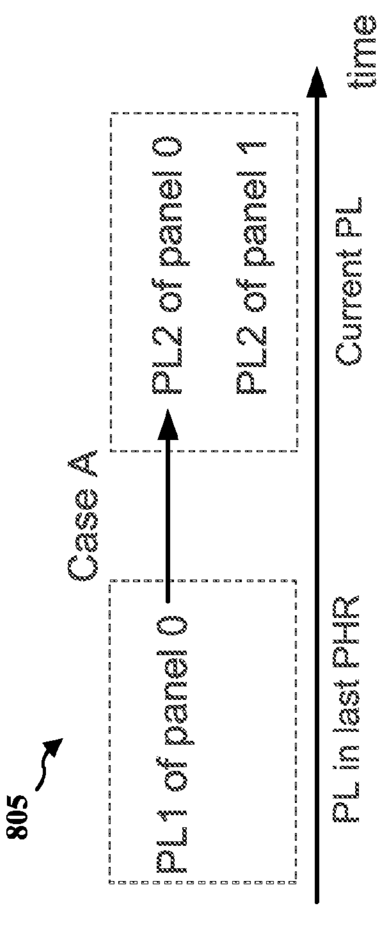


FIG. 8A

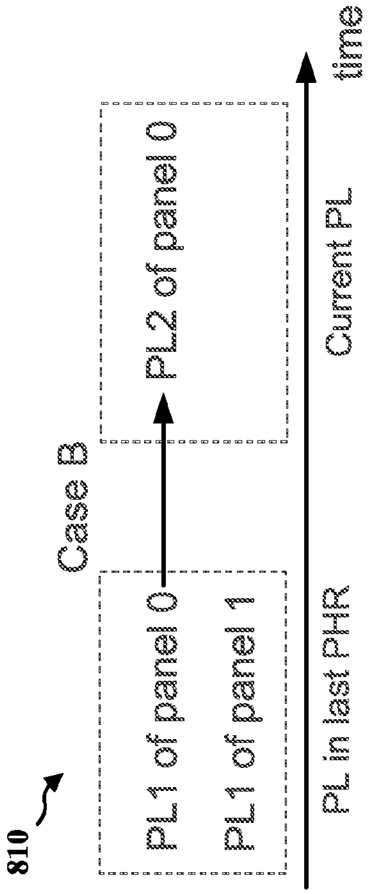


FIG. 8B

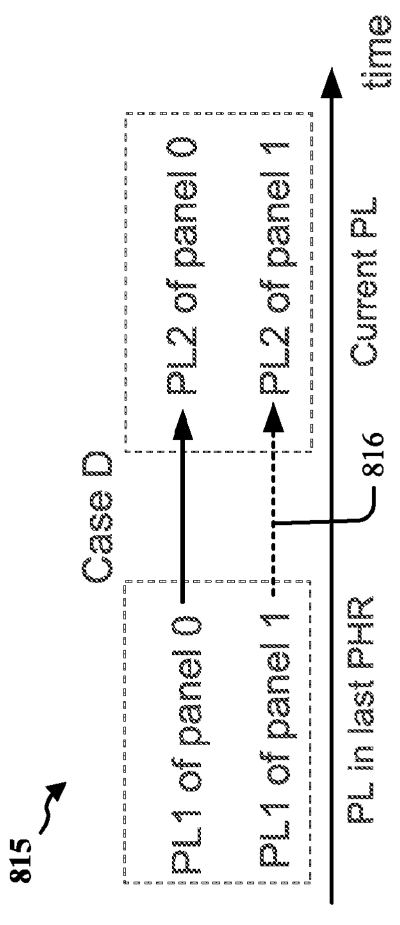


FIG. 8C

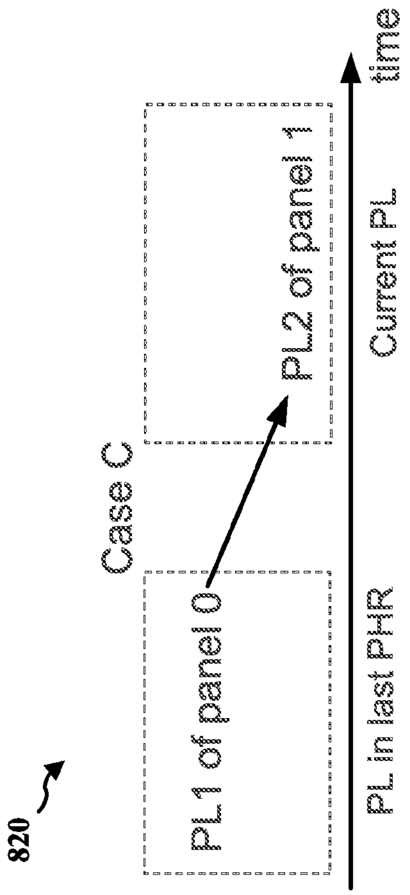


FIG. 8D

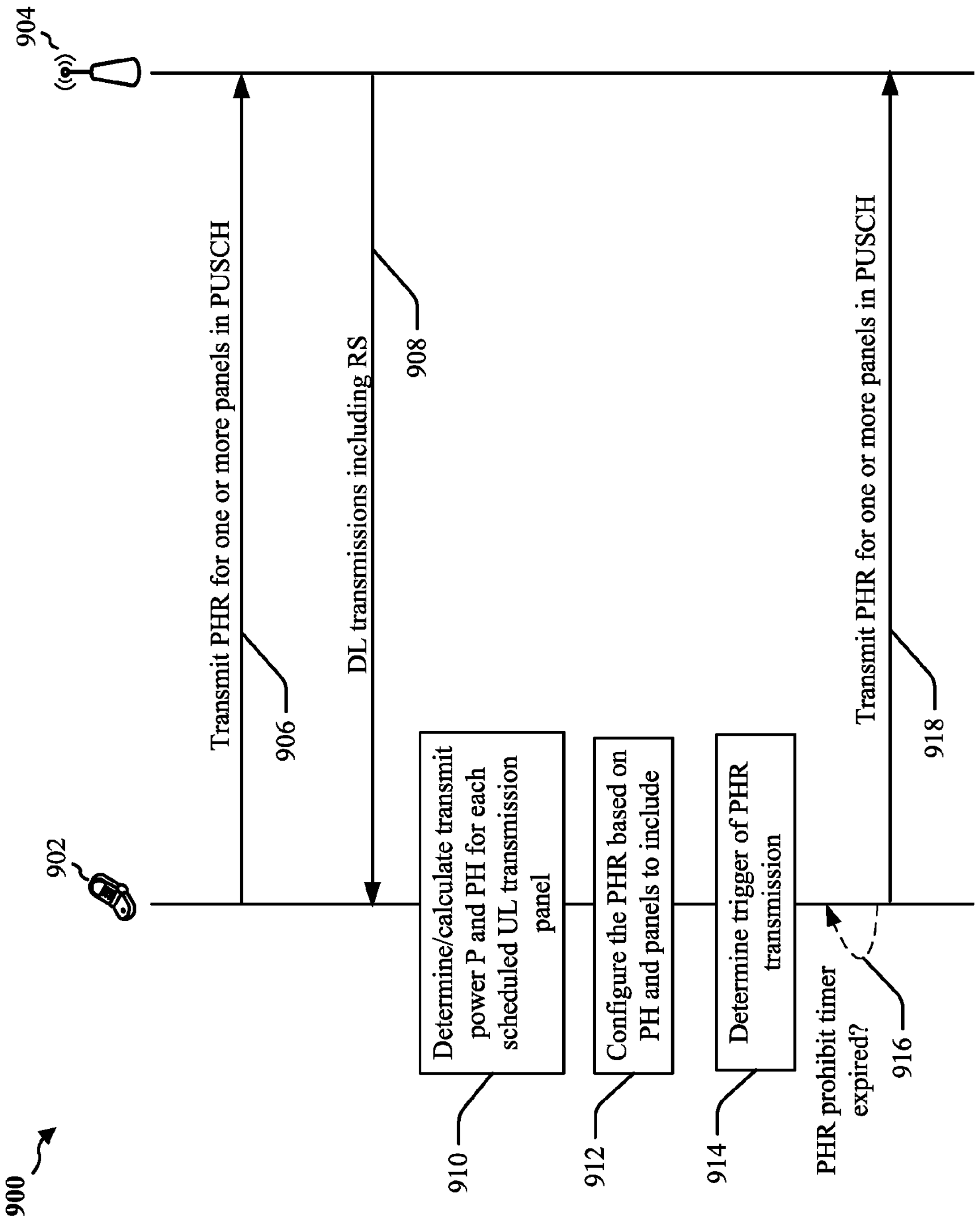

900
902
904
Transmit PHR for one or more panels in PUSCH
906
DL transmissions including RS
908
Determine/calculate transmit power P and PH for each scheduled UL transmission panel
910
Configure the PHR based on PH and panels to include
912
Determine trigger of PHR transmission
914
PHR prohibit timer expired?
916
Transmit PHR for one or more panels in PUSCH
918

FIG. 9

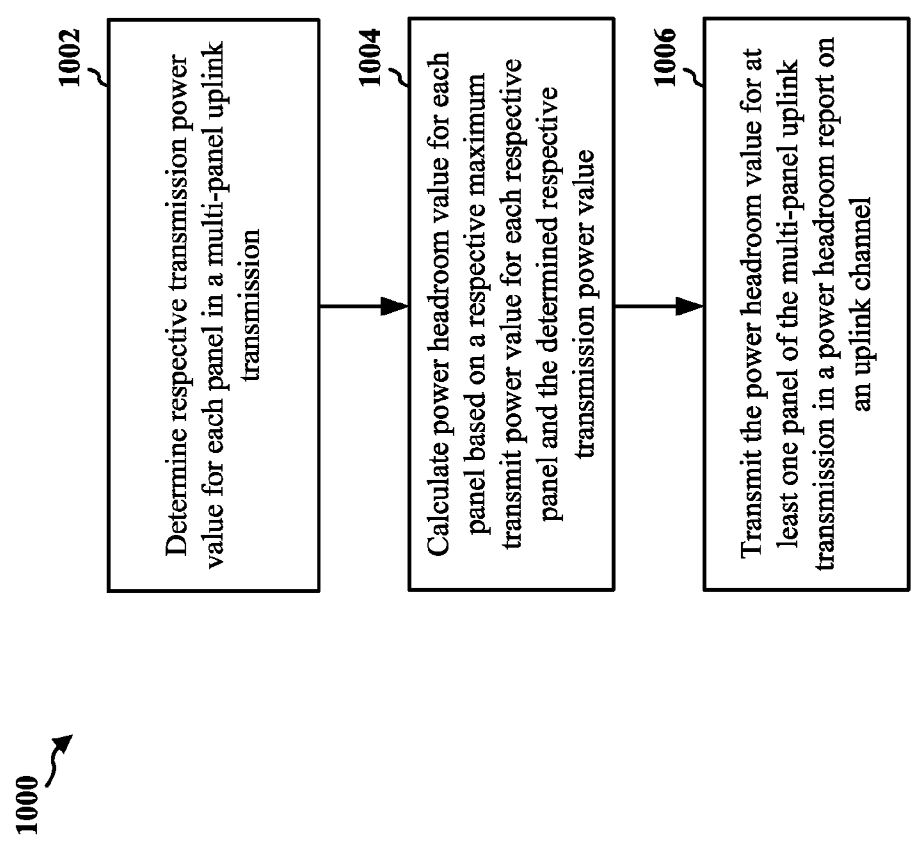

1000
1002
Determine respective transmission power value for each panel in a multi-panel uplink transmission
1004
Calculate power headroom value for each panel based on a respective maximum transmit power value for each respective panel and the determined respective transmission power value
1006
Transmit the power headroom value for at least one panel of the multi-panel uplink transmission in a power headroom report on an uplink channel

FIG. 10

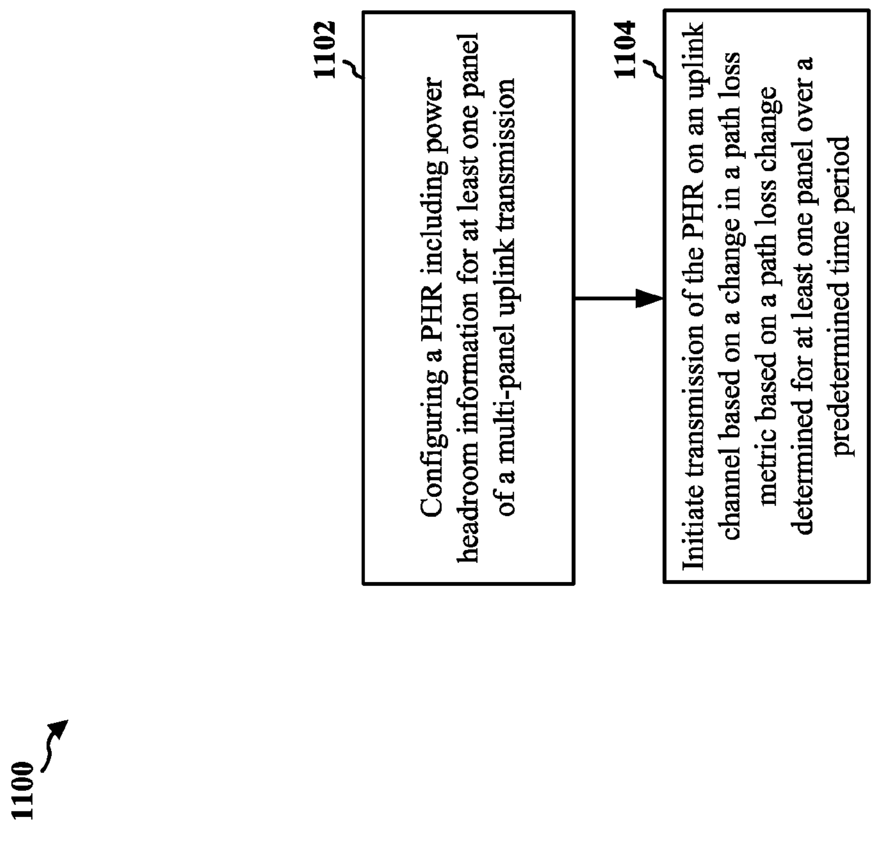

1100
1102
Configuring a PHR including power headroom information for at least one panel of a multi-panel uplink transmission
1104
Initiate transmission of the PHR on an uplink channel based on a change in a path loss metric based on a path loss change determined for at least one panel over a predetermined time period

FIG. 11

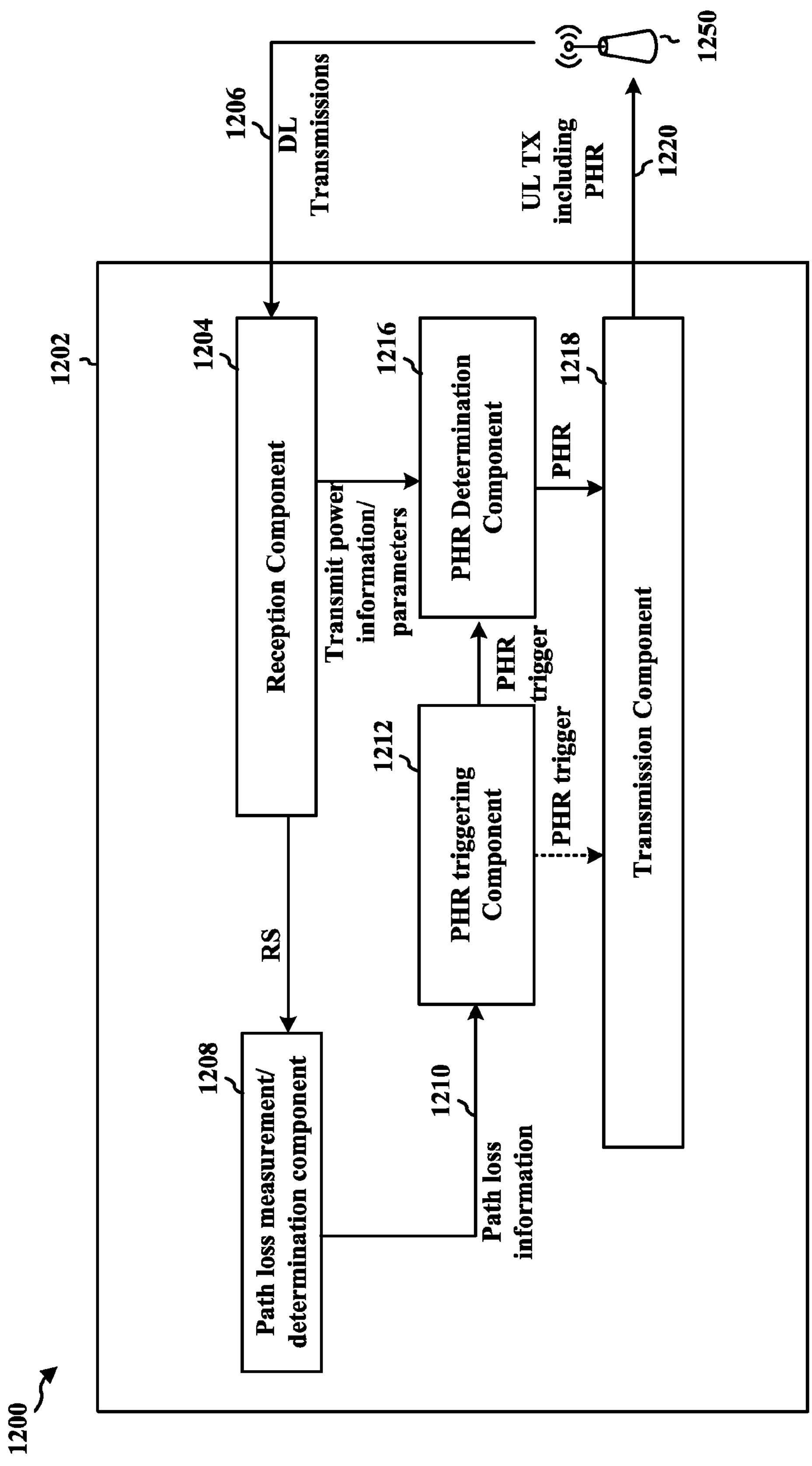

1200
1202
1204
Reception Component
1206
DL Transmissions
1250
Transmit power information/ parameters
1216
PHR Determination Component
PHR
1218
Transmission Component
1220
UL TX including PHR
RS
1208
Path loss measurement/ determination component
1210
Path loss information
1212
PHR triggering Component
PHR trigger
PHR trigger

FIG. 12

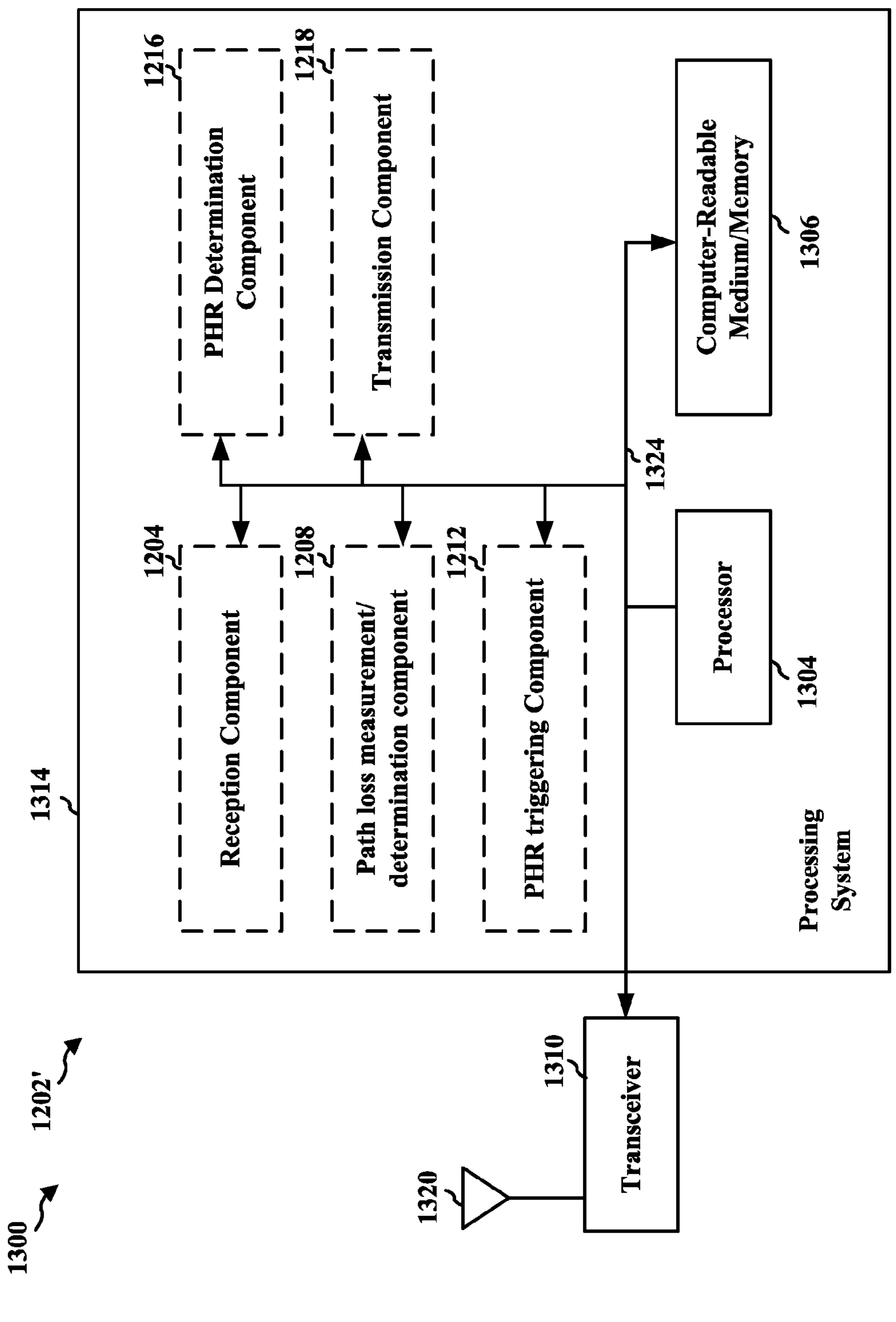

1300
1202'
1314
Reception Component
1204
Path loss measurement/
determination component
1208
PHR triggering Component
1212
PHR Determination
Component
1216
Transmission Component
1218
1324
Processor
1304
Computer-Readable
Medium/Memory
1306
Processing
System
Transceiver
1310
1320

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2020/092348

A. CLASSIFICATION OF SUBJECT MATTER

H04W 24/08(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04Q; H04L; H04M

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)

VEN;CNTXT;EPTXT;WOTXT;USTXT;CNKI;3GPP:panel， phr， multi， PH, power headroom report, power, maximum, per, schedul+, ue, transmission, network

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2019169590 A1 (GUANGDONG OPPO MOBILE TELECOMMUNICATIONS CORP LTD) 12 September 2019 (2019-09-12) description， page 2 line 30 – page 5 line 28	1-20
Y	WO 2019169590 A1 (GUANGDONG OPPO MOBILE TELECOMMUNICATIONS CORP LTD) 12 September 2019 (2019-09-12) description， page 2 line 30 – page 5 line 28	21-24
Y	US 2015163791 A1 (INNOVATIVE SONIC CORP) 11 June 2015 (2015-06-11) claims 1-10	21-24
A	CN 110915272 A (NTT DOCOMO INC) 24 March 2020 (2020-03-24) the whole document	1-24

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 February 2021	**22 February 2021**
Name and mailing address of the ISA/CN **National Intellectual Property Administration, PRC** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	Authorized officer **WANG,Ju**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(010)-62411392**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2020/092348

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2019169590	A1	12 September 2019	AU	2018412121	A1	01 October 2020
				SG	11202008648R	A	29 October 2020
				CN	111316686	A	19 June 2020
				TW	201939990	A	01 October 2019
				CN	111641961	A	08 September 2020
				CA	3093136	A1	12 September 2019
US	2015163791	A1	11 June 2015	US	10361833	B2	23 July 2019
				TW	201531135	A	01 August 2015
				TW	I555424	B	21 October 2016
CN	110915272	A	24 March 2020	JP	WO2019012635	A1	18 June 2020
				CA	3069641	A1	17 January 2019
				IL	271936	D0	27 February 2020
				WO	2019012635	A1	17 January 2019
				EP	3654704	A1	20 May 2020
				JP	6779380	B2	04 November 2020
				BR	112020000585	A2	14 July 2020
				IN	202037002706	A	28 February 2020