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(71) Applicant: APPLE INC. [US/US]; One Apple Park Way, Cupertino, California 95014 (US).

(72) Inventor; and
(71) Applicant *(for MG only)*: SUN, Haitong [CN/US]; One Apple Park Way, Cupertino, California 95014 (US).

(72) Inventors: YAO, Chunhai; International Finance Centre, 8 Jianguomenwai Avenue Chaoyang District, Beijing 100022 (CN). ZHANG, Dawei; One Apple Park Way, Cupertino, California 95014 (US). HE, Hong; One Apple Park Way, Cupertino, California 95014 (US). NABAR, Rohit, U.; One Apple Park Way, Cupertino, California 95014 (US). ZENG, Wei; One Apple Park Way, Cupertino, California 95014 (US). SUN, Yakun; One Apple Park Way, Cupertino, California 95014 (US). KIM, Yuchul; One Apple Park Way, Cupertino, California 95014 (US). ZHANG, Yushu; International Finance Centre, 8 Jianguomenwai Avenue Chaoyang District, Beijing 100022 (CN).

(74) Agent: CCPIT PATENT AND TRADEMARK LAW OFFICE; 8th Floor, Vantone New World Plaza, 2 Fuchengmenwai Street, Xicheng District, Beijing 100037 (CN).

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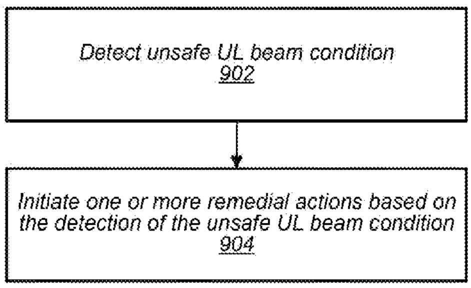

FIG. 9

(57) Abstract: Apparatuses, systems, and methods for a user equipment device (UE) to perform methods for triggering a change in beam configuration based on UL beam conditions. The UE may detect an unsafe UL beam condition for an UL beam based, at least in part, on an MPE level being exceeded by the UL beam. In response to the detection, remedial actions that to alleviate the unsafe UL beam condition may be performed. The remedial actions may prioritize UL beam quality over DL beam quality and may include reducing a transmit power of the UL beam based on an MPR, triggering an intra-panel antenna switch to a candidate UL beam that satisfies one or more conditions for intra-panel beam switching, triggering an inter-panel antenna switch to a candidate UL beam that satisfies one or more conditions for intra-panel beam switching, and/or signaling a beam failure to a network serving the UE.

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BEAM MANAGEMENT SOLUTION FOR MAXIMUM PERMISSIBLE EXPOSURE

FIELD

[0001] The present application relates to wireless devices, and more particularly to apparatuses, systems, and methods for a wireless device to trigger a change in beam configuration based on UL beam conditions, e.g., based on an UL beam reaching or exceeding a maximum permissible exposure (MPE) level.

DESCRIPTION OF THE RELATED ART

[0002] Wireless communication systems are rapidly growing in usage. In recent years, wireless devices such as smart phones and tablet computers have become increasingly sophisticated. In addition to supporting telephone calls, many mobile devices now provide access to the internet, email, text messaging, and navigation using the global positioning system (GPS), and are capable of operating sophisticated applications that utilize these functionalities.

[0003] Long Term Evolution (LTE) has become the technology of choice for the majority of wireless network operators worldwide, providing mobile broadband data and high-speed Internet access to their subscriber base. LTE defines a number of downlink (DL) physical channels, categorized as transport or control channels, to carry information blocks received from medium access control (MAC) and higher layers. LTE also defines a number of physical layer channels for the uplink (UL).

[0004] For example, LTE defines a Physical Downlink Shared Channel (PDSCH) as a DL transport channel. The PDSCH is the main data-bearing channel allocated to users on a dynamic and opportunistic basis. The PDSCH carries data in Transport Blocks (TB) corresponding to a MAC protocol data unit (PDU), passed from the MAC layer to the physical (PHY) layer once per Transmission Time Interval (TTI). The PDSCH is also used to transmit broadcast information such as System Information Blocks (SIB) and paging messages.

[0005] As another example, LTE defines a Physical Downlink Control Channel (PDCCH) as a DL control channel that carries the resource assignment for UEs that are contained in a Downlink Control Information (DCI) message. Multiple PDCCHs can be transmitted in the same subframe using Control Channel Elements (CCE), each of which is a nine set of four resource elements known as Resource Element Groups (REG). The PDCCH employs quadrature phase-shift keying (QPSK) modulation, with four QPSK symbols mapped to each REG. Furthermore, 1, 2, 4, or 8 CCEs can be used for a UE, depending on channel conditions, to ensure sufficient robustness.

[0006] Additionally, LTE defines a Physical Uplink Shared Channel (PUSCH) as a UL channel shared by all devices (user equipment, UE) in a radio cell to transmit user data to the network. The scheduling for all UEs is under control of the LTE base station (enhanced Node B, or eNB). The eNB uses the uplink scheduling grant (DCI format 0) to inform the UE about resource block (RB) assignment, and the modulation and coding scheme to be used. PUSCH typically supports QPSK and quadrature amplitude modulation (QAM). In addition to user data, the PUSCH also carries any control information necessary to decode the information, such as transport format indicators and multiple-in multiple-out (MIMO) parameters. Control data is multiplexed with information data prior to digital Fourier transform (DFT) spreading.

[0007] A proposed next telecommunications standard moving beyond the current International Mobile Telecommunications-Advanced (IMT-Advanced) Standards is called 5th generation mobile networks or 5th generation wireless systems, or 5G for short (otherwise known as 5G-NR for 5G New Radio, also simply referred to as NR). 5G-NR proposes a higher capacity for a higher density of mobile broadband users, also supporting device-to-device, ultra-reliable, and massive machine communications, as well as lower latency and lower battery consumption, than current LTE standards. Further, the 5G-NR standard may allow for less restrictive UE scheduling as compared to current LTE standards. Consequently, efforts are being made in ongoing developments of 5G-NR to take advantage of higher throughputs possible at higher frequencies.

SUMMARY

[0008] Embodiments relate to apparatuses, systems, and methods for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., such as to limit and/or avoid maximum possible exposure.

[0009] In some embodiments, a wireless device, e.g., such as a user equipment device (UE), may be configured to detect an unsafe uplink (UL) beam condition for an UL beam. The detection may be based, at least in part, on a maximum possible exposure (MPE) level being exceeded by the UL beam. In response to the detection, one or more remedial actions to alleviate the unsafe UL beam condition may be performed. The remedial actions may prioritize UL beam quality over DL beam quality. In some embodiments, the remedial actions may include any, any combination of, and/or all of reducing a transmit power of the UL beam based on a maximum power reduction (MPR),

triggering an intra-panel switch to a first candidate UL beam that satisfies one or more conditions for intra-panel beam switching, triggering an inter-panel switch to a second candidate UL beam that satisfies one or more conditions for intra-panel beam switching, and/or signaling a beam failure to a network serving the UE based on the unsafe UL beam condition.

[0010] The techniques described herein may be implemented in and/or used with a number of different types of devices, including but not limited to cellular phones, tablet computers, wearable computing devices, portable media players, and any of various other computing devices.

[0011] This Summary is intended to provide a brief overview of some of the subject matter described in this document. Accordingly, it will be appreciated that the above-described features are merely examples and should not be construed to narrow the scope or spirit of the subject matter described herein in any way. Other features, aspects, and advantages of the subject matter described herein will become apparent from the following Detailed Description, Figures, and Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] A better understanding of the present subject matter can be obtained when the following detailed description of various embodiments is considered in conjunction with the following drawings, in which:

[0013] Figure 1A illustrates an example wireless communication system according to some embodiments.

[0014] Figure 1B illustrates an example of a base station (BS) and an access point in communication with a user equipment (UE) device according to some embodiments.

[0015] Figure 2 illustrates an example simplified block diagram of a WLAN Access Point (AP), according to some embodiments.

[0016] Figure 3 illustrates an example block diagram of a UE according to some embodiments.

[0017] Figure 4 illustrates an example block diagram of a BS according to some embodiments.

[0018] Figure 5 illustrates an example block diagram of cellular communication circuitry, according to some embodiments.

[0019] Figure 6A illustrates an example of connections between an EPC network, an LTE base station (eNB), and a 5G NR base station (gNB).

[0020] Figure 6B illustrates an example of a protocol stack for an eNB and a gNB.

[0021] Figure 7A illustrates an example of a 5G network architecture that incorporates both 3GPP (e.g., cellular) and non-3GPP (e.g., non-cellular) access to the 5G CN, according to some embodiments.

[0022] Figure 7B illustrates an example of a 5G network architecture that incorporates both dual 3GPP (e.g., LTE and 5G NR) access and non-3GPP access to the 5G CN, according to some embodiments.

[0023] Figure 8 illustrates an example of a baseband processor architecture for a UE, according to some embodiments.

[0024] Figure 9 illustrates a block diagram of an example of a method for a UE to trigger a change in beam configuration based on UL beam conditions, according to some embodiments.

[0025] Figure 10 illustrates a block diagram of an example of a process for a UE to trigger a change in beam configuration based on UL beam conditions, according to some embodiments.

[0026] Figures 11-14 illustrate block diagrams of further examples of methods for a UE to trigger a change in UL beam configuration based on UL beam conditions, according to some embodiments.

[0027] While the features described herein may be susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to be limiting to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the subject matter as defined by the appended claims.

DETAILED DESCRIPTION

Terms

[0028] The following is a glossary of terms used in this disclosure:

[0029] **Memory Medium** – Any of various types of non-transitory memory devices or storage devices. The term “memory medium” is intended to include an installation medium, e.g., a CD-ROM, floppy disks, or tape device; a computer system memory or random access memory such as DRAM, DDR RAM, SRAM, EDO RAM, Rambus RAM, etc.; a non-volatile memory such as a Flash, magnetic media, e.g., a hard drive, or optical storage; registers, or other similar types of memory elements, etc. The memory medium may include other types of non-transitory memory as well or combinations thereof. In addition, the memory medium may be located in a first computer system in which the programs are executed, or may be located in a second different computer system which connects to the first computer system over a network, such as the Internet. In the latter instance, the second computer system may provide program instructions to the first computer for execution. The term “memory medium” may include two or more memory mediums which may reside in different locations, e.g., in different computer systems that are connected over a network. The memory medium may store program instructions (e.g., embodied as computer programs) that may be executed by one or more processors.

[0030] **Carrier Medium** – a memory medium as described above, as well as a physical transmission medium, such as a bus, network, and/or other physical transmission medium that conveys signals such as electrical, electromagnetic, or digital signals.

[0031] **Programmable Hardware Element** - includes various hardware devices comprising multiple programmable function blocks connected via a programmable interconnect. Examples include FPGAs (Field Programmable Gate Arrays), PLDs (Programmable Logic Devices), FPOAs (Field Programmable Object Arrays), and CPLDs (Complex PLDs). The programmable function blocks may range from fine grained (combinatorial logic or look up tables) to coarse grained (arithmetic logic units or processor cores). A programmable hardware element may also be referred to as "reconfigurable logic”.

[0032] **Computer System** – any of various types of computing or processing systems, including a personal computer system (PC), mainframe computer system, workstation, network appliance, Internet appliance, personal digital assistant (PDA), television system, grid computing system, or other device or combinations of devices. In general, the term "computer system" can be broadly defined to encompass any device (or combination of devices) having at least one processor that executes instructions from a memory medium.

[0033] **User Equipment (UE) (or “UE Device”)** – any of various types of computer systems devices which are mobile or portable and which performs wireless communications. Examples of UE devices include mobile telephones or smart phones (e.g., iPhone™, Android™-based phones), portable gaming devices (e.g., Nintendo DS™, PlayStation Portable™, Gameboy Advance™, iPhone™), laptops, wearable devices (e.g. smart watch, smart glasses), PDAs, portable Internet devices, music players, data storage devices, or other handheld devices, etc. In general, the term “UE” or “UE device” can be broadly defined to encompass any electronic, computing, and/or telecommunications device (or combination of devices) which is easily transported by a user and capable of wireless communication.

[0034] Base Station – The term "Base Station" has the full breadth of its ordinary meaning, and at least includes a wireless communication station installed at a fixed location and used to communicate as part of a wireless telephone system or radio system.

[0035] Processing Element – refers to various elements or combinations of elements that are capable of performing a function in a device, such as a user equipment or a cellular network device. Processing elements may include, for example: processors and associated memory, portions or circuits of individual processor cores, entire processor cores, processor arrays, circuits such as an ASIC (Application Specific Integrated Circuit), programmable hardware elements such as a field programmable gate array (FPGA), as well any of various combinations of the above.

[0036] Channel - a medium used to convey information from a sender (transmitter) to a receiver. It should be noted that since characteristics of the term “channel” may differ according to different wireless protocols, the term “channel” as used herein may be considered as being used in a manner that is consistent with the standard of the type of device with reference to which the term is used. In some standards, channel widths may be variable (e.g., depending on device capability, band conditions, etc.). For example, LTE may support scalable channel bandwidths from 1.4 MHz to 20MHz. In contrast, WLAN channels may be 22MHz wide while Bluetooth channels may be 1Mhz wide. Other protocols and standards may include different definitions of channels. Furthermore, some standards may define and use multiple types of channels, e.g., different channels for uplink or downlink and/or different channels for different uses such as data, control information, etc.

[0037] Band - The term "band" has the full breadth of its ordinary meaning, and at least includes a section of spectrum (e.g., radio frequency spectrum) in which channels are used or set aside for the same purpose.

[0038] Automatically – refers to an action or operation performed by a computer system (e.g., software executed by the computer system) or device (e.g., circuitry, programmable hardware elements, ASICs, etc.), without user input directly specifying or performing the action or operation. Thus the term "automatically" is in contrast to an operation being manually performed or specified by the user, where the user provides input to directly perform the operation. An automatic procedure may be initiated by input provided by the user, but the subsequent actions that are performed “automatically” are not specified by the user, i.e., are not performed “manually”, where the user specifies each action to perform. For example, a user filling out an electronic form by selecting each field and providing input specifying information (e.g., by typing information, selecting check boxes, radio selections, etc.) is filling out the form manually, even though the computer system must update the form in response to the user actions. The form may be automatically filled out by the computer system where the computer system (e.g., software executing on the computer system) analyzes the fields of the form and fills in the form without any user input specifying the answers to the fields. As indicated above, the user may invoke the automatic filling of the form, but is not involved in the actual filling of the form (e.g., the user is not manually specifying answers to fields but rather they are being automatically completed). The present specification provides various examples of operations being automatically performed in response to actions the user has taken.

[0039] **Approximately** - refers to a value that is almost correct or exact. For example, approximately may refer to a value that is within 1 to 10 percent of the exact (or desired) value. It should be noted, however, that the actual threshold value (or tolerance) may be application dependent. For example, in some embodiments, “approximately” may mean within 0.1% of some specified or desired value, while in various other embodiments, the threshold may be, for example, 2%, 3%, 5%, and so forth, as desired or as required by the particular application.

[0040] **Concurrent** – refers to parallel execution or performance, where tasks, processes, or programs are performed in an at least partially overlapping manner. For example, concurrency may be implemented using “strong” or strict parallelism, where tasks are performed (at least partially) in parallel on respective computational elements, or using “weak parallelism”, where the tasks are performed in an interleaved manner, e.g., by time multiplexing of execution threads.

[0041] Various components may be described as “configured to” perform a task or tasks. In such contexts, “configured to” is a broad recitation generally meaning “having structure that” performs the task or tasks during operation. As such, the component can be configured to perform the task even when the component is not currently performing that task (e.g., a set of electrical conductors may be configured to electrically connect a module to another module, even when the two modules are not connected). In some contexts, “configured to” may be a broad recitation of structure generally meaning “having circuitry that” performs the task or tasks during operation. As such, the component can be configured to perform the task even when the component is not currently on. In general, the circuitry that forms the structure corresponding to “configured to” may include hardware circuits.

[0042] Various components may be described as performing a task or tasks, for convenience in the description. Such descriptions should be interpreted as including the phrase “configured to.” Reciting a component that is configured to perform one or more tasks is expressly intended not to invoke 35 U.S.C. § 112(f) interpretation for that component.

Figures 1A and 1B - Communication Systems

[0043] Figure 1A illustrates a simplified example wireless communication system, according to some embodiments. It is noted that the system of Figure 1 is merely one example of a possible system, and that features of this disclosure may be implemented in any of various systems, as desired.

[0044] As shown, the example wireless communication system includes a base station 102A which communicates over a transmission medium with one or more user devices 106A, 106B, etc., through 106N. Each of the user devices may be referred to herein as a “user equipment” (UE). Thus, the user devices 106 are referred to as UEs or UE devices.

[0045] The base station (BS) 102A may be a base transceiver station (BTS) or cell site (a “cellular base station”) and may include hardware that enables wireless communication with the UEs 106A through 106N.

[0046] The communication area (or coverage area) of the base station may be referred to as a “cell.” The base station 102A and the UEs 106 may be configured to communicate over the transmission medium using any of various radio access technologies (RATs), also referred to as wireless communication technologies, or telecommunication standards, such as GSM, UMTS (associated with, for example, WCDMA or TD-SCDMA air interfaces), LTE, LTE-Advanced (LTE-A), 5G new radio (5G NR), HSPA, 3GPP2 CDMA2000 (e.g., 1xRTT, 1xEV-DO, HRPD, eHRPD), etc. Note that if the base station 102A is implemented in the context of LTE, it may alternately be referred to as an 'eNodeB' or ‘eNB’. Note that if the base station 102A is implemented in the context of 5G NR, it may alternately be referred to as ‘gNodeB’ or ‘gNB’.

[0047] As shown, the base station 102A may also be equipped to communicate with a network 100 (e.g., a core network of a cellular service provider, a telecommunication network such as a public switched telephone network (PSTN), and/or the Internet, among various possibilities). Thus, the base station 102A may facilitate communication between the user devices and/or between the user devices and the network 100. In particular, the cellular base station 102A may provide UEs 106 with various telecommunication capabilities, such as voice, SMS and/or data services.

[0048] Base station 102A and other similar base stations (such as base stations 102B…102N) operating according to the same or a different cellular communication standard may thus be provided as a network of cells, which may provide continuous or nearly continuous overlapping service to UEs 106A-N and similar devices over a geographic area via one or more cellular communication standards.

[0049] Thus, while base station 102A may act as a "serving cell" for UEs 106A-N as illustrated in Figure 1, each UE 106 may also be capable of receiving signals from (and possibly within communication range of) one or more other cells (which might be provided by base stations 102B-N and/or any other base stations), which may be referred to as "neighboring cells". Such cells may also be capable of facilitating communication between user devices and/or between user devices and the network 100. Such cells may include "macro" cells, "micro" cells, "pico" cells, and/or cells which provide any of various other granularities of service area size. For example, base stations 102A-B illustrated in Figure 1 might be macro cells, while base station 102N might be a micro cell. Other configurations are also possible.

[0050] In some embodiments, base station 102A may be a next generation base station, e.g., a 5G New Radio (5G NR) base station, or "gNB". In some embodiments, a gNB may be connected to a legacy evolved packet core (EPC) network and/or to a NR core (NRC) network. In addition, a gNB cell may include one or more transition and reception points (TRPs). In addition, a UE capable of operating according to 5G NR may be connected to one or more TRPs within one or more gNBs.

[0051] Note that a UE 106 may be capable of communicating using multiple wireless communication standards. For example, the UE 106 may be configured to communicate using a wireless networking (e.g., Wi-Fi) and/or peer-to-peer wireless communication protocol (e.g., Bluetooth, Wi-Fi peer-to-peer, etc.) in addition to at least one cellular communication protocol (e.g., GSM, UMTS (associated with, for example, WCDMA or TD-SCDMA air interfaces), LTE, LTE-A, 5G NR, HSPA, 3GPP2 CDMA2000 (e.g., 1xRTT, 1xEV-DO, HRPD, eHRPD), etc.). The UE 106 may also or alternatively be configured to communicate using one or more global navigational satellite systems (GNSS, e.g., GPS or GLONASS), one or more mobile television broadcasting standards (e.g., ATSC-M/H or DVB-H), and/or any other wireless communication protocol, if desired. Other combinations of wireless communication standards (including more than two wireless communication standards) are also possible.

[0052] Figure 1B illustrates user equipment 106 (e.g., one of the devices 106A through 106N) in communication with a base station 102 and an access point 112, according to some embodiments. The UE 106 may be a device with both cellular communication capability and non-cellular communication capability (e.g., Bluetooth, Wi-Fi, and so forth) such as a mobile phone, a hand-held device, a computer or a tablet, or virtually any type of wireless device.

[0053] The UE 106 may include a processor that is configured to execute program instructions stored in memory. The UE 106 may perform any of the method embodiments described herein by executing such stored instructions. Alternatively, or in addition, the UE 106 may include a programmable hardware element such as an FPGA (field-programmable gate array) that is configured to perform any of the method embodiments described herein, or any portion of any of the method embodiments described herein.

[0054] The UE 106 may include one or more antennas for communicating using one or more wireless communication protocols or technologies. In some embodiments, the UE 106 may be configured to communicate using, for example, CDMA2000 (1xRTT / 1xEV-DO / HRPD / eHRPD), LTE/LTE-Advanced, or 5G NR using a single shared radio and/or GSM, LTE, LTE-Advanced, or 5G NR using the single shared radio. The shared radio may couple to a single antenna, or may couple to multiple antennas (e.g., for MIMO) for performing wireless communications. In general, a radio may include any combination of a baseband processor, analog RF signal processing circuitry (e.g., including filters, mixers, oscillators, amplifiers, etc.), or digital processing circuitry (e.g., for digital modulation as well as other digital processing). Similarly, the radio may implement one or more receive and transmit chains using the aforementioned hardware. For example, the UE 106 may share one or more parts of a receive and/or transmit chain between multiple wireless communication technologies, such as those discussed above.

[0055] In some embodiments, the UE 106 may include separate transmit and/or receive chains (e.g., including separate antennas and other radio components) for each wireless communication protocol with which it is configured to communicate. As a further possibility, the UE 106 may include one or more radios which are shared between multiple wireless communication protocols, and one or more radios which are used exclusively by a single wireless communication protocol. For example, the UE 106 might include a shared radio for communicating using either of LTE or 5G NR (or LTE or 1xRTTor LTE or GSM), and separate radios for communicating using each of Wi-Fi and Bluetooth. Other configurations are also possible.

Figure 2 – Access Point Block Diagram

[0056] Figure 2 illustrates an exemplary block diagram of an access point (AP) 112. It is noted that the block diagram of the AP of Figure 2 is only one example of a possible system. As shown, the AP 112 may include processor(s) 204 which may execute program instructions for the AP 112. The processor(s) 204 may also be coupled (directly or indirectly) to memory management unit (MMU) 240, which may be configured to receive addresses from the processor(s) 204 and to translate those addresses to locations in memory (e.g., memory 260 and read only memory (ROM) 250) or to other circuits or devices.

[0057] The AP 112 may include at least one network port 270. The network port 270 may be configured to couple to a wired network and provide a plurality of devices, such as UEs 106, access to the Internet. For example, the network port 270 (or an additional network port) may be configured to couple to a local network, such as a home network or an enterprise network. For example, port 270 may be an Ethernet port. The local network may provide connectivity to additional networks, such as the Internet.

[0058] The AP 112 may include at least one antenna 234, which may be configured to operate as a wireless transceiver and may be further configured to communicate with UE 106 via wireless communication circuitry 230. The antenna 234 communicates with the wireless communication circuitry 230 via communication chain 232. Communication chain 232 may include one or more receive chains, one or more transmit chains or both. The wireless communication circuitry 230 may be configured to communicate via Wi-Fi or WLAN, e.g., 802.11. The wireless communication circuitry 230 may also, or alternatively, be configured to communicate via various other wireless communication technologies, including, but not limited to, 5G NR, Long-Term Evolution (LTE), LTE Advanced (LTE-A), Global System for Mobile (GSM), Wideband Code Division Multiple Access (WCDMA), CDMA2000, etc., for example when the AP is co-located with a base station in case of a small cell, or in other instances when it may be desirable for the AP 112 to communicate via various different wireless communication technologies.

[0059] In some embodiments, as further described below, an AP 112 may be configured to perform methods for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., to avoid and/or limit maximum possible exposure as further described herein.

<u>Figure 3 – Block Diagram of a UE</u>

[0060] Figure 3 illustrates an example simplified block diagram of a communication device 106, according to some embodiments. It is noted that the block diagram of the communication device of Figure 3 is only one example of a possible communication device. According to embodiments, communication device 106 may be a user equipment (UE) device, a mobile device or mobile station, a wireless device or wireless station, a desktop computer or computing device, a mobile computing device (e.g., a laptop, notebook, or portable computing device), a tablet and/or a combination of devices, among other devices. As shown, the communication device 106 may include a set of components 300 configured to perform core functions. For example, this set of components may be implemented as a system on chip (SOC), which may include portions for various purposes. Alternatively, this set of components 300 may be implemented as separate components or groups of components for the various purposes. The set of components 300 may be coupled (e.g., communicatively; directly or indirectly) to various other circuits of the communication device 106.

[0061] For example, the communication device 106 may include various types of memory (e.g., including NAND flash 310), an input/output interface such as connector I/F 320 (e.g., for connecting to a computer system; dock; charging station; input devices, such as a microphone, camera, keyboard; output devices, such as speakers; etc.), the display 360, which may be integrated with or external to the communication device 106, and cellular communication circuitry 330 such as for 5G NR, LTE, GSM, etc., and short to medium range wireless communication circuitry 329 (e.g., Bluetooth™ and WLAN circuitry). In some embodiments, communication device 106 may include wired communication circuitry (not shown), such as a network interface card, e.g., for Ethernet.

[0062] The cellular communication circuitry 330 may couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 335 and 336 as shown. The short to medium range wireless communication circuitry 329 may also couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 337 and 338 as shown. Alternatively, the short to medium range wireless communication circuitry 329 may couple (e.g., communicatively; directly or indirectly) to the antennas 335 and 336 in addition to, or instead of, coupling (e.g., communicatively; directly or indirectly) to the antennas 337 and 338. The short to medium range wireless communication circuitry 329 and/or cellular communication circuitry 330 may include multiple receive chains and/or multiple transmit chains for receiving and/or transmitting multiple spatial streams, such as in a multiple-input multiple output (MIMO) configuration.

[0063] In some embodiments, as further described below, cellular communication circuitry 330 may include dedicated receive chains (including and/or coupled to, e.g., communicatively; directly or indirectly. dedicated processors and/or radios) for multiple RATs (e.g., a first receive chain for LTE and a second receive chain for 5G NR). In addition, in some embodiments, cellular communication circuitry 330 may include a single transmit chain that may be switched between radios dedicated to specific RATs. For example, a first radio may be dedicated to a first RAT, e.g., LTE, and may be in communication with a dedicated receive chain and a transmit chain shared with an additional radio, e.g., a second radio that may be dedicated to a second RAT, e.g., 5G NR, and may be in communication with a dedicated receive chain and the shared transmit chain.

[0064] The communication device 106 may also include and/or be configured for use with one or more user interface elements. The user interface elements may include any of various elements, such as display 360 (which may be a touchscreen display), a keyboard (which may be a discrete keyboard or may be implemented as part of a touchscreen display), a mouse, a microphone and/or speakers, one or more cameras, one or more buttons, and/or any of various other elements capable of providing information to a user and/or receiving or interpreting user input.

[0065] The communication device 106 may further include one or more smart cards 345 that include SIM (Subscriber Identity Module) functionality, such as one or more UICC(s) (Universal Integrated Circuit Card(s)) cards 345.

[0066] As shown, the SOC 300 may include processor(s) 302, which may execute program instructions for the communication device 106 and display circuitry 304, which may perform graphics processing and provide display signals to the display 360. The processor(s) 302 may also be coupled to memory management unit (MMU) 340, which may be configured to receive addresses from the processor(s) 302 and translate those addresses to locations in memory (e.g., memory 306, read only memory (ROM) 350, NAND flash memory 310) and/or to other circuits or devices, such as the display circuitry 304, short to medium range wireless communication circuitry 329, cellular communication circuitry 330, connector I/F 320, and/or display 360. The MMU 340 may be configured to perform memory protection and page table translation or set up. In some embodiments, the MMU 340 may be included as a portion of the processor(s) 302.

[0067] As noted above, the communication device 106 may be configured to communicate using wireless and/or wired communication circuitry. The communication device 106 may be configured to perform methods for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., to avoid and/or limit maximum possible exposure as further described herein.

[0068] As described herein, the communication device 106 may include hardware and software components for implementing the above features for a communication device 106 to communicate a scheduling profile for power savings to a network. The processor 302 of the communication device 106 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 302 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 302 of the communication device 106, in conjunction with one or more of the other components 300, 304, 306, 310, 320, 329, 330, 340, 345, 350, 360 may be configured to implement part or all of the features described herein.

[0069] In addition, as described herein, processor 302 may include one or more processing elements. Thus, processor 302 may include one or more integrated circuits (ICs) that are configured to perform the functions of processor 302. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processor(s) 302.

[0070] Further, as described herein, cellular communication circuitry 330 and short to medium range wireless communication circuitry 329 may each include one or more processing elements. In other words, one or more processing elements may be included in cellular communication circuitry 330 and, similarly, one or more processing elements may be included in short to medium range wireless communication circuitry 329. Thus, cellular communication circuitry 330 may include one or more integrated circuits (ICs) that are configured to perform the functions of cellular communication circuitry 330. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of cellular communication circuitry 330. Similarly, the short to medium range wireless communication circuitry 329 may include one or more ICs that are configured to perform the functions of short to medium range wireless communication circuitry 329. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of short to medium range wireless communication circuitry 329.

Figure 4 – Block Diagram of a Base Station

[0071] Figure 4 illustrates an example block diagram of a base station 102, according to some embodiments. It is noted that the base station of Figure 4 is merely one example of a possible base station. As shown, the base station 102 may include processor(s) 404 which may execute program instructions for the base station 102. The processor(s) 404 may also be coupled to memory management unit (MMU) 440, which may be configured to receive addresses from the processor(s) 404 and translate those addresses to locations in memory (e.g., memory 460 and read only memory (ROM) 450) or to other circuits or devices.

[0072] The base station 102 may include at least one network port 470. The network port 470 may be configured to couple to a telephone network and provide a plurality of devices, such as UE devices 106, access to the telephone network as described above in Figures 1 and 2.

[0073] The network port 470 (or an additional network port) may also or alternatively be configured to couple to a cellular network, e.g., a core network of a cellular service provider. The core network may provide mobility related services and/or other services to a plurality of devices, such as UE devices 106. In some cases, the network port 470 may couple to a telephone network via the core network, and/or the core network may provide a telephone network (e.g., among other UE devices serviced by the cellular service provider).

[0074] In some embodiments, base station 102 may be a next generation base station, e.g., a 5G New Radio (5G NR) base station, or "gNB". In such embodiments, base station 102 may be connected to a legacy evolved packet core (EPC) network and/or to a NR core (NRC) network. In addition, base station 102 may be considered a 5G NR cell and may include one or more transition and reception points (TRPs). In addition, a UE capable of operating according to 5G NR may be connected to one or more TRPs within one or more gNBs.

[0075] The base station 102 may include at least one antenna 434, and possibly multiple antennas. The at least one antenna 434 may be configured to operate as a wireless transceiver and may be further configured to communicate with UE devices 106 via radio 430. The antenna 434 communicates with the radio 430 via communication chain 432. Communication chain 432 may be a receive chain, a transmit chain or both. The radio 430 may be configured to communicate via various wireless communication standards, including, but not limited to, 5G NR, LTE, LTE-A, GSM, UMTS, CDMA2000, Wi-Fi, etc.

[0076] The base station 102 may be configured to communicate wirelessly using multiple wireless communication standards. In some instances, the base station 102 may include multiple radios, which may enable the base station 102 to communicate according to multiple wireless communication technologies. For example, as one possibility, the base station 102 may include an LTE radio for performing communication according to LTE as well as a 5G NR radio for performing communication according to 5G NR. In such a case, the base station 102 may be capable of operating as both an LTE base station and a 5G NR base station. As another possibility, the base station 102 may include a multi-mode radio which is capable of performing communications according to any of multiple wireless communication technologies (e.g., 5G NR and Wi-Fi, LTE and Wi-Fi, LTE and UMTS, LTE and CDMA2000, UMTS and GSM, etc.).

[0077] As described further subsequently herein, the BS 102 may include hardware and software components for implementing or supporting implementation of features described herein. The processor 404 of the base station 102 may be configured to implement or support implementation of part or all of the methods described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively, the processor 404 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit), or a combination thereof. Alternatively (or in addition) the processor 404 of the BS 102, in conjunction with one or more of the other components 430, 432, 434, 440, 450, 460, 470 may be configured to implement or support implementation of part or all of the features described herein.

[0078] In addition, as described herein, processor(s) 404 may be comprised of one or more processing elements. In other words, one or more processing elements may be included in processor(s) 404. Thus, processor(s) 404 may include one or more integrated circuits (ICs) that are configured to perform the functions of processor(s) 404. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processor(s) 404.

[0079] Further, as described herein, radio 430 may be comprised of one or more processing elements. In other words, one or more processing elements may be included in radio 430. Thus, radio 430 may include one or more integrated circuits (ICs) that are configured to perform the functions of radio 430. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of radio 430.

<u>Figure 5: Block Diagram of Cellular Communication Circuitry</u>

[0080] Figure 5 illustrates an example simplified block diagram of cellular communication circuitry, according to some embodiments. It is noted that the block diagram of the cellular communication circuitry of Figure 5 is only one example of a possible cellular communication circuit. According to embodiments, cellular communication circuitry 330 may be included in a communication device, such as communication device 106 described above. As noted above, communication device 106 may be a user equipment (UE) device, a mobile device or mobile station, a wireless device or wireless station, a desktop computer or computing device, a mobile computing device (e.g., a laptop, notebook, or portable computing device), a tablet and/or a combination of devices, among other devices.

[0081] The cellular communication circuitry 330 may couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 335a-b and 336 as shown (in Figure 3). In some embodiments, cellular communication circuitry 330 may include dedicated receive chains (including and/or coupled to, e.g., communicatively; directly or indirectly. dedicated processors and/or radios) for multiple RATs (e.g., a first receive chain for LTE and a second receive chain for 5G NR). For example, as shown in Figure 5, cellular communication circuitry 330 may include a modem 510 and a modem 520. Modem 510 may be configured for communications according to a first RAT, e.g., such as LTE or LTE-A, and modem 520 may be configured for communications according to a second RAT, e.g., such as 5G NR.

[0082] As shown, modem 510 may include one or more processors 512 and a memory 516 in communication with processors 512. Modem 510 may be in communication with a radio frequency (RF) front end 530. RF front end 530 may include circuitry for transmitting and receiving radio signals. For example, RF front end 530 may include receive circuitry (RX) 532 and transmit circuitry (TX) 534. In some embodiments, receive circuitry 532 may be in communication with downlink (DL) front end 550, which may include circuitry for receiving radio signals via antenna 335a.

[0083] Similarly, modem 520 may include one or more processors 522 and a memory 526 in communication with processors 522. Modem 520 may be in communication with an RF front end 540. RF front end 540 may include circuitry for transmitting and receiving radio signals. For example, RF front end 540 may include receive circuitry 542 and transmit circuitry 544. In some embodiments, receive circuitry 542 may be in communication with DL front end 560, which may include circuitry for receiving radio signals via antenna 335b.

[0084] In some embodiments, a switch 570 may couple transmit circuitry 534 to uplink (UL) front end 572. In addition, switch 570 may couple transmit circuitry 544 to UL front end 572. UL front end 572 may include circuitry for transmitting radio signals via antenna 336. Thus, when cellular communication circuitry 330 receives instructions to transmit according to the first RAT (e.g., as supported via modem 510), switch 570 may be switched to a first state that allows modem 510 to transmit signals according to the first RAT (e.g., via a transmit chain that includes transmit circuitry 534 and UL front end 572). Similarly, when cellular communication circuitry 330 receives instructions to transmit according to the second RAT (e.g., as supported via modem 520), switch 570 may be switched to a second state that allows modem 520 to transmit signals according to the second RAT (e.g., via a transmit chain that includes transmit circuitry 544 and UL front end 572).

[0085] In some embodiments, the cellular communication circuitry 330 may be configured to perform methods for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., to avoid and/or limit maximum possible exposure as further described herein.

[0086] As described herein, the modem 510 may include hardware and software components for implementing the above features or for time division multiplexing UL data for NSA NR operations, as well as the various other techniques described herein. The processors 512 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 512 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 512, in conjunction with one or more of the other components 530, 532, 534, 550, 570, 572, 335 and 336 may be configured to implement part or all of the features described herein.

[0087] In addition, as described herein, processors 512 may include one or more processing elements. Thus, processors 512 may include one or more integrated circuits (ICs) that are configured to perform the functions of processors 512. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processors 512.

[0088] As described herein, the modem 520 may include hardware and software components for implementing the above features for communicating a scheduling profile for power savings to a network, as well as the various other techniques described herein. The processors 522 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 522 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 522, in conjunction with one or more of the other components 540, 542, 544, 550, 570, 572, 335 and 336 may be configured to implement part or all of the features described herein.

[0089] In addition, as described herein, processors 522 may include one or more processing elements. Thus, processors 522 may include one or more integrated circuits (ICs) that are configured to perform the functions of processors 522. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processors 522.

<u>5G NR Architecture with LTE</u>

[0090] In some implementations, fifth generation (5G) wireless communication will initially be deployed concurrently with current wireless communication standards (e.g., LTE). For example, dual connectivity between LTE and 5G new radio (5G NR or NR) has been specified as part of the initial deployment of NR. Thus, as illustrated in Figures 6A-B, evolved packet core (EPC) network 600 may continue to communicate with current LTE base stations (e.g., eNB 602). In addition, eNB 602 may be in communication with a 5G NR base station (e.g., gNB 604) and may pass data between the EPC network 600 and gNB 604. Thus, EPC network 600 may be used (or reused) and gNB 604 may serve as extra capacity for UEs, e.g., for providing increased downlink throughput to UEs. In other words, LTE may be used for control plane signaling and NR may be used for user plane signaling. Thus, LTE may be used to establish connections to the network and NR may be used for data services.

[0091] Figure 6B illustrates a proposed protocol stack for eNB 602 and gNB 604. As shown, eNB 602 may include a medium access control (MAC) layer 632 that interfaces with radio link control

(RLC) layers 622a-b. RLC layer 622a may also interface with packet data convergence protocol (PDCP) layer 612a and RLC layer 622b may interface with PDCP layer 612b. Similar to dual connectivity as specified in LTE-Advanced Release 12, PDCP layer 612a may interface via a master cell group (MCG) bearer with EPC network 600 whereas PDCP layer 612b may interface via a split bearer with EPC network 600.

[0092] Additionally, as shown, gNB 604 may include a MAC layer 634 that interfaces with RLC layers 624a-b. RLC layer 624a may interface with PDCP layer 612b of eNB 602 via an X_2 interface for information exchange and/or coordination (e.g., scheduling of a UE) between eNB 602 and gNB 604. In addition, RLC layer 624b may interface with PDCP layer 614. Similar to dual connectivity as specified in LTE-Advanced Release 12, PDCP layer 614 may interface with EPC network 600 via a secondary cell group (SCG) bearer. Thus, eNB 602 may be considered a master node (MeNB) while gNB 604 may be considered a secondary node (SgNB). In some scenarios, a UE may be required to maintain a connection to both an MeNB and a SgNB. In such scenarios, the MeNB may be used to maintain a radio resource control (RRC) connection to an EPC while the SgNB may be used for capacity (e.g., additional downlink and/or uplink throughput).

5G Core Network Architecture – Interworking with Wi-Fi

[0093] In some embodiments, the 5G core network (CN) may be accessed via (or through) a cellular connection/interface (e.g., via a 3GPP communication architecture/protocol) and a non-cellular connection/interface (e.g., a non-3GPP access architecture/protocol such as Wi-Fi connection). Figure 7A illustrates an example of a 5G network architecture that incorporates both 3GPP (e.g., cellular) and non-3GPP (e.g., non-cellular) access to the 5G CN, according to some embodiments. As shown, a user equipment device (e.g., such as UE 106) may access the 5G CN through both a radio access network (RAN, e.g., such as gNB or base station 604) and an access point, such as AP 112. The AP 112 may include a connection to the Internet 700 as well as a connection to a non-3GPP inter-working function (N3IWF) 702 network entity. The N3IWF may include a connection to a core access and mobility management function (AMF) 704 of the 5G CN. The AMF 704 may include an instance of a 5G mobility management (5G MM) function associated with the UE 106. In addition, the RAN (e.g., gNB 604) may also have a connection to the AMF 704. Thus, the 5G CN may support unified authentication over both connections as well as allow simultaneous registration for UE 106 access via both gNB 604 and AP 112. As shown, the AMF 704 may include one or more functional entities associated with the 5G CN (e.g., network slice selection function (NSSF) 720, short message service function (SMSF) 722, application function (AF) 724, unified data management (UDM) 726, policy control function (PCF) 728, and/or authentication server function (AUSF) 730). Note that these functional entities may also be supported by a session management function (SMF) 706a and an SMF 706b of the 5G CN. The AMF 706 may be connected to (or in communication with) the SMF 706a. Further, the gNB 604 may in communication with (or connected to) a user plane function (UPF) 708a that may also be communication with the SMF 706a. Similarly, the N3IWF 702 may be communicating with a UPF 708b that may also be communicating with the SMF 706b. Both UPFs may be communicating with the data network (e.g., DN 710a and 710b) and/or the Internet 700 and IMS core network 710.

[0094] Figure 7B illustrates an example of a 5G network architecture that incorporates both dual 3GPP (e.g., LTE and 5G NR) access and non-3GPP access to the 5G CN, according to some embodiments. As shown, a user equipment device (e.g., such as UE 106) may access the 5G CN through both a radio access network (RAN, e.g., such as gNB or base station 604 or eNB or base station 602) and an access point, such as AP 112. The AP 112 may include a connection to the Internet 700 as well as a connection to the N3IWF 702 network entity. The N3IWF may include a connection to the AMF 704 of the 5G CN. The AMF 704 may include an instance of the 5G MM function associated with the UE 106. In addition, the RAN (e.g., gNB 604) may also have a connection to the AMF 704. Thus, the 5G CN may support unified authentication over both connections as well as allow simultaneous registration for UE 106 access via both gNB 604 and AP 112. In addition, the 5G CN may support dual-registration of the UE on both a legacy network (e.g., LTE via base station 602) and a 5G network (e.g., via base station 604). As shown, the base station 602 may have connections to a mobility management entity (MME) 742 and a serving gateway (SGW) 744. The MME 742 may have connections to both the SGW 744 and the AMF 704. In addition, the SGW 744 may have connections to both the SMF 706a and the UPF 708a. As shown, the AMF 704 may include one or more functional entities associated with the 5G CN (e.g., NSSF 720, SMSF 722, AF 724, UDM 726, PCF 728, and/or AUSF 730). Note that UDM 726 may also include a home subscriber server (HSS) function and the PCF may also include a policy and charging rules function (PCRF). Note further that these functional entities may also be supported by the SMF706a and the SMF 706b of the 5G CN. The AMF 706 may be connected to (or in communication with) the SMF 706a. Further, the gNB 604 may in communication with (or connected to) the UPF 708a that may also be communication with the SMF 706a. Similarly, the N3IWF 702 may be communicating with a UPF 708b that may also be communicating with the SMF 706b. Both UPFs may be communicating with the data network (e.g., DN 710a and 710b) and/or the Internet 700 and IMS core network 710.

[0095] Note that in various embodiments, one or more of the above described network entities may be configured to perform methods to improve security checks in a 5G NR network, including mechanisms for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., to avoid and/or limit maximum possible exposure, e.g., as further described herein.

[0096] Figure 8 illustrates an example of a baseband processor architecture for a UE (e.g., such as UE 106), according to some embodiments. The baseband processor architecture 800 described in Figure 8 may be implemented on one or more radios (e.g., radios 329 and/or 330 described above) or modems (e.g., modems 510 and/or 520) as described above. As shown, the non-access stratum (NAS) 810 may include a 5G NAS 820 and a legacy NAS 850. The legacy NAS 850 may include a communication connection with a legacy access stratum (AS) 870. The 5G NAS 820 may include communication connections with both a 5G AS 840 and a non-3GPP AS 830 and Wi-Fi AS 832. The 5G NAS 820 may include functional entities associated with both access stratums. Thus, the 5G NAS 820 may include multiple 5G MM entities 826 and 828 and 5G session management (SM) entities 822 and 824. The legacy NAS 850 may include functional entities such as short message service (SMS) entity 852, evolved packet system (EPS) session management (ESM) entity 854, session management (SM) entity 856, EPS mobility management (EMM) entity 858, and mobility management (MM)/ GPRS mobility management (GMM) entity 860. In addition, the legacy AS 870 may include functional entities such as LTE AS 872, UMTS AS 874, and/or GSM/GPRS AS 876.

[0097] Thus, the baseband processor architecture 800 allows for a common 5G-NAS for both 5G cellular and non-cellular (e.g., non-3GPP access). Note that as shown, the 5G MM may maintain individual connection management and registration management state machines for each connection. Additionally, a device (e.g., UE 106) may register to a single PLMN (e.g., 5G CN) using 5G cellular access as well as non-cellular access. Further, it may be possible for the device to be in a connected state in one access and an idle state in another access and vice versa. Finally, there may be common 5G-MM procedures (e.g., registration, de-registration, identification, authentication, as so forth) for both accesses.

[0098] Note that in various embodiments, one or more of the above described functional entities of the 5G NAS and/or 5G AS may be configured to perform methods for a UE to trigger a change in beam configuration based on UL beam conditions, e.g., to avoid and/or limit maximum possible exposure, e.g., as further described herein.

<u>Beam Management Solution for MPE</u>

[0099] In current implementations, a mobile station, such as a user equipment device (UE), may not be allowed (e.g., due to laws and/or regulations) to position (point) radio frequency (RF) beams in certain directions due to human safety concerns, e.g., to remain below a maximum permissible exposure (MPE) level. Additionally, a mobile station may have a maximum transmit power limited (e.g., below a threshold) due to human safety concerns, e.g., to remain below a maximum permissible exposure (MPE) level. For example, the Electronic Code of Federal Regulations, Title 47, defines MPE levels in the United States. In particular, 47 CFR 1.1310 defines exposure limits for specific frequency ranges for Occupational/Controlled Exposure as well as General Population/Uncontrolled Exposure. Such disruptions, e.g., beam blocking due to position of the wireless station and/or reduced transmit power (to stay below a threshold) may adversely impact user experience.

[00100] Embodiments described herein provide systems, methods, and mechanisms for a user equipment device (UE), such as UE 106, to comply with regulations while maintaining an optimal user experience. In other words, embodiments described herein provide systems, methods, and mechanisms for a UE, such as UE 106, to trigger a change in beam configuration based on UL beam conditions, e.g., avoid and/or limit maximum possible exposure. In some embodiments, once a UE identifies an uplink (UL) beam as unsafe (e.g., due to human safety concerns), the UE may:

(1) continue use of the UL beam, but at a reduced transmission power;

(2) transition to another UL beam within a current antenna panel;

(3) transition to another UL beam within another antenna panel; and/or

(4) signal a beam failure to the network.

In some embodiments, which option the UE choses may be dependent on current transmission conditions and/or local conditions (e.g., position and/or orientation of the UE relative to a user) associated with the UE. In some embodiments, the UE may first attempt to reduce transmission power prior to attempting other solutions.

[00101] For example, Figure 9 illustrates a block diagram of an example of a method for a UE to trigger a change in beam configuration based on UL beam conditions, according to some embodiments. The method shown in Figure 9 may be used in conjunction with any of the systems, methods, or devices shown in the Figures, among other devices. In various embodiments, some of the method elements shown may be performed concurrently, in a different order than shown, or may be omitted. Additional method elements may also be performed as desired. As shown, this method may operate as follows.

[00102] At 902, a UE, such as UE 106, may detect an unsafe uplink (UL) beam condition. In some embodiments, safety of an UL beam may be based, at least in part, on a direction of the UL beam relative to a user. In some embodiments, safety of an UL beam may be based, at least in part, on a position and/or orientation of the UE relative to the user. In some embodiments, safety of an UL beam may be based, at least in part, on a transmission power level of the UE. In some embodiments, safety of an UL beam may be relative to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam. In some embodiments, detection of the unsafe UL beam condition may include determining that one or more of a direction of the UL beam relative to a user is unsafe for a current transmission power, a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00103] At 904, the UE may initiate (and/or perform) one or more remedial actions based on the detection of the unsafe UL beam condition. In some embodiments, the one or more remedial actions may prioritize UL beam quality over downlink (DL) beam quality. For example, the UE may reduce transmission power of the UL beam, signal a beam failure to the network based on the detection of the unsafe UL beam condition to initiate selection of a new UL beam (and/or a new beam pair (e.g., UL and downlink (DL) beams), and/or transition to another UL beam within a current antenna panel and/or transition to another UL beam within another antenna panel. In some embodiments, the UE may attempt to reduce transmission power prior to initiating beam re-selection and/or transitioning to another beam (intra-panel and/or inter-panel).

[00104] For example, in some embodiments, when the UE reduces transmission power of the UL beam, the reduction may be based on a maximum power reduction (MPR), e.g., as signaled to the UE and/or as specified (e.g., via a standard). In some embodiments, the UE may reduce transmission power such that power exposure for each UL beam is reduced below the MPE level. Note that MPR may be defined as a maximum allowable reduction in UL transmit power to enable a UE to avoid non-linear transmission characteristics and/or to satisfy adjacent channel leakage requirements. In some embodiments, the MPR may be beam specific. In some embodiments, the UE may report a power headroom to the network (e.g., to a base station of the network, such a gNB 604) if an MPR change is higher than a threshold. In other words, if the reduction in transmission power is greater than a pre-determine amount, the UE may notify the network, e.g., to initiate a beam reselection procedure. In some embodiments, the UE may report power headroom to the network if the MPR

change is for at least one spatial relationship in a serving cell in a cell group is higher than a threshold. In some embodiments, the UE may report power headroom to the network when the MPR is higher than a threshold. In some embodiments, the UE may only report the power headroom if a timer associated with reporting the power headroom (e.g., a phr-ProhibitTimer and/or a timer specific to MPE events) has expired. In some embodiments, the MPR change may be determined based, at least in part, on a current MPR and an MPR since last transmission of a power headroom report in a medium access control (MAC) entity for new transmissions. In some embodiments, the threshold may be predefined and/or configured by higher layer signaling, e.g., such as radio resource control (RRC) signaling. In some embodiments, a spatial relationship information considered may have been configured in sounding reference signaling (SRS). In some embodiments, the SRS may include at least one type of the SRS for codebook/non-codebook/beam management/antenna switching. In some embodiments, a serving cell group index may be configured by higher layer signaling and/or predefined, e.g. all cells in frequency range 2.

[00105] In some embodiments, when reporting the power headroom, the UE may report an SRS resource index within and/or associated with a MAC control element (CE) for the power headroom report. In some embodiments, after decoding a MAC protocol data unit (PDU), the network may identify the unsafe beam and perform beam selection and/or beam re-selection.

[00106] In some embodiments, 3GPP TS 38.321 may be amended to include the following text: "phr-ProhibitTimer expires or has expired, when the MAC entity has UL resources for new transmission, and the following is true for any of the activated Serving Cells in frequency range 2 of any MAC entity with configured uplink:

- there are UL resources allocated for transmission or there is a PUCCH transmission on this cell, and the required power backoff due to power management for at least one spatial relation info configured in SRS for this cell has changed more than phr-Tx-PowerFactorChange dB since the last transmission of a PHR when the MAC entity had UL resources allocated for transmission or PUCCH transmission on this cell."

[00107] As another example of a remedial action, in some embodiments, after a UE identifies an unsafe UL beam, the UE may switch to another candidate UL beam dependent upon satisfying one or more conditions. The conditions may include:

(1) an MPR for the unsafe UL beam is greater than a first threshold;

(2) a layer 1 (L1) reference signal received power (RSRP) with MPR reduction for the unsafe UL beam is less than a second threshold;

(3) an L1-RSRP for the candidate UL beam is greater than a third threshold; and/or

(4) an MPR for the candidate UL beam is less than a fourth threshold.

In some embodiments, each threshold may be predefined and/or configured via higher layer signaling. In some embodiments, such an UL beam switch may cause a beam pair mismatch between the UE and the network. In some embodiments, to resolve the mismatch, the UE may trigger a sounding reference signal (SRS) procedure for beam management and/or the UE may trigger L1-RSRP based beam reporting. In either case, the UE trigger (request) may be sent via a MAC CE, via PUCCH, and/or via contention based PRACH.

[00108] In some embodiments, if the UE triggers an SRS procedure for beam management, the UE may convey a subset of and/or all of:

(a) a synchronization signal block (SSB) resource index (SSBRI), a channel state information reference signal (CSI-RS) resource index (CRI), and/or an SRS resource index (SRI) configured in a spatial relationship information element and/or an SRS resource indicator (SRI) for codebook/non-codebook;

(b) a serving cell index; and/or

(c) a bandwidth part index.

In some embodiments, after receiving such a triggering message, the network may trigger an SRS procedure for beam management for network beam refinement to update the spatial relationship information with the source.

[00109] In some embodiments, if the UE triggers L1-RSRP based beam reporting, the network may respond with an uplink grant with a dedicated radio network temporary identifier (RNTI). In some embodiments, after receiving the network's response, the UE may report the L1-RSRP with MPR impact.

[00110] As a further example of a remedial action, in some embodiments, after a UE identifies an unsafe UL beam, the UE may switch to another antenna panel dependent upon satisfying one or more conditions, such as:

(1) an MPR for the unsafe UL beam is greater than a first threshold;

(2) an L1-RSRP with MPR reduction for the unsafe UL beam is less than a second threshold;

(3) an L1-RSRP for the candidate UL beam in the new antenna panel is greater than a third threshold; and/or

(4) an MPR for the candidate UL beam in the new antenna panel is less than a fourth threshold.

In some embodiments, each threshold may be predefined and/or configured via higher layer signaling. In some embodiments, if the UE uses one antenna panel for downlink reception and another antenna panel (e.g., the new antenna panel) for uplink transmission, the UE may not receive downlink signals that are transmitted within a timing window around the downlink signal for pathloss measurement. In some embodiments, the timing window can be configured by higher layer signaling, predefined, and/or based on a UE capability. In some embodiments, within the timing window, the UE may switch to the new antenna panel for uplink transmission and/or measurement of downlink signal for pathloss measurement.

[00111] In some embodiments, if the UE, after selection of the new antenna panel for the UL beam, switches the DL beam to the new antenna panel, the UE may perform a contention based PRACH based procedure. In some embodiments, after the procedure is finished, all the downlink and uplink beams may be based on the SSB and/or CSI-RS identified by the PRACH. Alternatively, in some embodiments, the UE may trigger an SRS procedure for beam management and/or a L1-RSRP beam report.

[00112] As a further example of a remedial action, in some embodiments, after a UE identifies an unsafe UL beam, the UE may signal a beam failure to the network. Note that beam failure detection is typically carried out based on DL measurement quality based on hypothetical PDCCH BLER. For example, if (RSRP, SINR) measurement of a beam is below a threshold consistently for a period of time, beam failure may be declared for this beam, with the assumption that DL and UL beams have similar quality. However, upon identification of an unsafe UL beam (e.g., when MPE issue occurs), the UL beam quality may differ from DL beam quality since additional MPR may be needed for the UL beam, e.g., if the UL beam points to a human body. Thus, in some embodiments, UL signal quality may be used as a complement to DL signal quality for beam failure detection and radio link failure detection. In some embodiments, an out-of-sync threshold may be separately configured for UL, thus, when the UE evaluates beam failure, power management maximum power reduction (P-MPR) (e.g., a UE controlled parameter to meet specific absorption rate (SAR) requirements) may be considered prior to comparing with a threshold, e.g.:

(1) UL_signal_quality = DL_measurement - P-MPR

(2) DL_Measurement(Beam) – P-MPR(Beam) < UL_Threshold for beam failure detection.

[00113] In some embodiments, when both UL and DL quality are considered for beam failure detection, there may be 4 possible states:

(1) DL_meas > DL_thres && UL_qual > UL_thres (DL and UL good)

(2) DL_meas > DL_thres && UL_qual < UL_thres (DL good, UL lost)

(3) DL_meas < DL_thres && UL_qual > UL_thres (DL lost, UL good)

(4) DL_meas < DL_thres && UL_qual < UL_thres (DL and UL lost)

Thus, to enhance beam failure detection, beam failure declaration may take both UL beam quality and DL beam quality into consideration jointly. In other words, the UE may declare a beam failure if DL beam failure is detected, UL beam failure is detected, or if both UL and DL beam failure is detected. In some embodiments, the UE may base candidate beam selection on UL signal quality and/or on a combination of UL and DL signal quality.

[00114] In some embodiments, when the UE detects an unsafe UL beam, the UE may use UL beam quality to determine RACH resources, e.g., {DL_Measurement – P-MPR} for RACH resource selection. In some embodiments, a threshold may be configured for DL and/or UL beam quality and the UE may transmit RACH on any UL beam that passes the threshold, e.g., in order to reduce latency.

[00115] Figure 10 illustrates a block diagram of an example of a process for a UE to trigger a change in beam configuration based on UL beam conditions, according to some embodiments. The process shown in Figure 10 may be used in conjunction with any of the systems, methods, or devices shown in the Figures, among other devices. In various embodiments, some of the process elements shown may be performed concurrently, in a different order than shown, or may be omitted. Additional process elements may also be performed as desired. As shown, this process may operate as follows.

[00116] At 1002, a UE, such as UE 106 may detect an unsafe UL beam condition. In some embodiments, safety of an UL beam may be based, at least in part, on one or more of a direction of the UL beam relative to a user, a position and/or orientation of the UE relative to the user, and/or a transmission power level of the UE. In some embodiments, safety of an UL beam may be relative to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam. In other words, detection of the unsafe UL beam condition may include determining that a direction of the UL beam relative to a user is unsafe for a current transmission power, determining that a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or determining that a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00117] At 1004, the UE, in order to prioritize UL beam quality over downlink (DL) beam quality, may attempt to reduce transmission power for the unsafe UL beam. In some embodiments, reduction of the transmission power may be based on a maximum power reduction (MPR). The MPR may be signaled to the UE (e.g., via higher layer signaling such as RRC signaling) and/or specified by a standard. In some embodiments, the UE may reduce transmission power such that power exposure for each UL beam is reduced below the MPE level. In some embodiments, the MPR may be beam specific.

[00118] At 1006, the UE may determine whether the reduction in transmission power was successful. In other words, the UE may determine whether transmissions can be made successfully using the reduced transmission power. In some embodiments, the UE may report a power headroom to the network (e.g., to a base station of the network, such a gNB 604) if an MPR change is higher than a threshold. In other words, if the reduction in transmission power is greater than a pre-determine amount, the UE may notify the network. In some embodiments, the UE may report power headroom to the network if the MPR change for at least one spatial relationship in a serving cell in a cell group is higher than a threshold. In some embodiments, the UE may report power headroom to the network when the MPR is higher than a threshold. In some embodiments, the UE may only report the power headroom if a timer associated with reporting the power headroom (e.g., a phr-ProhibitTimer and/or a timer specific to MPE events) has expired. In some embodiments, the MPR change may be determined based, at least in part, on a current MPR and an MPR since last transmission of a power headroom report in a medium access control (MAC) entity for new transmissions. In some embodiments, the threshold may be predefined and/or configured by higher layer signaling, e.g., such as radio resource control (RRC) signaling.

[00119] At 1008, responsive to the reduction in transmission power succeeding, the UE may use the UL beam at the reduced transmission power and transmit a power headroom repot to the network at the next opportunity. In some embodiments, the next opportunity to transmit the power headroom report may be based on expiration of the timer associated with reporting the power headroom (e.g., a phr-ProhibitTimer and/or a timer specific to MPE events).

[00120] At 1010, responsive to the reduction in transmission power failing, the UE may consider whether to signal a beam failure to the network.

[00121] At 1012, responsive to determining to signal a beam failure to the network, the UE may perform (and/or initiate) a beam reselection procedure. In some embodiments, when reporting the power headroom, the UE may report an SRS resource index within and/or associated with a MAC control element (CE) for the power headroom report. In some embodiments, after decoding a MAC protocol data unit (PDU), the network may identify the unsafe beam and perform beam selection and/or beam re-selection. In some embodiments, UL signal quality may be used as a complement to

DL signal quality for beam failure detection and radio link failure detection. In some embodiments, an out-of-sync threshold may be separately configured for UL, thus, when the UE evaluates beam failure, P-MPR may be considered prior to comparing with a threshold, e.g.:

(1) UL_signal_quality = DL_measurement - P-MPR

(2) DL_Measurement(Beam) – P-MPR(Beam) < UL_Threshold.

In some embodiments, the UE may use UL beam quality to determine RACH resources, e.g., {DL_Measurement – P-MPR} for RACH resource selection. In some embodiments, a threshold may be configured for DL and/or UL beam quality and the UE may transmit RACH on any UL beam that passes the threshold, e.g., in order to reduce latency.

[00122] At 1014, responsive to determining to not signal a beam failure to the network, the UE may attempt to select an alternate UL beam. In some embodiments, the alternate UL beam may be intra-panel (e.g., the unsafe UL beam and the alternate UL beam may be co-located in an antenna panel of the UE). In some embodiments, the alternate UL beam may be inter-panel (e.g., the unsafe UL bean and the alternate UL beam may be located in different antenna panels of the UE). In some embodiments, one or more conditions may be satisfied prior to switching to the alternate UL beam. For example, in some embodiments, the conditions may include the MPR for the unsafe UL beam being greater than a first threshold, an L1-RSRP with MPR reduction for the unsafe UL beam being less than a second threshold, an L1-RSRP for the alternate UL beam being greater than a third threshold, and/or an MPR for the alternate UL beam being less than a fourth threshold. In some embodiments, each threshold may be predefined and/or configured via higher layer signaling, e.g., such as RRC signaling. In some embodiments, such an UL beam switch may cause a beam pair (e.g., UL and DL beam) mismatch between the UE and the network. In some embodiments, to resolve the mismatch, the UE may trigger a sounding reference signal (SRS) procedure for beam management and/or the UE may trigger L1-RSRP based beam reporting. In either case, the UE trigger (request) may be sent via a MAC CE, via PUCCH, and/or via contention based PRACH.

[00123] In some embodiments, when the UE triggers an SRS procedure for beam management, the UE may transmit, to the network, one or more of an SSBRI, a CSI-RS CRI, an SRS SRI configured in a spatial relationship information element, an SRS SRI for codebook/non-codebook, a serving cell index, and/or a bandwidth part index. In some embodiments, after receiving such a triggering message, the network may trigger an SRS procedure for beam management for network beam refinement to update the spatial relationship information with the UE.

[00124] In some embodiments, if the UE triggers L1-RSRP based beam reporting, the network may respond with an uplink grant with a dedicated radio network temporary identifier (RNTI). In some embodiments, after receiving the network's response, the UE may report the L1-RSRP with MPR impact.

[00125] At 1016, the UE may determine whether the selection to the alternate UL beam was successful. In some embodiments, when selection is not successful (e.g., an alternate UL beam does not meet one or more conditions), the process may return to 1012 and the UE may initiate a beam reselection procedure based on UL beam conditions. Alternatively, when selection of the alternate UL beam is success, the process may continue at 1018.

[00126] At 1018, the UE may transmit using the alternate UL beam, e.g., based on determining that selection of the alternate UL beam was successful. Alternatively, if the selection was not successful, the process may return to 1010 and the UE may signal a beam failure to the network. In some embodiments, when the alternate UL beam is in a different antenna panel as compared to the unsafe UL beam, the UE may switch the DL beam to the antenna panel of the alternate UL beam. In such embodiments, the UE may perform a contention based PRACH based procedure. In some embodiments, after completion of the PRACH based procedure, all the DL and UL beams may be based on an SSB identified by the PRACH procedure. In some embodiments, after completion of the PRACH based procedure, all the DL and UL beams may be based on a channel state information reference signal (CSI-RS) identified by the PRACH procedure. Alternatively, in some embodiments, the UE may trigger an SRS procedure for beam management and/or a L1-RSRP beam report.

[00127] Figures 11-14 illustrate block diagrams of further examples of methods for a UE to trigger a change in UL beam configuration based on UL beam conditions, according to some embodiments. The methods shown in Figures 11-14 may be used in conjunction with any of the systems, methods, or devices shown in the Figures, among other devices. In various embodiments, some of the method elements shown may be performed concurrently, in a different order than shown, or may be omitted. Additional method elements may also be performed as desired. In some embodiments, one or more of the methods may be combined. As shown, these methods may operate as follows.

[00128] Turning to Figure 11, at 1102, a UE, such as UE 106 may detect an unsafe UL beam condition. In some embodiments, detection of the unsafe UL beam condition may include determining that a direction of the UL beam relative to a user is unsafe for a current transmission power, determining that a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or determining that a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00129] At 1104, the UE, in order to prioritize UL beam quality over downlink (DL) beam quality, may reduce transmission power for the unsafe UL beam. In some embodiments, reduction of the transmission power may be based on an MPR that may be signaled to the UE (e.g., via higher layer signaling such as RRC signaling) and/or specified by a standard. In some embodiments, the UE may reduce transmission power such that power exposure for each UL beam is reduced below the MPE level. In some embodiments, the MPR may be beam specific.

[00130] In some embodiments, when the UE determines that transmissions cannot be made successfully using the reduced transmission power, the UE may report a power headroom to the network (e.g., to a base station of the network, such a gNB 604). In some embodiments, the UE may report power headroom to the network when an MPR change is higher than a threshold. In other words, if the reduction in transmission power is greater than a pre-determine amount, the UE may notify the network. In some embodiments, the UE may report power headroom to the network if the MPR change for at least one spatial relationship in a serving cell in a cell group is higher than a threshold. In some embodiments, the UE may report power headroom to the network when the MPR is higher than a threshold. In some embodiments, the UE may only report the power headroom if a timer associated with reporting the power headroom (e.g., a phr-ProhibitTimer and/or a timer specific to MPE events) has expired. In some embodiments, the MPR change may be determined based, at least in part, on a current MPR and an MPR since last transmission of a power headroom report in a medium access control (MAC) entity for new transmissions. In some embodiments, the threshold may be predefined and/or configured by higher layer signaling, e.g., such as radio resource control (RRC) signaling. In some embodiments, when reporting the power headroom, the UE may report an SRS resource index within and/or associated with a MAC control element (CE) for the power headroom report. In some embodiments, after decoding a MAC protocol data unit (PDU), the network may identify the unsafe beam and perform beam selection and/or beam re-selection.

[00131] In some embodiments, responsive to the reduction in transmission power succeeding, the UE may use the UL beam at the reduced transmission power and transmit a power headroom repot to the network at the next opportunity. In some embodiments, the next opportunity to transmit the power headroom report may be based on expiration of the timer associated with reporting the power headroom (e.g., a phr-ProhibitTimer and/or a timer specific to MPE events).

[00132] Turning to Figure 12, at 1202, a UE, such as UE 106 may detect an unsafe UL beam condition. In some embodiments, detection of the unsafe UL beam condition may include determining that a direction of the UL beam relative to a user is unsafe for a current transmission power, determining that a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or determining that a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00133] At 1204, the UE, in order to prioritize UL beam quality over downlink (DL) beam quality, may signal a beam failure to the network based on the unsafe UL beam condition. In some embodiments, UL signal quality may be used as a complement to DL signal quality for beam failure detection and radio link failure detection. In some embodiments, an out-of-sync threshold may be separately configured for UL, thus, when the UE evaluates beam failure, P-MPR may be considered prior to comparing with a threshold, e.g. DL_Measurement(Beam) – P-MPR(Beam) < UL_Threshold for beam failure detection. Thus, beam failure declaration may take both UL beam quality and DL beam quality into consideration jointly, in some embodiments. In other words, the UE may declare a beam failure if DL beam failure is detected, UL beam failure is detected, or if both UL and DL beam failure is detected. In some embodiments, the UE may base candidate beam selection on UL signal quality and/or on a combination of UL and DL signal quality. In some embodiments, the UE may use UL beam quality to determine RACH resources, e.g., {DL_Measurement – P-MPR} for RACH resource selection. In some embodiments, a threshold may be configured for DL and/or UL beam quality and the UE may transmit RACH on any UL beam that passes the threshold, e.g., in order to reduce latency.

[00134] Turning to Figure 13, at 1302, a UE, such as UE 106 may detect an unsafe UL beam condition. In some embodiments, detection of the unsafe UL beam condition may include determining that a direction of the UL beam relative to a user is unsafe for a current transmission power, determining that a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or determining that a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00135] At 1304, the UE may, in order to prioritize UL beam quality over downlink (DL) beam quality, trigger an intra-panel UL beam switch. In some embodiments, one or more conditions may be satisfied prior to switching to an alternate UL beam. For example, in some embodiments, the conditions may include the MPR for the unsafe UL beam being greater than a first threshold, an L1-

RSRP with MPR reduction for the unsafe UL beam being less than a second threshold, an L1-RSRP for the alternate UL beam being greater than a third threshold, and/or an MPR for the alternate UL beam being less than a fourth threshold. In some embodiments, each threshold may be predefined and/or configured via higher layer signaling, e.g., such as RRC signaling. In some embodiments, such an UL beam switch may cause a beam pair mismatch between the UE and the network. In some embodiments, to resolve the mismatch, the UE may trigger a sounding reference signal (SRS) procedure for beam management and/or the UE may trigger L1-RSRP based beam reporting. In either case, the UE trigger (request) may be sent via a MAC CE, via PUCCH, and/or via contention based PRACH.

[00136] In some embodiments, if the UE triggers an SRS procedure for beam management, the UE may convey a subset of and/or all of:

(a) a synchronization signal block (SSB) resource index (SSBRI), a channel state information reference signal (CSI-RS) resource index (CRI), and/or an SRS resource index (SRI) configured in a spatial relationship information element and/or an SRS resource indicator (SRI) for codebook/non-codebook;

(b) a serving cell index; and/or

(c) a bandwidth part index.

In some embodiments, after receiving such a triggering message, the network may trigger an SRS procedure for beam management for network beam refinement to update the spatial relationship information with the source.

[00137] In some embodiments, if the UE triggers L1-RSRP based beam reporting, the network may respond with an uplink grant with a dedicated radio network temporary identifier (RNTI). In some embodiments, after receiving the network's response, the UE may report the L1-RSRP with MPR impact.

[00138] Turning to Figure 14, at 1402, a UE, such as UE 106 may detect an unsafe UL beam condition. In some embodiments, detection of the unsafe UL beam condition may include determining that a direction of the UL beam relative to a user is unsafe for a current transmission power, determining that a position and/or orientation of the UE relative to the user is unsafe for a current transmission power, and/or determining that a transmission power level of the UE is unsafe. In some embodiments, determining that the transmission power level is unsafe for the UL beam may include comparing the transmission power level to a maximum permissible exposure (MPE) level for an operating frequency range of the UL beam.

[00139] At 1404, the UE may, in order to prioritize UL beam quality over downlink (DL) beam quality, trigger an inter-panel UL beam switch. In some embodiments, one or more conditions may be satisfied prior to switching to an alternate UL beam. For example, in some embodiments, the conditions may include the MPR for the unsafe UL beam being greater than a first threshold, an L1-RSRP with MPR reduction for the unsafe UL beam being less than a second threshold, an L1-RSRP for the alternate UL beam being greater than a third threshold, and/or an MPR for the alternate UL beam being less than a fourth threshold. In some embodiments, each threshold may be predefined and/or configured via higher layer signaling, e.g., such as RRC signaling. In some embodiments, such an UL beam switch may cause a beam pair (e.g., UL and DL beam) mismatch between the UE and the network. In some embodiments, to resolve the mismatch, the UE may trigger a sounding reference signal (SRS) procedure for beam management and/or the UE may trigger L1-RSRP based beam reporting. In either case, the UE trigger (request) may be sent via a MAC CE, via PUCCH, and/or via contention based PRACH.

[00140] In some embodiments, when the UE triggers an SRS procedure for beam management, the UE may transmit, to the network, one or more of an SSBRI, a CSI-RS CRI, an SRS SRI configured in a spatial relationship information element, an SRS SRI for codebook/non-codebook, a serving cell index, and/or a bandwidth part index. In some embodiments, after receiving such a triggering message, the network may trigger an SRS procedure for beam management for beam refinement to update the spatial relationship information with the UE.

[00141] In some embodiments, if the UE triggers L1-RSRP based beam reporting, the network may respond with an uplink grant with a dedicated radio network temporary identifier (RNTI). In some embodiments, after receiving the network's response, the UE may report the L1-RSRP with MPR impact.

[00142] It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

[00143] Embodiments of the present disclosure may be realized in any of various forms. For example, some embodiments may be realized as a computer-implemented method, a computer-readable memory medium, or a computer system. Other embodiments may be realized using one or more custom-designed hardware devices such as ASICs. Still other embodiments may be realized using one or more programmable hardware elements such as FPGAs.

[00144] In some embodiments, a non-transitory computer-readable memory medium may be configured so that it stores program instructions and/or data, where the program instructions, if executed by a computer system, cause the computer system to perform a method, e.g., any of the method embodiments described herein, or, any combination of the method embodiments described herein, or, any subset of any of the method embodiments described herein, or, any combination of such subsets.

[00145] In some embodiments, a device (e.g., a UE 106) may be configured to include a processor (or a set of processors) and a memory medium, where the memory medium stores program instructions, where the processor is configured to read and execute the program instructions from the memory medium, where the program instructions are executable to implement any of the various method embodiments described herein (or, any combination of the method embodiments described herein, or, any subset of any of the method embodiments described herein, or, any combination of such subsets). The device may be realized in any of various forms.

[00146] Although the embodiments above have been described in considerable detail, numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such variations and modifications.

CLAIMS

What is claimed is:

1. A user equipment device (UE), comprising:

at least one antenna;

at least one radio, wherein the at least one radio is configured to perform cellular communication using at least one radio access technology (RAT);

one or more processors coupled to the at least one radio, wherein the one or more processors and the at least one radio are configured to perform voice and/or data communications;

wherein the one or more processors are configured to cause the UE to:

detect an unsafe uplink (UL) beam condition for at least one UL beam based, at least in part, on a maximum possible exposure (MPE) level; and

perform one or more remedial actions including at least one of:

reducing a transmit power of the at least one UL beam based on a maximum power reduction (MPR);

triggering an intra-panel switch to a first candidate UL beam that satisfies one or more conditions for intra-panel beam switching;

triggering an inter-panel switch to a second candidate UL beam that satisfies one or more conditions for intra-panel beam switching; or

signaling a beam failure to a network serving the UE based on the unsafe UL beam condition.

2. The UE of claim 1,

wherein, to detect the unsafe UL beam condition, the one or more processors are further configured to cause the UE to determine one or more of:

a direction of the at least one UL beam relative to a user is unsafe for a transmission power of the at least one UL beam;

a position and/or orientation of the UE relative to the user is unsafe for the transmission power of the at least one UL beam; or

a transmission power level of the UE is unsafe based on the MPE level for an operating frequency range of the at least one UL beam.

3. The UE of claim 1,

wherein the one or more processors are further configured to cause the UE to:

report a power headroom to the network when a change in MPR exceeds a first threshold or when a value of the MPR exceeds a second threshold.

4. The UE of claim 3,

wherein the report is sent at the expiration of a timer associated with reporting the power headroom.

5. The UE of claim 4,

wherein the time associated with reporting the power headroom is specific to detection of unsafe UL beam conditions.

6. The UE of claim 3,

wherein the change in MPR is based on a current MPR and an MPR since last transmission of a power headroom report in a medium access control (MAC) entity for new transmissions.

7. The UE of claim 1,

wherein signaling the beam failure to the network serving the UE includes the UE comparing a UL beam quality measurement to an UL beam quality threshold, wherein beam failure is signaled when the UL beam quality measurement is less than the UL beam quality threshold.

8. The UE of claim 7,

wherein the UL beam quality measurement is based on a downlink (DL) beam quality measurement less a power management maximum power reduction (P-MPR).

9. The UE of claim 7,

wherein the one or more processors are further configured to cause the UE to:

determine random access channel resources (RACH) based on the UL beam quality measurement.

10. An apparatus, comprising:

a memory; and

a processing element in communication with the memory, wherein the processing element is configured to:

detect an unsafe uplink (UL) beam condition for at least one UL beam based, at least in part, on a maximum possible exposure (MPE) level; and

perform, based on detection of the unsafe UL beam condition, one or more remedial actions to alleviate the unsafe UL beam condition, wherein the one or more remedial actions prioritize UL beam quality over DL beam quality.

11. The apparatus of claim 10,

wherein the one or more remedial actions includes triggering an intra-panel switch to a first UL beam that satisfies one or more conditions for intra-panel beam switching, wherein the one or more conditions include at least one of:

a maximum power reduction (MPR) for the unsafe UL beam exceeding a first threshold;

a layer 1 (L1) reference signal received power (RSRP) with MPR reduction for the unsafe UL beam being less than a second threshold;

an L1-RSRP for the first UL beam exceeding a third threshold; or

an MPR for the first UL beam being less than a fourth threshold.

12. The apparatus of claim 11,

wherein the first, second, third, and fourth thresholds are predefined by a standard or configured via higher layer signaling with a network.

13. The apparatus of claim 11,

wherein switching to the first UL beam causes a beam pair mismatch with a network, and wherein to resolve the beam pair mismatch, the processing element is further configured to trigger a sounding reference signal (SRS) procedure for beam management or an L1-RSRP based beam reporting procedure.

14. The apparatus of claim 13,

wherein a request to trigger the SRS procedure or the L1-RSRP based beam reporting procedure is transmitted via at least one of a medium access control (MAC) control element (CE), a physical uplink control channel (PUCCH) transmission, or a contention based physical random access channel (PRACH) procedure.

15. The apparatus of claim 13,

wherein the processing element, as part of the SRS procedure, is further configured to generate instructions to transmit one or more of:

a synchronization signal block (SSB) resource index (SSBRI);

a channel state information reference signal (CSI-RS) resource index (CRI);

an SRS resource index (SRI) configured in a spatial relationship information element;

SRS resource indicator (SRI) for codebook/non-codebook;

a serving cell index; or

a bandwidth part index.

16. The apparatus of claim 13,

wherein the processing element, as part of the L1-RSRP based reporting procedure, is further configured to:

receive, from a network, an UL grant with a dedicated radio network temporary identifier (RNTI); and

report, to the network, L1-RSRP with MPR impact.

17. A non-transitory computer readable memory medium storing program instructions executable by processing circuitry to cause a user equipment device (UE) to:

detect an unsafe uplink (UL) beam condition for at least one UL beam based, at least in part, on a maximum possible exposure (MPE) level; and

perform, based on detection of the unsafe UL beam condition, one or more remedial actions to alleviate the unsafe UL beam condition, wherein the one or more remedial actions prioritize UL beam quality over DL beam quality, and wherein the one or more remedial actions include at least one of:

reducing a transmit power of the at least one UL beam based on a maximum power reduction (MPR);

triggering an intra-panel switch to a first candidate UL beam that satisfies one or more conditions for intra-panel beam switching;

triggering an inter-panel switch to a second candidate UL beam that satisfies one or more conditions for intra-panel beam switching; or

signaling a beam failure to a network serving the UE based on the unsafe UL beam condition.

18. The non-transitory computer readable memory medium of claim 17,

wherein the one or more conditions for intra-panel beam switching includes at least one of:

a maximum power reduction (MPR) for the unsafe UL beam exceeding a first threshold;

a layer 1 (L1) reference signal received power (RSRP) with MPR reduction for the unsafe UL beam being less than a second threshold;

an L1-RSRP for the first UL beam exceeding a third threshold; or

an MPR for the first UL beam being less than a fourth threshold; and

wherein the first, second, third, and fourth thresholds are predefined by a standard or configured via higher layer signaling with a network.

19. The non-transitory computer readable memory medium of claim 17,

wherein, when the one or more remedial actions includes triggering an inter-panel switch to the second UL beam, the programming instructions are further executable to cause the UE to:

perform a contention based physical random access control channel (PRACH) based procedure to switch a downlink (DL) beam to pair with the second UL beam.

20. The non-transitory computer readable memory medium of claim 17,

wherein upon completion of the PRACH based procedure, the second UL beam and the DL beam are based on a synchronization signal block (SSB) or a channel state information reference signal (CSI-RS) identified by the PRACH based procedure.

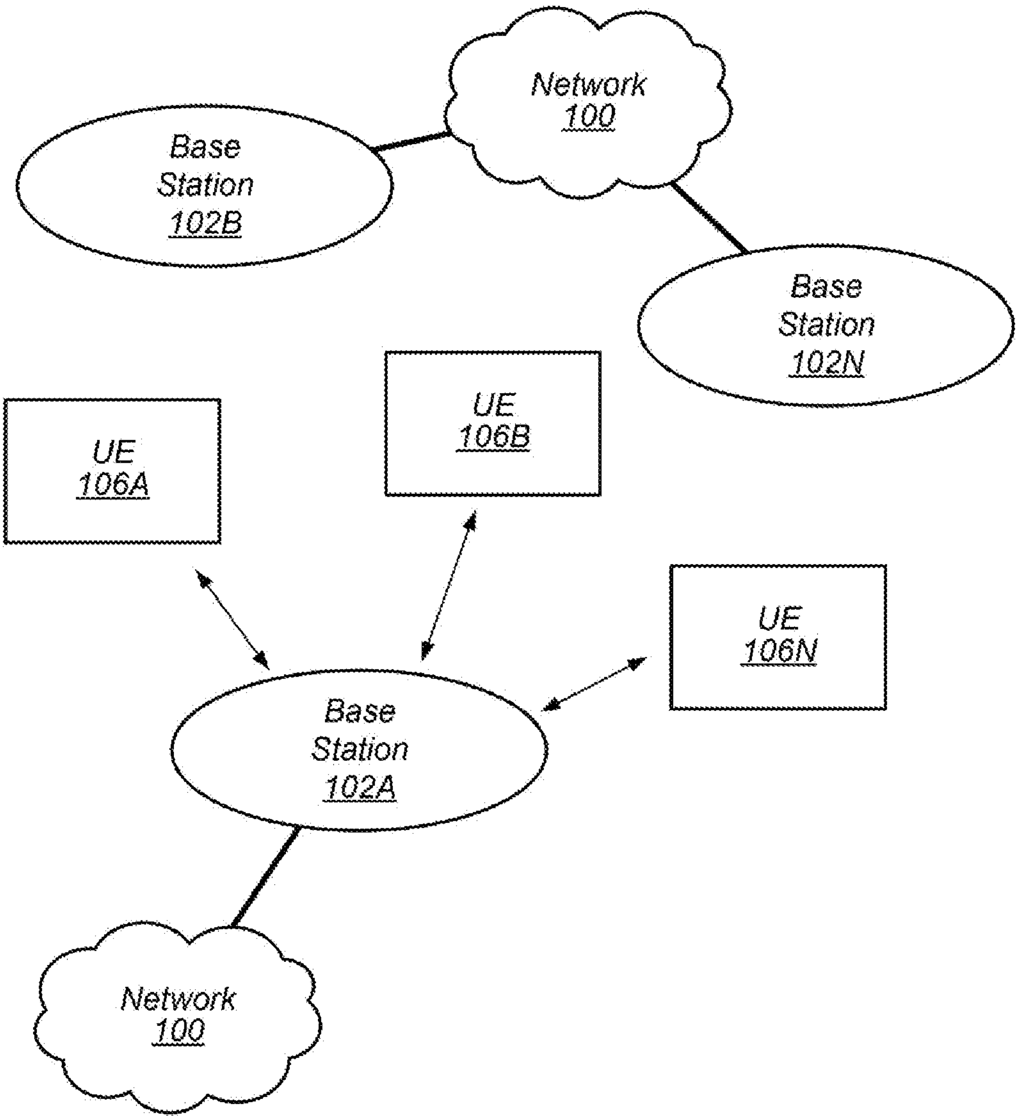

Network
100
Base
Station
102B
Base
Station
102N
UE
106A
UE
106B
UE
106N
Base
Station
102A
Network
100

FIG. 1A

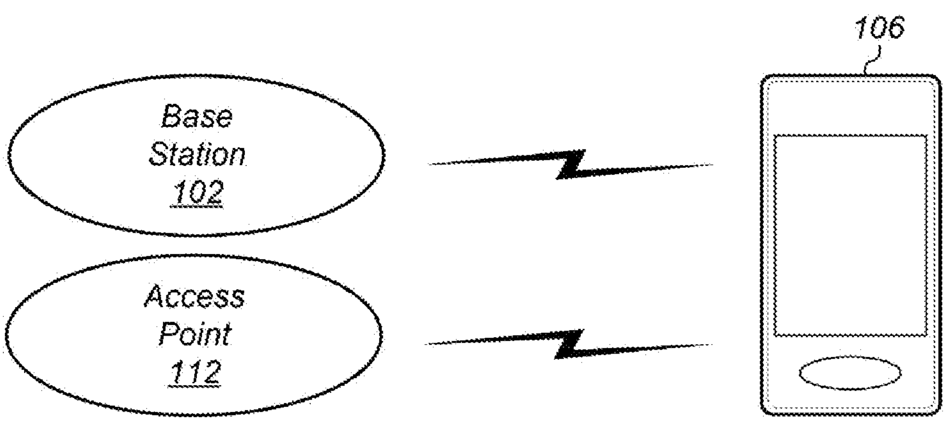

106
Base
Station
102
Access
Point
112

FIG. 1B

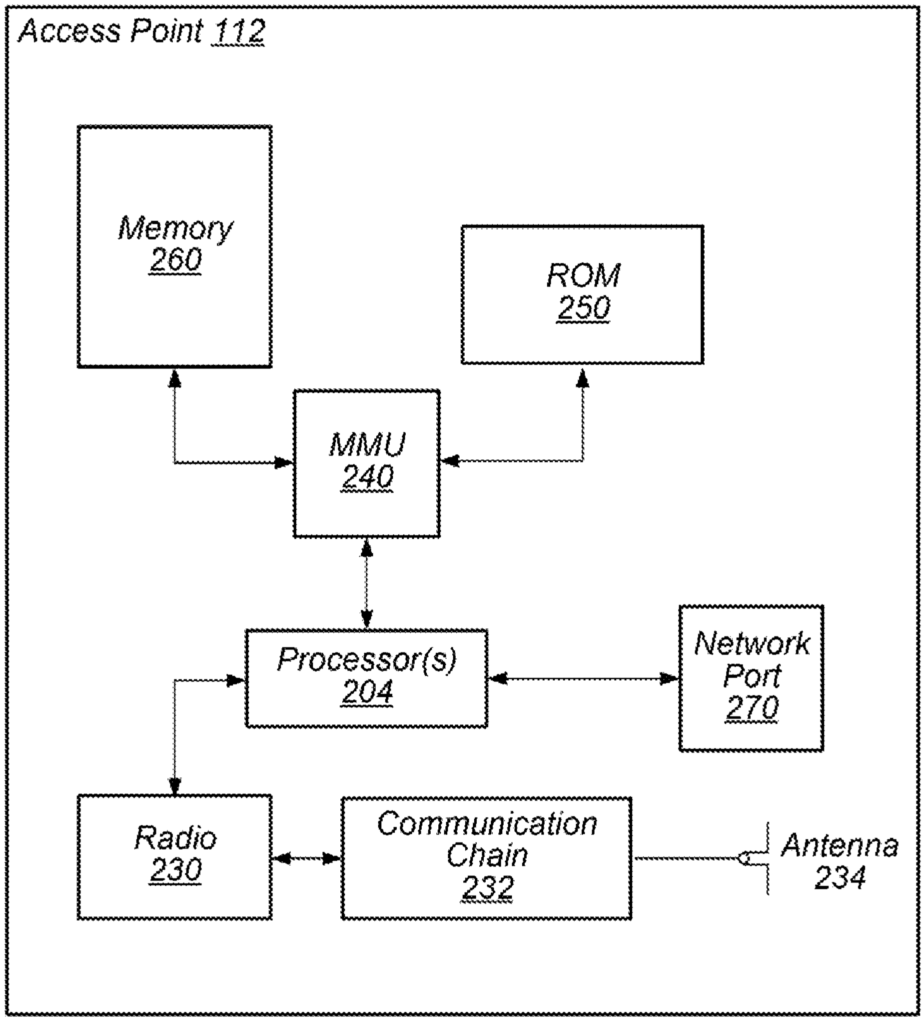

Access Point 112
Memory 260
ROM 250
MMU 240
Processor(s) 204
Network Port 270
Radio 230
Communication Chain 232
Antenna 234

FIG. 2

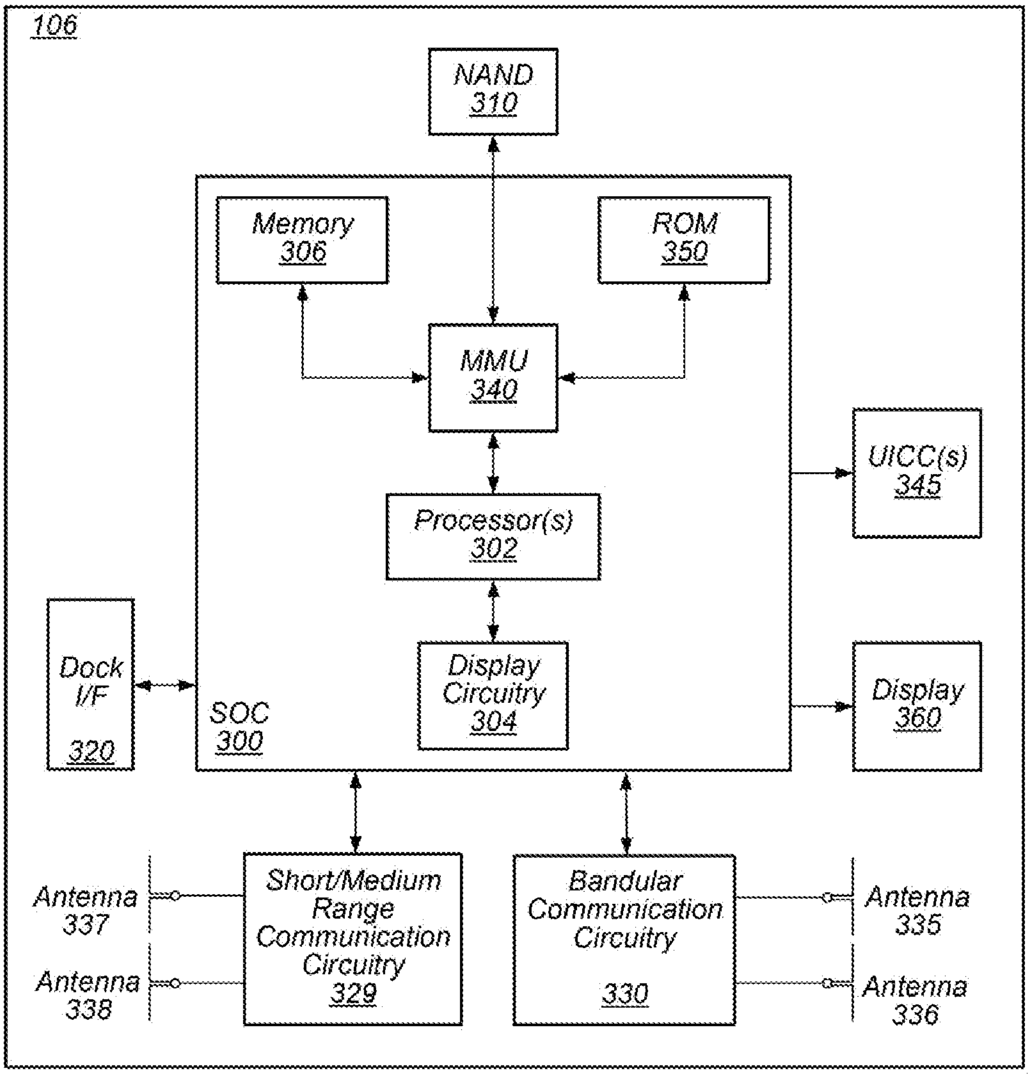

106
NAND
310
Memory
306
ROM
350
MMU
340
UICC(s)
345
Processor(s)
302
Dock
I/F
320
Display
Circuitry
304
SOC
300
Display
360
Antenna
337
Short/Medium
Range
Communication
Circuitry
329
Bandular
Communication
Circuitry
330
Antenna
335
Antenna
338
Antenna
336

FIG. 3

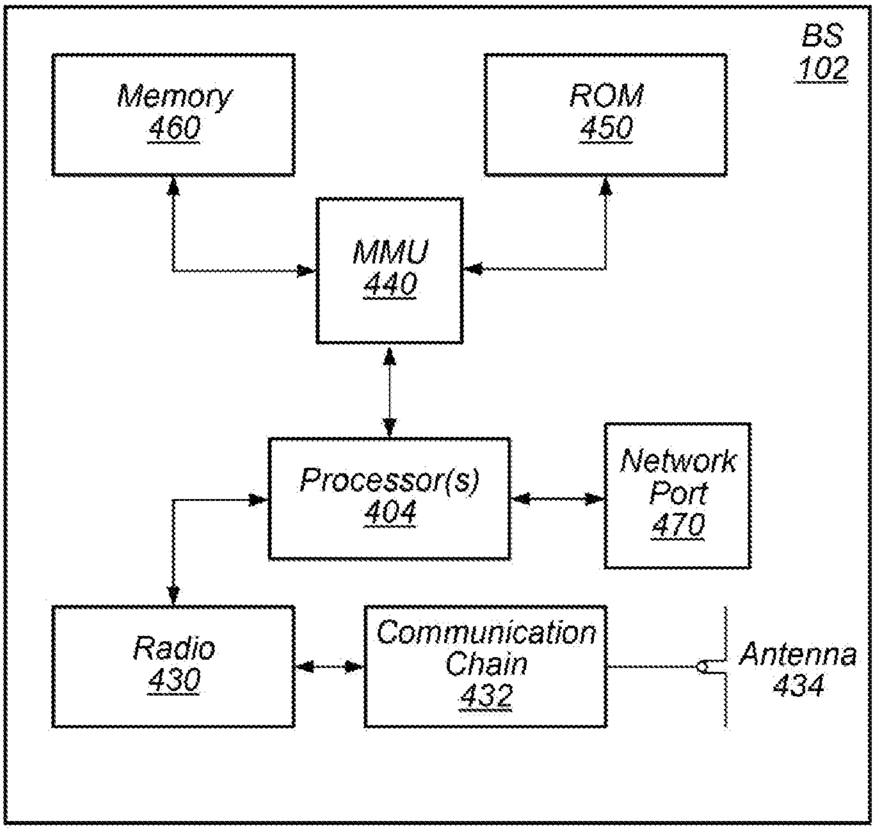

BS
102
Memory
460
ROM
450
MMU
440
Processor(s)
404
Network
Port
470
Radio
430
Communication
Chain
432
Antenna
434

FIG. 4

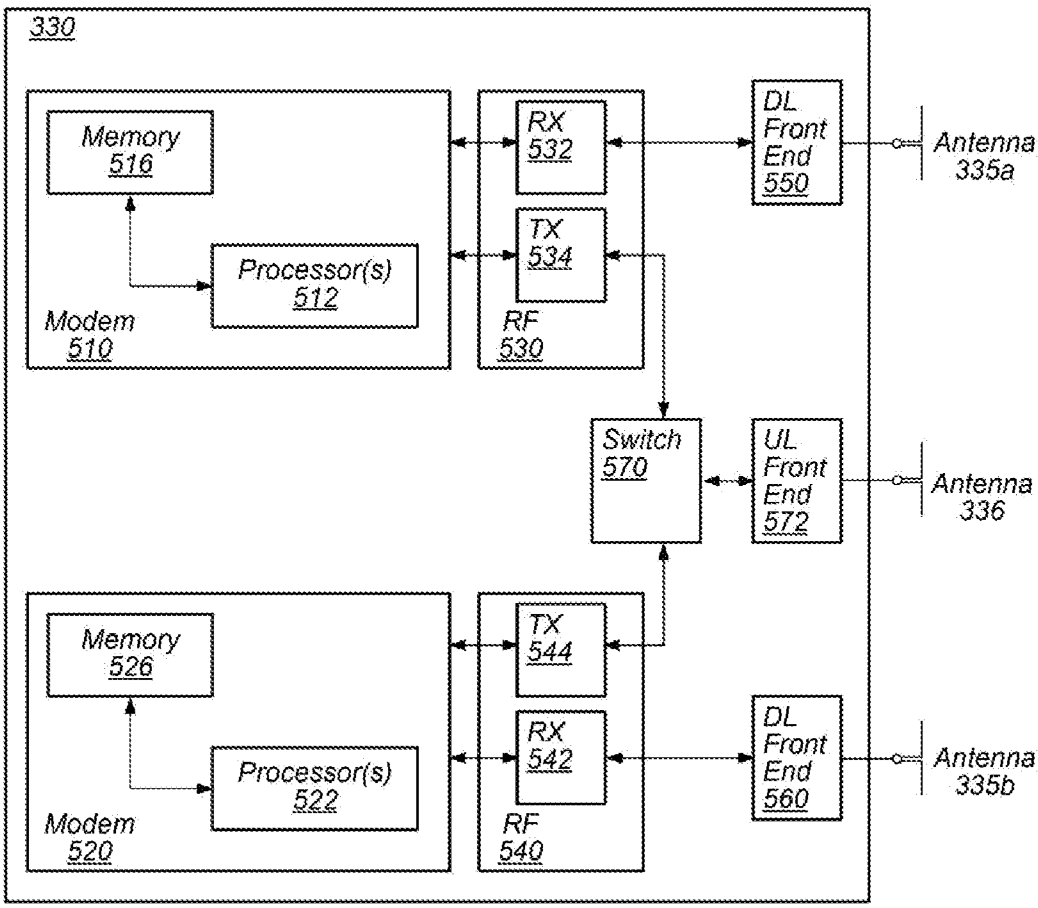

330
Memory
516
Processor(s)
512
Modem
510
RX
532
TX
534
RF
530
DL
Front
End
550
Antenna
335a
Switch
570
UL
Front
End
572
Antenna
336
Memory
526
Processor(s)
522
Modem
520
TX
544
RX
542
RF
540
DL
Front
End
560
Antenna
335b

FIG. 5

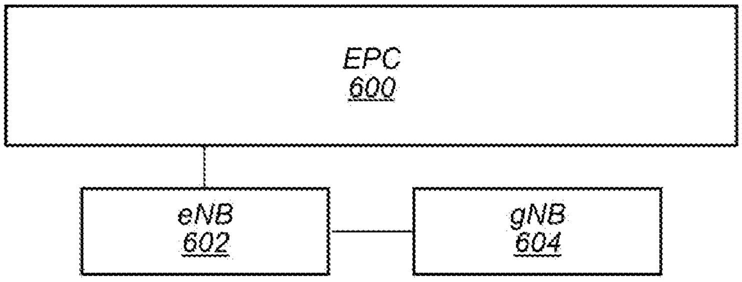

EPC
600
eNB
602
gNB
604

FIG. 6A

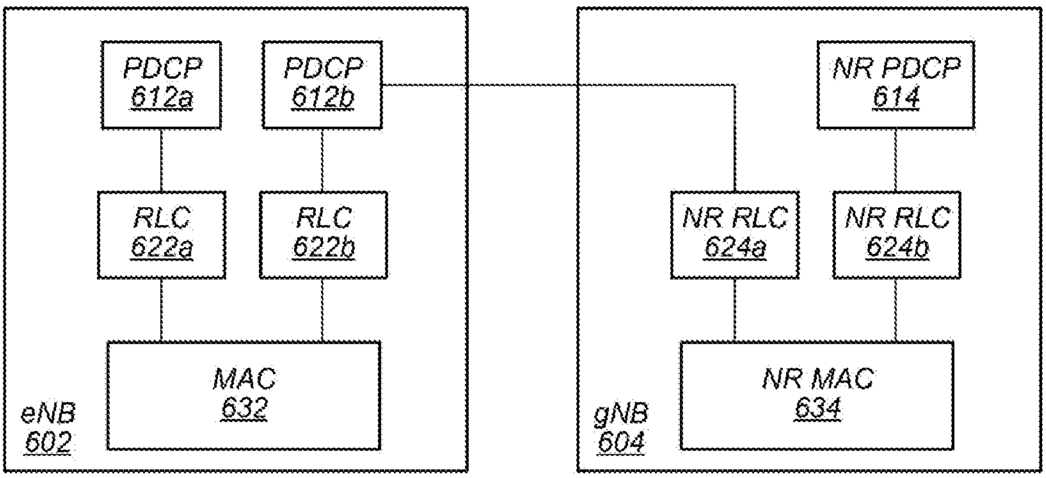
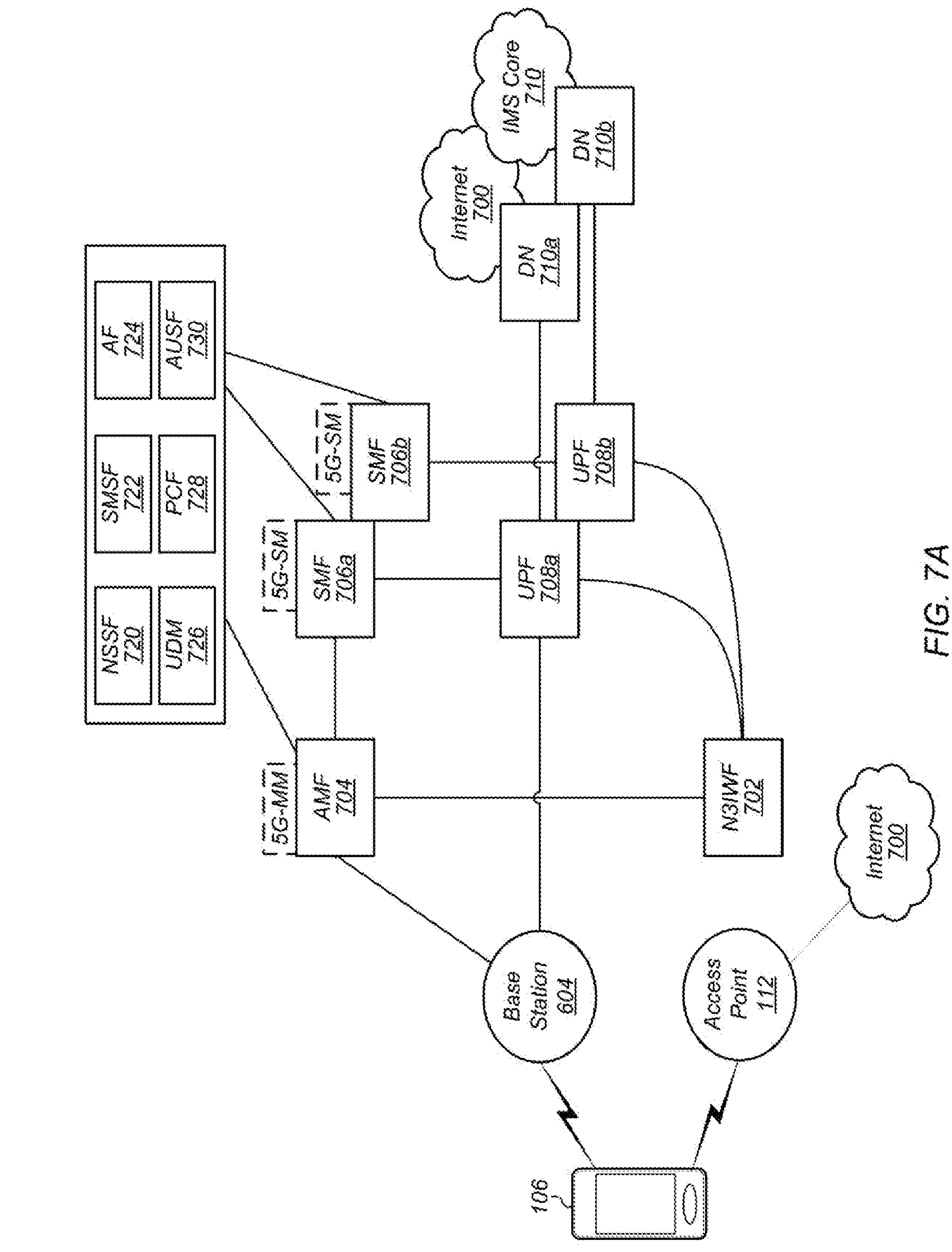

PDCP
612a
PDCP
612b
NR PDCP
614
RLC
622a
RLC
622b
NR RLC
624a
NR RLC
624b
MAC
632
NR MAC
634
eNB
602
gNB
604

FIG. 6B



NSSF 720
SMSF 722
AF 724
UDM 726
PCF 728
AUSF 730
Internet 700
IMS Core 710
DN 710a
DN 710b
5G-SM
SMF 706a
SMF 706b
UPF 708a
UPF 708b
5G-MM
AMF 704
N3IWF 702
Internet 700
Base Station 604
Access Point 112
106

FIG. 7A

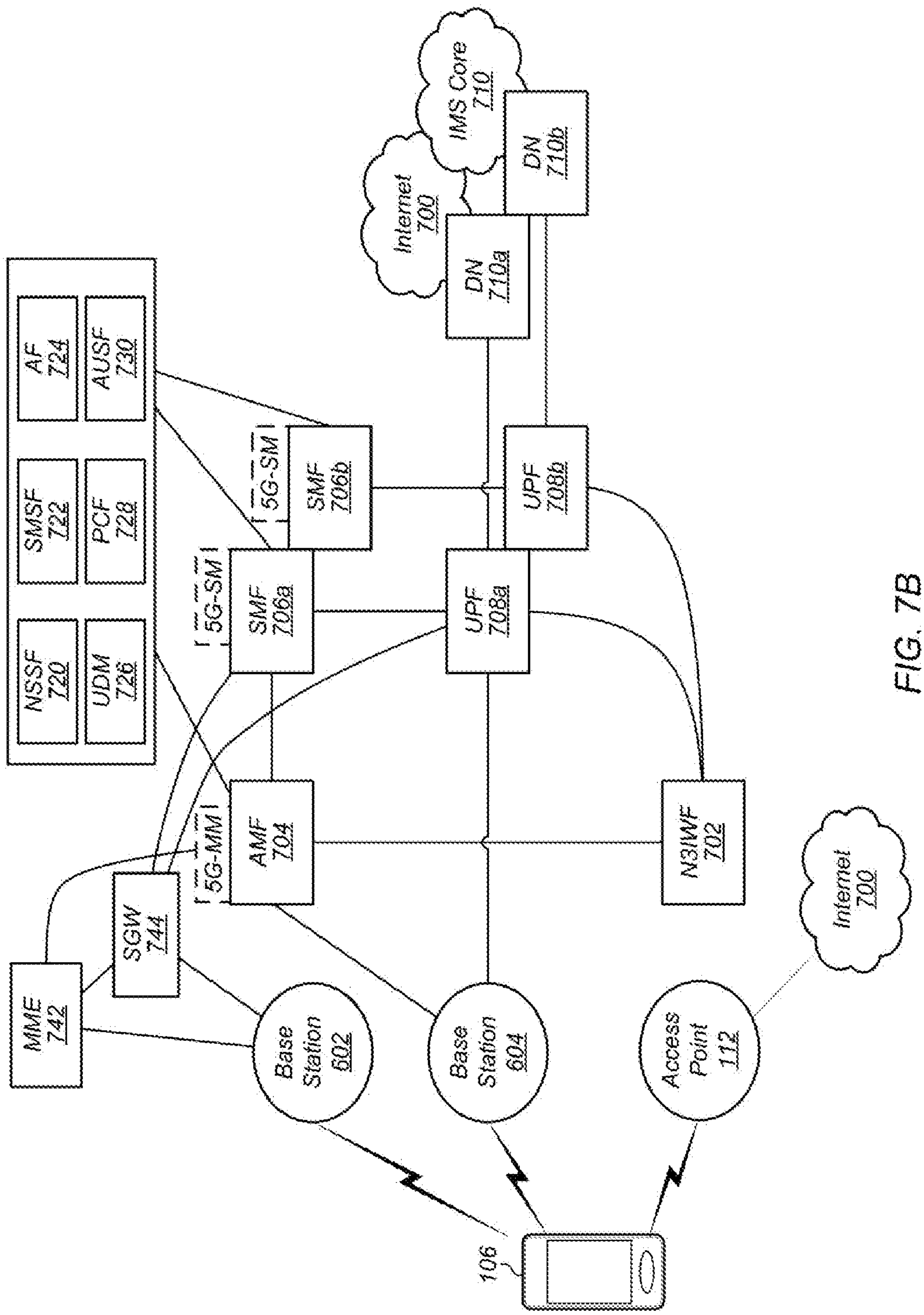

NSSF 720
SMSF 722
AF 724
UDM 726
PCF 728
AUSF 730
Internet 700
IMS Core 710
DN 710b
DN 710a
5G-SM
SMF 706b
UPF 708b
5G-SM
SMF 706a
UPF 708a
5G-MM
AMF 704
N3IWF 702
MME 742
SGW 744
Base Station 602
Base Station 604
Access Point 112
Internet 700
106

FIG. 7B

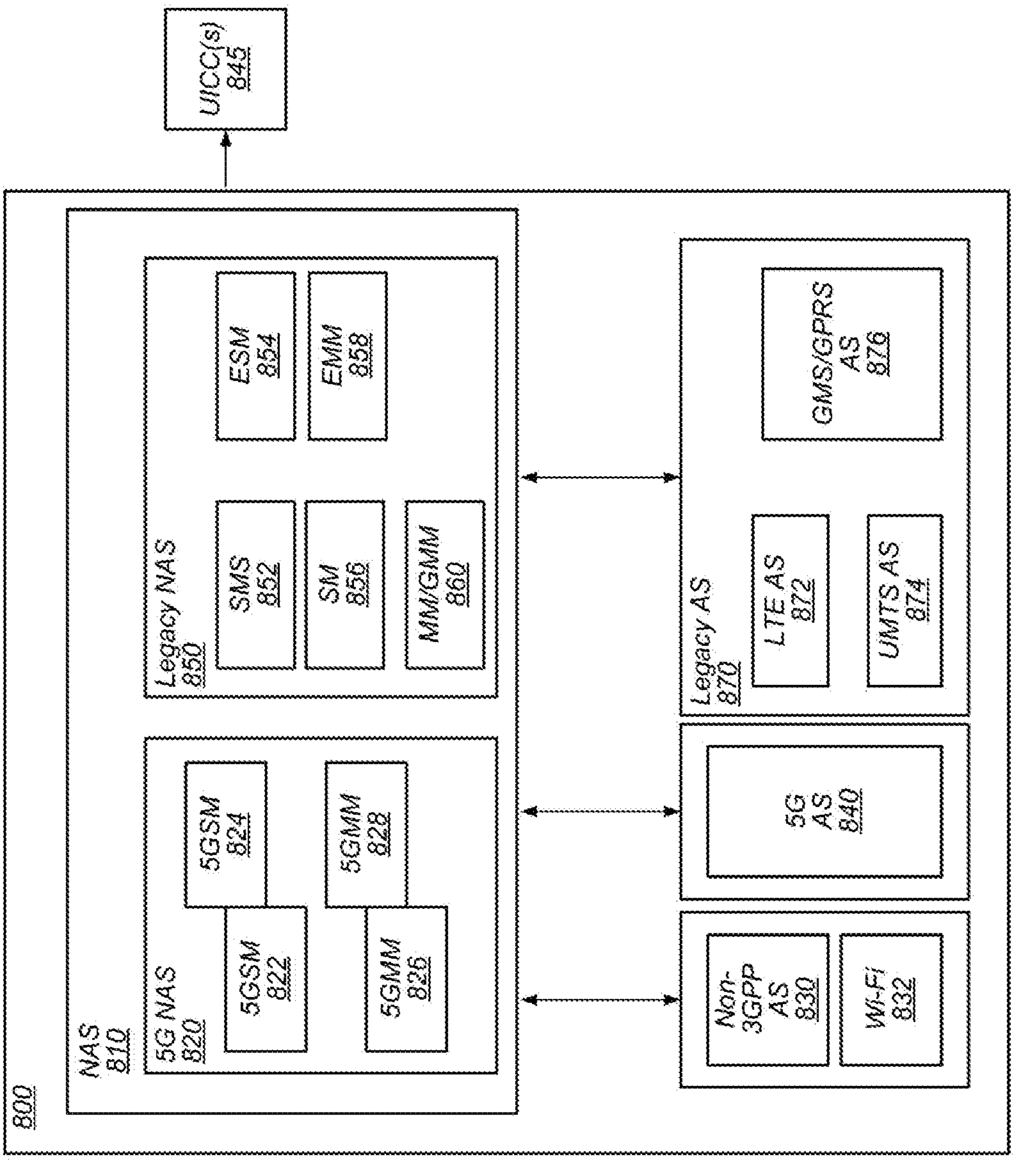

UICC(s)
845
800
NAS
810
5G NAS
820
5GSM
822
5GSM
824
5GMM
826
5GMM
828
Legacy NAS
850
SMS
852
SM
856
MM/GMM
860
ESM
854
EMM
858
Non-3GPP AS
830
Wi-Fi
832
5G AS
840
Legacy AS
870
LTE AS
872
UMTS AS
874
GMS/GPRS AS
876

FIG. 8

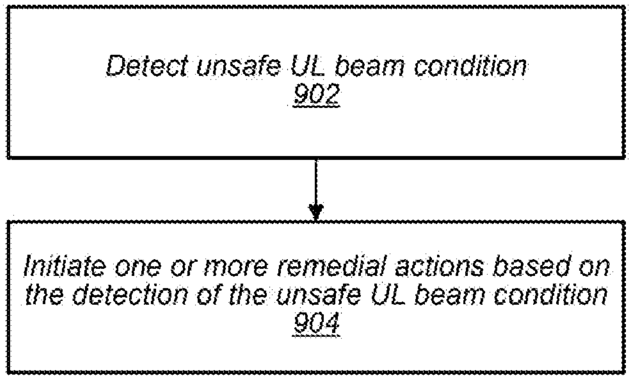

Detect unsafe UL beam condition
902
Initiate one or more remedial actions based on the detection of the unsafe UL beam condition
904

FIG. 9

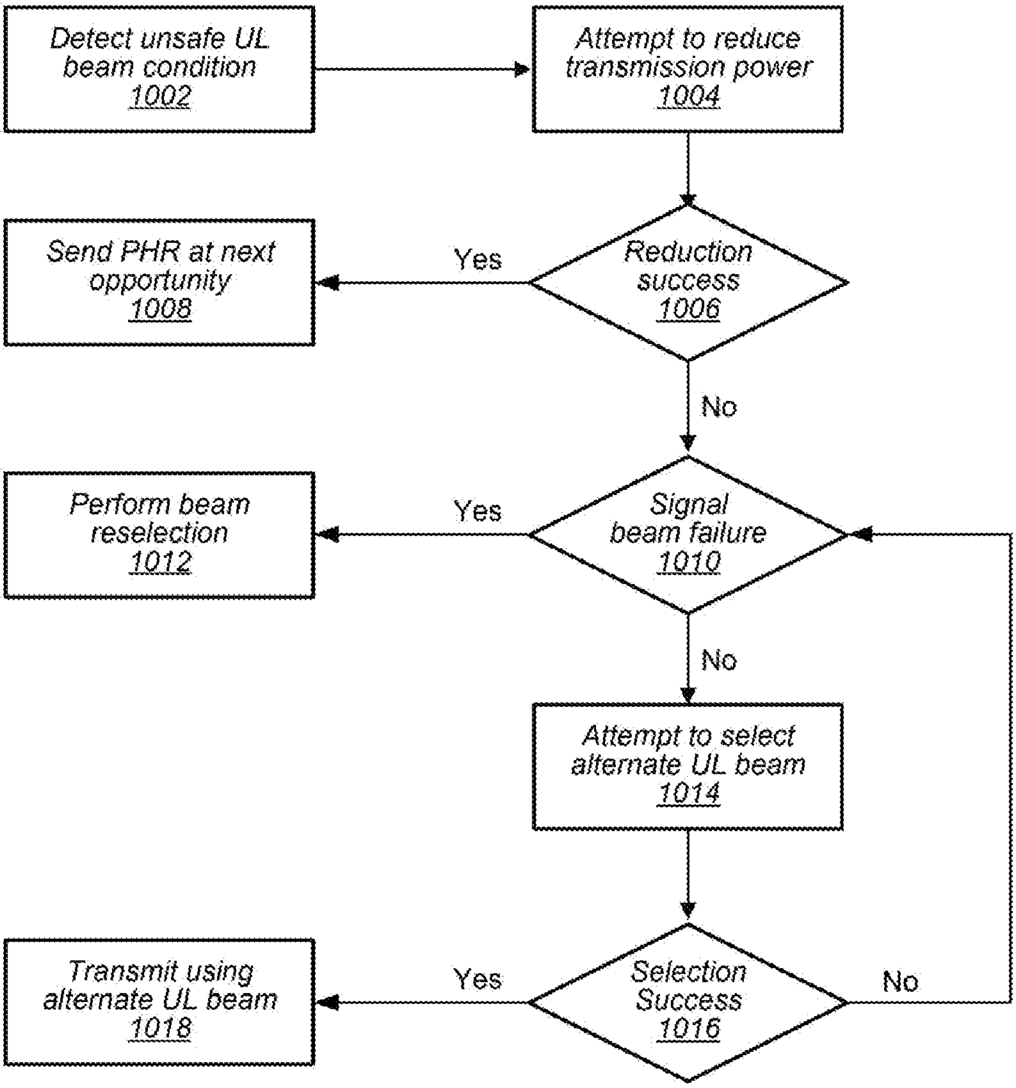

Detect unsafe UL beam condition
1002
Attempt to reduce transmission power
1004
Reduction success
1006
Yes
Send PHR at next opportunity
1008
No
Signal beam failure
1010
Yes
Perform beam reselection
1012
No
Attempt to select alternate UL beam
1014
Selection Success
1016
Yes
Transmit using alternate UL beam
1018
No

FIG. 10

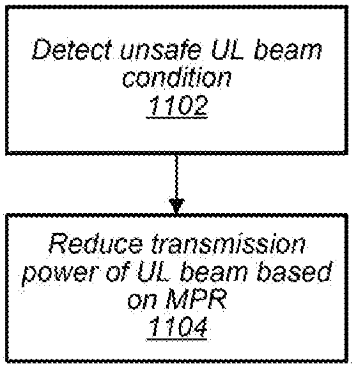


FIG. 11

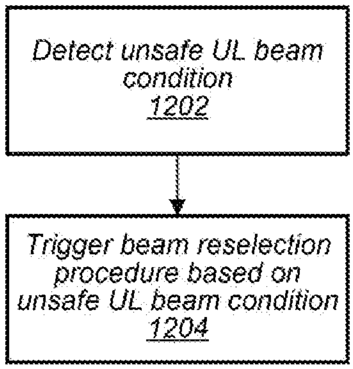


FIG. 12

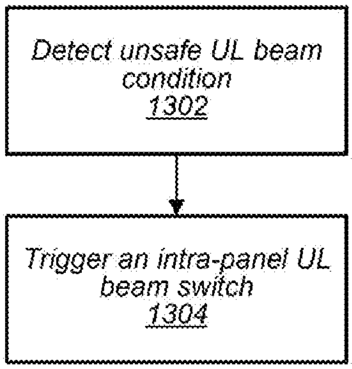


FIG. 13

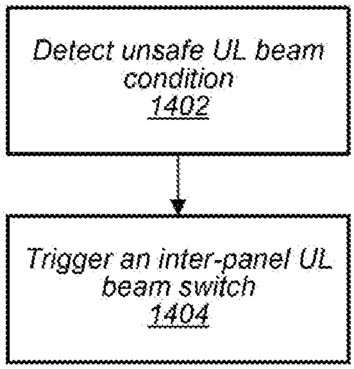


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/105721

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/02(2018.01)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)

H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT, WPI, EPODOC, CNKI:MPE，MPR，uplink, antenna, switch???, exposure,power, signal, threshold

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104779437 A (HUIZHOU TCL MOBILE COMM CO.， LTD.) 15 July 2015 (2015-07-15) description， paragraphs [0024]-[0043]	1-2，7-10，17，19-20
A	WO 2019037158 A1 (QUALCOMM INCORPORATED) 28 February 2019 (2019-02-28) the whole document	1-20
A	CN 102684756 A (TOSHIBA CORP.) 19 September 2012 (2012-09-19) the whole document	1-20
A	US 2019190584 A1 (INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE) 20 June 2019 (2019-06-20) the whole document	1-20
A	CN 101874364 A (NTT DOCOMO INC.) 27 October 2010 (2010-10-27) the whole document	1-20
A	CN 104980205 A (ZTE CORP.) 14 October 2015 (2015-10-14) the whole document	1-20

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "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
22 May 2020	**10 June 2020**

Name and mailing address of the ISA/CN

National Intellectual Property Administration, PRC
6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088
China

Facsimile No. **(86-10)62019451**

Authorized officer

ZHANG,Miao

Telephone No. **86-(10)-53962616**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2019/105721

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	104779437	A	15 July 2015	CN	104779437	B	19 June 2018
WO	2019037158	A1	28 February 2019	WO	2019037026	A1	28 February 2019
CN	102684756	A	19 September 2012	CN	102684756	B	29 October 2014
				JP	2012191262	A	04 October 2012
				JP	5289486	B2	11 September 2013
US	2019190584	A1	20 June 2019	US	10541743	B2	21 January 2020
				TW	201929451	A	16 July 2019
				TW	I658707	B	01 May 2019
CN	101874364	A	27 October 2010	JP	2009088690	A	23 April 2009
				RU	2010115223	A	10 November 2011
				JP	5026207	B2	12 September 2012
				MX	2010003372	A	05 May 2010
				US	2010254326	A1	07 October 2010
				KR	20100085039	A	28 July 2010
				BR	PI0817680	A2	14 April 2015
				EP	2194735	A1	09 June 2010
				WO	2009041638	A1	02 April 2009
CN	104980205	A	14 October 2015	WO	2015154358	A1	15 October 2015