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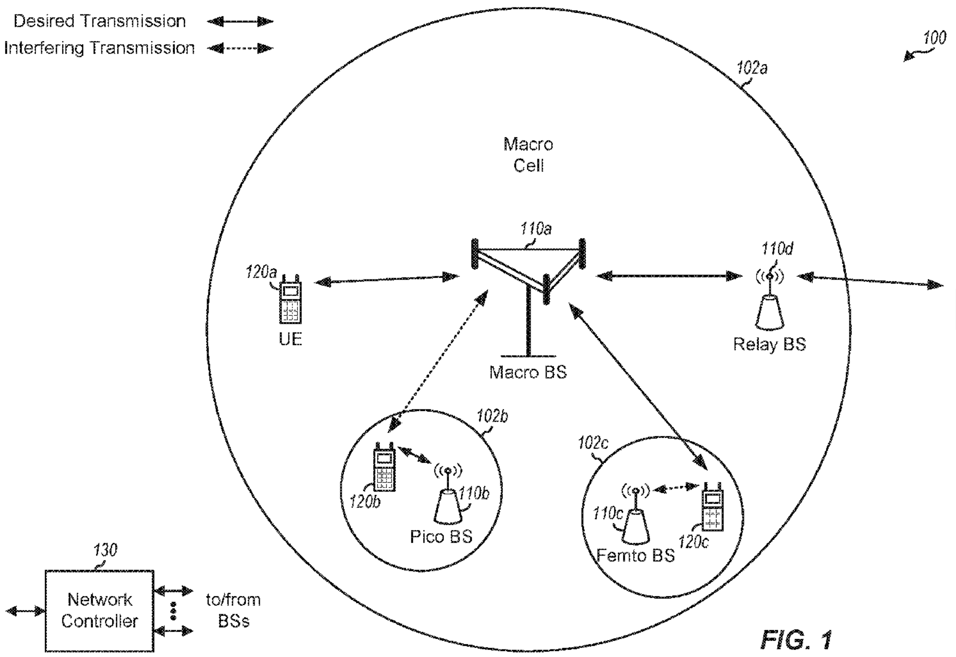

FIG. 1

(57) Abstract: Aspects of the present disclosure provide techniques and apparatus for wireless communication. In one aspect, a method is provided which may be performed by a wireless device such as a user equipment (UE). The method generally includes: attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS); determining a random access response (RAR) reception from the BS failed; measuring signal quality of the BS observed at the UE in response to the determined RAR reception failure; determining whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and starting a next RACH procedure attempt, at the first CE level or the second CE level, with the BS. In one aspect, a method is provided which may be performed by a wireless device such as a UE, for example, that is preparing for a random access

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channel (RACH) procedure with a base station (BS). The method generally includes: measuring signal quality of the BS observed at the UE; determining a coverage enhancement (CE) level and a RACH attempt counter value based at least in part of the measured signal quality; and attempting the RACH procedure based at least in part on the determined CE level and RACH attempt counter value.

COVERAGE ENHANCEMENT (CE) LEVEL AND TRANSMIT POWER DETERMINATION TECHNIQUES FOR USER EQUIPMENT (UE) IN EXTENDED COVERAGE

BACKGROUND

Field of the Disclosure

[0001] Certain aspects of the present disclosure generally relate to wireless communications and, more particularly, to enhanced CE level and transmit power determination techniques for UEs in extended coverage.

Description of Related Art

[0002] Wireless communication systems are widely deployed to provide various types of communication content such as voice, data, and so on. These systems may be multiple-access systems capable of supporting communication with multiple users by sharing the available system resources (e.g., bandwidth and transmit power). Examples of such multiple-access systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE)/LTE-Advanced (LTE-A) systems and orthogonal frequency division multiple access (OFDMA) systems.

[0003] Generally, a wireless multiple-access communication system can simultaneously support communication for multiple wireless terminals. Each terminal communicates with one or more base stations (BSs) via transmissions on the forward and reverse links. The forward link (or downlink) refers to the communication link from the BSs to the terminals, and the reverse link (or uplink) refers to the communication link from the terminals to the BSs. This communication link may be established via a single-input single-output, multiple-input single-output or a multiple-input multiple-output **(MIMO)** system.

[0004] A wireless communication network may include a number of BSs that can support communication for a number of wireless devices. Wireless devices may include user equipments (UEs). Machine type communications (MTC) may refer to communication involving at least one remote device on at least one end of the communication and may include forms of data communication which involve one or more entities that do not necessarily need human interaction. MTC UEs may include UEs that are capable of MTC communications with MTC servers and/or other MTC devices through Public Land Mobile Networks (PLMN), for example. Wireless devices may include Intemet-of-Things (loT) devices (e.g., narrowband loT (NB-IoT) devices). loT may refer to a network of physical objects, devices, or “things”. loT devices may be embedded with, for example, electronics, software, or sensors and may have network connectivity, which enable these devices to collect and exchange data.

[0005] Some next generation, NR, or 5G networks may include a number of base stations, each simultaneously supporting communication for multiple communication devices, such as UEs. In LTE or LTE-A network, a set of one or more BSs may define an e NodeB (eNB). In other examples (e.g., in a next generation or 5G network), a wireless multiple access communication system may include a number of distributed units (e.g., edge units (EUs), edge nodes (ENs), radio heads (RHs), smart radio heads (SRHs), transmission reception points (TRPs), etc.) in communication with a number of central units (e.g., CU, central nodes (CNs), access node controllers (ANCs), etc.), where a set of one or more distributed units (DUs), in communication with a CU, may define an access node (e.g., AN, a new radio base station (NR BS), a NR NB, a network node, a gNB, a 5G BS, an access point (AP), etc.). A BS or DU may communicate with a set of UEs on downlink channels (e.g., for transmissions from a BS or to a UE) and uplink channels (e.g., for transmissions from a UE to a BS or DU).

[0006] These multiple access technologies have been adopted in various telecommunication standards to provide a common protocol that enables different wireless devices to communicate on a municipal, national, regional, and even global level. NR (e.g., 5G radio access) is an example of an emerging telecommunication standard. NR is a set of enhancements to the LTE mobile standard promulgated by 3GPP. NR is designed to better support mobile broadband Internet access by improving spectral efficiency, lowering costs, improving services, making use of new spectrum, and better integrating with other open standards using OFDMA with a cyclic prefix (CP) on the downlink (DL) and on the uplink (UL) as well as support beamforming, MIMO antenna technology, and carrier aggregation.

[0007] However, as the demand for mobile broadband access continues to increase, there exists a need for further improvements in LTE, MTC, loT, and NR (new radio) technology. Preferably, these improvements should be applicable to other multi-access technologies and the telecommunication standards that employ these technologies.

SUMMARY

[0008] The systems, methods, and devices of the disclosure each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this disclosure as expressed by the claims which follow, some features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled "DETAILED DESCRIPTION" one will understand how the features of this disclosure provide advantages that include improved communications between access points and stations in a wireless network.

[0009] Certain aspects of the present disclosure generally relate to CE level and transmit power determination techniques.

[0010] Certain aspects of the present disclosure provide a method, performed by a wireless device, such as a user equipment (UE). The method generally includes: attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS); determining a random access response (RAR) reception from the BS failed; measuring signal quality of the BS observed at the UE in response to the determined RAR reception failure; determining whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and starting a next RACH procedure attempt, at the first CE level or the second CE) level, with the BS.

[0011] Certain aspects of the present disclosure provide an apparatus. The apparatus generally includes at least one processor configured to: attempt a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS); determine a random access response (RAR) reception from the BS failed; measure signal quality of the BS observed at the UE in response to the determined RAR reception failure; determine whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and start a next RACH procedure attempt, at the first CE level or the second CE level, with the BS.

[0012] Certain aspects of the present disclosure provide an apparatus. The apparatus generally includes: means for attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS); means for determining a random access response (RAR) reception from the BS failed; means for measuring signal quality of the BS observed at the UE in response to the determined RAR reception failure; means for determining whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and means for starting a next RACH procedure attempt, at the first CE level or the second CE level, with the BS.

[0013] Certain aspects of the present disclosure provide a computer-readable medium. The computer-readable medium generally includes code, which when executed by at least one processor, causes the at least one processor to: attempt a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS); determine a random access response (RAR) reception from the BS failed; measure signal quality of the BS observed at the UE in response to the determined RAR reception failure; determine whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and start a next RACH procedure attempt, at the first CE level or the second CE level, with the BS.

[0014] Certain aspects of the present disclosure provide a method of wireless communications by a user equipment (UE) preparing for a random access channel (RACH) procedure with a base station (BS). The method generally includes: measuring signal quality of the BS observed at the UE; determining a coverage enhancement (CE) level and a preamble transmission counter value based at least in part of the measured signal quality; and attempting the RACH procedure based at least in part on the determined CE level and preamble transmission counter value.

[0015] Certain aspects of the present disclosure provide an apparatus preparing for a random access channel (RACH) procedure with a base station (BS). The apparatus generally includes at least one processor configured to: measure signal quality of the BS observed at the UE; determine a coverage enhancement (CE) level and a preamble transmission counter value based at least in part of the measured signal quality; and attempt the RACH procedure based at least in part on the determined CE level and preamble transmission counter value.

[0016] Certain aspects of the present disclosure provide an apparatus preparing for a random access channel (RACH) procedure with a base station (BS). The apparatus generally includes: means for measuring signal quality of the BS observed at the UE; means for determining a coverage enhancement (CE) level and a preamble transmission counter value based at least in part of the measured signal quality; and means for attempting the RACH procedure based at least in part on the determined CE level and preamble transmission counter value.

[0017] Certain aspects of the present disclosure provide a computer-readable medium for an apparatus preparing for a random access channel (RACH) procedure with a base station (BS). The computer-readable medium generally includes code, which when executed by at least one processor, causes the at least one processor to: measure signal quality of the BS observed at the UE; determine a coverage enhancement (CE) level and a preamble transmission counter value based at least in part of the measured signal quality; and attempt the RACH procedure based at least in part on the determined CE level and preamble transmission counter value.

[0018] Numerous other aspects are provided including methods, apparatus, systems, computer program products, computer-readable medium, and processing systems. To the accomplishment of the foregoing and related ends, the one or more aspects comprise the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative features of the one or more aspects. These features are indicative, however, of but a few of the various ways in which the principles of various aspects may be employed, and this description is intended to include all such aspects and their equivalents.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description, briefly summarized above, may be had by reference to aspects, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only certain typical aspects of this disclosure and are therefore not to be considered limiting of its scope, for the description may admit to other equally effective aspects.

[0020] FIG. 1 is a block diagram conceptually illustrating an example of a wireless communication network, in accordance with certain aspects of the present disclosure.

[0021] FIG. 2 shows a block diagram conceptually illustrating an example of a base station (BS) in communication with a user equipment (UE) in a wireless communications network, in accordance with certain aspects of the present disclosure.

[0022] FIG. 3 is a block diagram conceptually illustrating an example of a frame structure in a wireless communications network, in accordance with certain aspects of the present disclosure.

[0023] FIG. 4 is a block diagram conceptually illustrating two exemplary subframe formats with the normal cyclic prefix, in accordance with certain aspects of the present disclosure.

[0024] FIG. 5 illustrates an exemplary subframe configuration for enhanced/evolved machine type communications (eMTC), in accordance with certain aspects of the present disclosure.

[0025] FIG. 6 illustrates an example deployment of narrowband Tnternet-of-Things (NB-IoT), in accordance with certain aspects of the present disclosure.

[0026] FIG. 7 illustrates an example logical architecture of a distributed radio access network (RAN), in accordance with certain aspects of the present disclosure.

[0027] FIG. 8 illustrates an example physical architecture of a distributed RAN, in accordance with certain aspects of the present disclosure.

[0028] FIG. 9 is a diagram illustrating an example of a downlink (DL)-centric subframe, in accordance with certain aspects of the present disclosure.

[0029] FIG. 10 is a diagram illustrating an example of an uplink (UL)-centric subframe, in accordance with certain aspects of the present disclosure.

[0030] FIG. 11 is a flow diagram illustrating example operations for a UE, in accordance with certain aspects of the present disclosure.

[0031] FIG. 12 is a flow diagram illustrating example operations for a UE, in accordance with certain aspects of the present disclosure.

[0032] FIG. 13 is a flow diagram illustrating example operations for a UE, in accordance with certain aspects of the present disclosure.

[0033] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements disclosed in one aspect may be beneficially utilized on other aspects without specific recitation.

DETAILED DESCRIPTION

[0034] Aspects of the present disclosure provide techniques for CE level and transmit power determination for UEs in extended coverage. The techniques described herein may be used for various wireless communication networks such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA and other networks. The terms “network” and “system” are often used interchangeably. A CDMA network may implement a radio technology such as universal terrestrial radio access (UTRA), cdma2000, etc. UTRA includes wideband CDMA (WCDMA), time division synchronous CDMA (TD-SCDMA), and other variants of CDMA. cdma2000 covers IS-2000, IS-95 and IS-856 standards. A TDMA network may implement a radio technology such as global system for mobile communications (GSM). An OFDMA network may implement a radio technology such as evolved UTRA (E-UTRA), ultra mobile broadband (UMB), IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20, Flash-OFDMCD, etc. UTRA and E-UTRA are part of universal mobile telecommunication system (UMTS). 3GPP Long Term Evolution (LTE) and LTE-Advanced (LTE-A), in both frequency division duplex (FDD) and time division duplex (TDD), are new releases of UMTS that use E-UTRA, which employs OFDMA on the downlink and SC-FDMA on the uplink. UTRA, E-UTRA, UMTS, LTE, LTE-A and GSM are described in documents from an organization named “3rd Generation Partnership Project” (3GPP). cdma2000 and UME are described in documents from an organization named “3rd Generation Partnership Project 2” (3GPP2). NR (e.g., 5G radio access) is an example of an emerging telecommunication standard. NR is a set of enhancements to the LTE mobile standard promulgated by 3GPP. The techniques described herein may be used for the wireless networks and radio technologies mentioned above as well as other wireless networks and radio technologies. For clarity, certain aspects of the techniques are described below' for LTE/LTE-Advanced, and LTE/LTE-Advanced (LTE-A) terminology is used in much of the description below. LTE and LTE-A are referred to generally as LTE. Depending on the context, “channel” may refer to the channel on which signaling/data/information is transmitted or received, or to the signaling/data/information that is transmitted or received on the channel.

[0035] It is noted that while aspects may be described herein using terminology commonly associated with 3G and/or 4G wireless technologies, aspects of the present disclosure can be applied in other generation-based communication systems, such as 5G and later.

EXAMPLE WIRELESS COMMUNICATIONS NETWORK

[0036] FIG. 1 illustrates an example wireless communication network 100, in which aspects of the present disclosure may be practiced. For example, techniques presented herein may be used for cell CE level determination in wireless communication network 100, which may be an LTE or later network that includes narrowband Internet-of-things (NB-IoT) and/or enhanced/evolved machine type communications (eMTC) devices. Wireless communication network 100 may include base stations (BSs) 110 and user equipment (UEs) 120. In aspects, a BS 110 can determine at least one narrowband region of a wideband region for communication with a UE 120. UE 120, which may be a low cost device, such a NB-IoT device or an eMTC UE, can determine the narrowband region and receive, send, monitor, or decode information on the narrowband region for communication with BS 110.

[0037] Wireless communication network 100 may be a long term evolution (LTE) network or some other wireless network, such as a new radio (NR) or 5G network. Wireless communication network 100 may include a number of BSs 110 and other network entities. A BS is an entity that communicates with UEs and may also be referred to as a NR BS, a Node B (NB), an evolved/enhanced NB (eNB), a 5G NB, a gNB, an access point (AP), a transmission reception point (TRP), etc. Each BS may provide communication coverage for a particular geographic area. In 3GPP, the term “cell” can refer to a coverage area of a BS and/or a BS subsystem serving this coverage area, depending on the context in which the term is used.

[0038] A BS may provide communication coverage for a macro cell, a pico cell, a femto cell, and/or other types of cell. A macro cell may cover a relatively large geographic area (e.g., several kilometers in radius) and may allow' unrestricted access by UEs with sendee subscription. A pico cell may cover a relatively small geographic area and may allow unrestricted access by UEs with service subscription. A femto cell may-cover a relatively small geographic area (e.g., a home) and may allow- restricted access by UEs having association with the femto cell (e.g., UEs in a closed subscriber group (CSG)). A BS for a macro cell may be referred to as a macro BS. A BS for a pico cell may be referred to as a pico BS. A BS for a femto cell may be referred to as a femto BS or a home BS. In the example shown in FIG. 1, BS 110a may be a macro BS for a macro cell 102a, BS 110b may be a pico BS for a pico cell 102b, and BS 110c may be a femto BS for a femto cell 102c. A BS may support one or multiple (e.g., three) cells.

[0039] Wireless communication network 100 may also include relay stations. A relay-station is an entity that can receive a transmission of data from an upstream station (e.g., BS 110 or UE 120) and send a transmission of the data to a downstream station (e.g., UE 120 or BS 110). A relay station may also be a UE that can relay transmissions for other UEs. In the example shown in FIG. 1, relay station 110d may communicate with macro BS 110a and UE 120d in order to facilitate communication between BS 110a and UE 120d. A relay station may also be referred to as a relay BS, a relay, etc.

[0040] Wireless communication network 100 may be a heterogeneous network that includes BSs of different types, e.g., macro BSs, pico BSs, femto BSs, relay BSs, etc. These different types of BSs may have different transmit power levels, different coverage areas, and different impact on interference in wireless communication network 100. For example, macro BSs may have a high transmit power level (e.g., 5 to 40 Watts) whereas pico BSs, femto BSs, and relay BSs may have lower transmit power levels (e.g., 0.1 to 2 Watts).

[0041] Network controller 130 may couple to a set of BSs and may provide coordination and control for these BSs. Network controller 130 may communicate with the BSs via a backhaul. The BSs may also communicate with one another, e.g., directly or indirectly via a wireless or wireline backhaul.

[0042] UEs 120 (e.g., UE 120a, UE 120b, UE 120c) may be dispersed throughout wireless communication network 100, and each UE may be stationary or mobile. A UE may also be referred to as an access terminal, a terminal, a mobile station, a subscriber unit, a station, a Customer Premises Equipment (CPE), etc. A UE may he a cellular phone (e.g., a smart phone), a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a laptop computer, a cordless phone, a wireless local loop (WLL) station, a tablet, a camera, a drone, a robot/robotic device, a netbook, a smartbook, an ultrabook, a medical device, medical equipment, a healthcare device, a biometric sensor/de vice, a wearable device such as a smart watch, smart clothing, smart glasses, virtual reality goggles, a smart wristband, and/or smart jewelry (e.g., a smart ring, a smart bracelet, etc.), an entertainment device (e.g., a music device, a video device, a gaming device, a satellite radio, etc.), industrial manufacturing equipment, a navigation/positioning device (e.g., GNSS (global navigation satellite system) devices based on, for example, GPS (global positioning system), Beidou, GLONASS, Galileo, terrestrial-based devices, etc.), or any other suitable device configured to communicate via a wireless or wired medium. Some UEs may be implemented as loT (Internet of things) UEs. IoT UEs include, for example, robots/robotic devices, drones, remote devices, sensors, meters, monitors, cameras, location tags, etc., that may communicate with a BS, another device (e.g., remote device), or some other entity. IoT UEs may include MTC/eMTC UEs, NB-IoT UEs, as well as other types of UEs. A wireless node may provide, for example, connectivity for or to a network (e.g., a wide area network such as Internet or a cellular network) via a wired or wireless communication link.

[0043] One or more UEs 120 in the wireless communication network 100 (e.g., an LTE network) may be a narrowband bandwidth UE. As used herein, devices with limited communication resources, e.g. smaller bandwidth, may he referred to generally as narrowband (NB) UEs or bandwidth limited (BL) UEs. In one example, a limited bandwidth may be 1.4 MHz. In another example, a limited bandwidth may be 5 MHz. Similarly, legacy devices, such as legacy and/or advanced UEs (e.g., in LTE) may be referred to generally as wideband UEs. Generally, wideband UEs are capable of operating on a larger amount of bandwidth than narrowband UEs.

[0044] In FIG. 1, a solid line with double arrows indicates desired transmissions between a UE and a serving BS, wiiich is a BS designated to serve the UE on the downlink and/or uplink. A dashed line with double arrows indicates potentially interfering transmissions between a UE and a BS.

[0045] In general, any number of wireless networks may be deployed in a given geographic area. Each wireless network may support a particular radio access technology (RAT) and may operate on one or more frequencies. A RAT may also be referred to as a radio technology, an air interface, etc. A frequency may also be referred to as a carrier, a frequency channel, etc. Each frequency may support a single RAT in a given geographic area in order to avoid interference between wireless networks of different RATs. In some cases, NR or 5G RAT networks may be deployed.

[0046] In some examples, access to the air interface may be scheduled, wherein a scheduling entity (e.g., a BS 110) allocates resources for communication among some or all devices and equipment within its service area or cell. The scheduling entity may be responsible for scheduling, assigning, reconfiguring, and releasing resources for one or more subordinate entities. For scheduled communication, subordinate entities utilize resources allocated by the scheduling entity. BSs 110 are not the only entities that may-function as a scheduling entity. In some examples, UE 120 may function as a scheduling entity, scheduling resources for one or more subordinate entities (e.g., one or more other UEs 120). In this example, the UE is functioning as a scheduling entity, and other UEs utilize resources scheduled by the UE for wireless communication. A UE may function as a scheduling entity in a peer-to-peer (P2P) network, and/or in a mesh network. In a mesh network example, UEs may optionally communicate directly with one another in addition to communicating with the scheduling entity.

[0047] Thus, in a wireless communication network with a scheduled access to time-frequency resources and having a cellular configuration, a P2P configuration, and a mesh configuration, a scheduling entity and one or more subordinate entities may communicate utilizing the scheduled resources.

[0048] FIG. 2 show's a block diagram of a design of BS 110 and UE 120, which may be one of the BSs 110 and one of the UEs 120 in FIG. 1. BS 110 may be equipped with T antennas 234a through 234t, and UE 120 may be equipped with R antennas 252a through 252r, where in general $T \geq 1$ and $R \geq 1$.

[0049] At BS 110, transmit processor 220 may receive data from a data source 212 for one or more UEs, select one or more modulation and coding schemes (MCS) for each UE based on channel quality indicators (CQIs) received from the UE, process (e.g., encode and modulate) the data for each UE based on the MCS(s) selected for the UE, and provide data symbols for all UEs. Transmit processor 220 may also process system information (e.g., for static resource partitioning information (SRPI), etc.) and control information (e.g., CQI requests, grants, upper layer signaling, etc.) and provide overhead symbols and control symbols. Processor 220 may also generate reference symbols for reference signals (e.g., the cell-specific reference signal (CRS)) and synchronization signals (e.g., the primary synchronization signal (PSS) and the secondary synchronization signal (SSS)). Transmit (TX) multiple-input multiple-output (MIMO) processor 230 may perform spatial processing (e.g., preceding) on the data symbols, the control symbols, the overhead symbols, and/or the reference symbols, if applicable, and may provide *T* output symbol streams to *T* modulators (MODs) 232a through 232t. Each modulator 232 may process a respective output symbol stream (e.g., for OFDM, etc.) to obtain an output sample stream. Each modulator 232 may further process (e.g., convert to analog, amplify, filter, and upeonvert) the output sample stream to obtain a downlink signal. *T* downlink signals from modulators 232a through 232t may be transmitted via T antennas 234a through 234t, respectively.

[0050] At UE 120, antennas 252a through 252r may receive the downlink signals from base station 110 and/or other BSs and may provide received signals to demodulators (DEMODs) 254a through 254r, respectively. Each demodulator 254 may condition (e.g., filter, amplify, downconvert, and digitize) its received signal to obtain input samples. Each demodulator 254 may further process the input samples (e.g., for OFDM, etc.) to obtain received symbols. MIMO detector 256 may obtain received symbols from all *R* demodulators 254a through 254r, perform MIMO detection on the received symbols if applicable, and provide detected symbols. Receive processor 258 may process (e.g., demodulate and decode) the detected symbols, provide decoded data for UE 120 to data sink 260, and provide decoded control information and system information to controller/processor 280. A channel processor may determine reference signal received power (RSRP), received signal strength indicator (RSSI), reference signal received quality (RSRQ), CQI, etc.

[0051] On the uplink, at UE 120, transmit processor 264 may receive and process data from data source 262 and control information (e.g., for reports comprising RSRP, RSSI, RSRQ, CQI, etc.) from controller/processor 280. Processor 264 may also generate reference symbols for one or more reference signals. The symbols from transmit processor 264 may be precoded by TX MIMO processor 266 if applicable, further processed by modulators 254a through 254r (e.g., for SC-FDM, OFDM, etc.), and transmitted to BS 110. At BS 110, the uplink signals from UE 120 and other UEs may be received by antennas 234, processed by demodulators 232, detected by MIMO detector 236 if applicable, and further processed by receive processor 238 to obtain decoded data and control information sent by UE 120. Processor 238 may provide the decoded data to data sink 239 and the decoded control information to controller/processor 240. BS 110 may include communication unit 244 and communicate to network controller 130 via communication unit 244. Network controller 130 may include communication unit 294, controller/processor 290, and memory 292.

[0052] Controllers/processors 240 and 280 may direct the operation at BS 110 and UE 120, respectively, to perform techniques presented herein. For example, processor 240 and/or other processors and modules at BS 110, and processor 280 and/or other processors and modules at UE 120, may perform or direct operations of BS 110 and UE 120, respectively. For example, controller/processor 240 and/or other controllers/processors and modules at BS 110 may perform or direct operations of BS 110. For example, controller/processor 280 and/or other controllers/processors and modules at UE 120 may perform or direct operations 1100, 1200, and 1300 shown in FIGs. 11, 12, and 13, respectively. Memories 242 and 282 may store data and program codes for BS 110 and UE 120, respectively. Scheduler 246 may schedule UEs for data transmission on the downlink and/or uplink.

[0053] FIG. 3 shows an exemplary frame structure 300 for frequency division duplexing (FDD) in a wireless communication system (e.g., such as wireless communication network 100). The transmission timeline for each of the downlink and uplink may be partitioned into units of radio frames. Each radio frame may have a predetermined duration (e.g., 10 milliseconds (ms)) and may be partitioned into 10 subframes with indices of 0 through 9. Each subframe may include two slots. Each radio frame may thus include 20 slots with indices of 0 through 19. Each slot may include L symbol periods, for example, seven symbol periods for a normal cyclic prefix (as shown in FIG. 3) or six symbol periods for an extended cyclic prefix. The $2L$ symbol periods in each subframe may be assigned indices of 0 through $2L-1$.

[0054] In certain wireless communication systems (e.g., LTE), a BS (e.g., such as a BS 110) may transmit a PSS and a SSS on the downlink in the center of the system bandwidth for each cell supported by the BS. The PSS and SSS may be transmitted in symbol periods 6 and 5, respectively, in subframes 0 and 5 of each radio frame with the normal cyclic prefix, as shown in FIG. 3. The PSS and SSS may be used by UEs (e.g., such as UEs 120) for cell search and acquisition. The BS may transmit a CRS across the system bandwidth for each cell supported by the BS. The CRS may be transmitted in certain symbol periods of each subframe and may be used by the UEs to perform channel estimation, channel quality measurement, and/or other functions. The BS may also transmit a physical broadcast channel (PBCH) in symbol periods 0 to 3 in slot 1 of certain radio frames. The PBCH may carry some system information. The BS may transmit other system information such as system information blocks (SIBs) on a physical downlink shared channel (PDSCH) in certain subframes. The BS may transmit control information/data on a physical downlink control channel (PDCCH) in the first B symbol periods of a subframe, where B may be configurable for each subframe. The BS may transmit traffic data and/or other data on the PDSCH in the remaining symbol periods of each subframe.

[0055] In certain systems (e.g., such as NR or 5G systems), a BS may transmit these or other signals in these locations or in different locations of the subframe.

[0056] FIG. 4 shows two exemplary subframe formats 410 and 420 with the normal cyclic prefix. The available time frequency resources may be partitioned into resource blocks (RBs). Each RB may cover 12 subcarriers in one slot and may include a number of resource elements (REs). Each RE may cover one subcarrier in one symbol period and may be used to send one modulation symbol, which may be a real or complex value.

[0057] Subframe format 410 may be used for two antennas. A CRS may he transmitted from antennas 0 and 1 in symbol periods 0, 4, 7 and 11. A reference signal is a signal that is known *a priori* by a transmitter and a receiver and may also be referred to as pilot. A CRS is a reference signal that is specific for a cell, e.g., generated based on a cell identity (ID). In FIG. 4, for a given RE with label Ra, a modulation symbol may be transmitted on that RE from antenna a, and no modulation symbols may be transmitted on that RE from other antennas. Subframe format 420 may be used with four antennas. A CRS may be transmitted from antennas 0 and 1 in symbol periods 0, 4, 7 and 11 and from antennas 2 and 3 in symbol periods 1 and 8. For both subframe formats 410 and 420, a CRS may be transmitted on evenly spaced subcarriers, which may be determined based on cedi ID. CRSs may be transmitted on the same or different subcarriers, depending on their cell IDs. For both subframe formats 410 and 420, REs not used for the CRS may be used to transmit data (e.g., traffic data, control data, and/or other data).

[0058] The PSS, SSS, CRS and PBCH in LTE are described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

[0059] An interlace structure may be used for each of the downlink and uplink for FDD in LTE. For example, Q interlaces with indices of 0 through $Q - 1$ may be defined, where Q may be equal to 4, 6, 8, 10, or some other value. Each interlace may include subframes that are spaced apart by Q frames. In particular, interlace q may include subframes $q, q + Q, q + 2Q$, etc., where q G $\{0,\ldots,Q-1\}$.

[0060] The wireless network may support hybrid automatic retransmission request (HARQ) for data transmission on the downlink and uplink. For HARQ, a transmitter (e.g., a BS) may send one or more transmissions of a packet until the packet is decoded correctly by a receiver (e.g., a UE) or some other termination condition is encountered. For synchronous HARQ, all transmissions of the packet may be sent in subframes of a single interlace. For asynchronous HARQ, each transmission of the packet may be sent in any subframe.

[0061] A UE may be located within the coverage of multiple BS. One of these BSs may be selected to serve the UE. The serving BS may be selected based on various criteria such as received signal strength, received signal quality, pathloss, etc. Received signal quality may be quantified by a signal-to-noise-and-interference ratio (SINR), or a RSRQ, or some other metric. The UE may operate in a dominant interference scenario in which the UE may observe high interference from one or more interfering BS.

[0062] The wireless communication network may support a 180 kHz deployment for narrowband operation (e.g., NB-IoT) with different deployment modes. In one example, narrowband operations may he deployed in-band, for example, using RBs within a wider system bandwidth. In one case, narrowband operations may use one RB within the wider system bandwidth of an existing network (e.g., such as an LTE network). In this case, the 180 kHz bandwidth for the RB may have to be aligned with a wideband RB. In one example, narrowband operations may be deployed in the unused RBs within a carrier guard-band (e.g., LTE). In this deployment, the 180 kHz RB within the guard band may he aligned with a 15 kHz tone grid of wideband LTE, for example, in order to use the same Fast Fourier Transform (FFT) and/or reduce interference in-band legacy LTE communications.

Example Narrowband Communications

[0063] The focus of traditional LTE design (e.g., for legacy “non MTC” devices) is on the improvement of spectral efficiency, ubiquitous coverage, and enhanced quality of service (QoS) support. Current LTE system downlink (DL) and uplink (UL) link budgets are designed for coverage of high end devices, such as state-of-the-art smartphones and tablets, which may support a relatively large DL and UL link budget.

[0064] However, as described above, one or more UEs in the wireless communication netw'ork (e.g., wireless communication network 100) may be devices that have limited communication resources, such as narrowband UEs, as compared to other (wideband) devices in the wireless communication network. For narrowband UEs, various requirements may be relaxed as only a limited amount of information may need to be exchanged. For example, maximum bandwidth may be reduced (relative to wideband UEs), a single receive radio frequency (RE) chain may be used, peak rate may be reduced (e.g., a maximum of 100 bits for a transport block size), transmit power may be reduced, Rank 1 transmission may be used, and half duplex operation may be performed.

[0065] In some cases, if half-duplex operation is performed, MTC UEs may have a relaxed switching time to transition from transmitting to receiving (or receiving to transmitting). For example, the switching time may be relaxed from 20μs for regular UEs to lms for MTC UEs. Release 12 MTC UEs may still monitor downlink (DL) control channels in the same way as regular UEs, for example, monitoring for wideband control channels in the first few symbols (e.g., PDCCH) as well as narrowband control channels occupying a relatively narrowband, but spanning a length of a subframe (e.g., enhanced **PDCCH** or **ePDCCH).**

[0066] Certain standards (e.g., LTE Release 13) may introduce support for various additional MTC enhancements, referred to herein as enhanced MTC (or eMTC). For example, eMTC may provide MTC UEs with coverage enhancements up to 15dB.

[0067] As illustrated in the subframe structure 500 of FIG. 5, eMTC UEs can support narrowband operation while operating in a wider system bandwidth (e.g., 1.4/3/5/10/15/20MHz). In the example illustrated in FIG. 5, a conventional legacy control region 510 may span system bandwidth of a first few symbols, while a narrowband region 530 of the system bandwidth (spanning a narrow portion of a data region 520) may be reserved for an MTC physical downlink control channel (referred to herein as an M-PDCCH) and for an MTC physical downlink shared channel (referred to herein as an M-PDSCH). In some cases, an MTC UE monitoring the narrowband region may operate at 1.4MHz or 6 resource blocks (RBs).

[0668] However, as noted above, eMTC UEs may be able to operate in a cell with a bandwidth larger than 6 RBs. Within this larger bandwidth, each eMTC UE may still operate (e.g., monitor/receive/transmit) while abiding by a 6-physical resource block (PRB) constraint. In some cases, different eMTC UEs may be served by different narrowband regions (e.g., with each spanning 6-PRB blocks). As the system bandwidth may span from 1.4 to 20 MHz, or from 6 to 100 RBs, multiple narrowband regions may exist within the larger bandwidth. An eMTC UE may also switch or hop between multiple narrowband regions in order to reduce interference.

Example Narrowband Intemet-of-Things

[0069] The Intemet-of-Things (loT) may refer to a network of physical objects, devices, or “things”. loT devices may be embedded with, for example, electronics, software, or sensors and may have network connectivity, which enable these devices to collect and exchange data. IoT devices may be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems and resulting in improved efficiency, accuracy, and economic benefit. Systems that include IoT devices augmented with sensors and actuators may be referred to cyber-physical systems. Cyber-physical systems may include technologies such as smart grids, smart homes, intelligent transportation, and/or smart cities. Each “thing” (e.g., loT device) may be uniquely identifiable through its embedded computing system may be able to interoperate within existing infrastructure, such as Internet infrastructure.

[0070] NB-IoT may refer to a narrowband (NB) radio technology specially designed for the loT. NB-IoT may focus on indoor coverage, low cost, long battery life, and large number of devices. To reduce the complexity of UEs, NB-IoT may allow for narrowband deployments utilizing one PRB (e.g., 180 kHz + 20 kHz guard band). NB-IoT deployments may utilize higher layer components of certain systems (e.g., LTE) and hardware to allow for reduced fragmentation and cross compatibility with, for example, NB-LTE/NB-loT and/or eMTC.

[0071] FIG. 6 illustrates an example deployment 600 of NB-ioT, according to certain aspects of the present disclosure. Three NB-ioT deployment configurations include in-band, guard-band, and standalone. For the in-band deployment configuration, NB-ioT may coexist with a legacy system (e.g., GSM, WCDMA, and/or LTE system(s)) deployed in the same frequency band. For example, the wideband LTE channel may be deployed in various bandwidths between 1.4 MHz to 20 MHz. As shown in FIG. 6, a dedicated RB 602 within that bandwidth may be available for use by NB-ioT and/or the RBs 1204 may be dynamically allocated for NB-ioT. As shown in FIG. 6, in an in-band deployment, one RB, or 200 kHz, of a wideband channel (e.g., LTE) may be used for NB-IoT.

[0072] Certain systems (e.g., LTE) may include unused portions of the radio spectrum between carriers to guard against interference between adjacent carriers. In some deployments, NB-IoT may be deployed in a guard band 606 of the wideband channel.

[0073] In other deployments, NB-IoT may be deployed standalone (not shown). In a standalone deployment, for example, one 200 MHz carrier may be utilized to carry NB-IoT traffic and GSM spectrum may be reused.

[0074] Deployments of NB-ioT may include synchronization signals such as PSS for frequency and timing synchronization and SSS to convey system information. For NB-ioT operations, PSS/SSS timing boundaries may be extended as compared to the existing PSS/SSS frame boundaries in legacy systems (e.g., LTE), for example, from 10 ms to 40 ms. Based on the timing boundary, a UE is able to receive a PBCH transmission, which may be transmitted in subframe 0 of a radio frame.

Example NR/5G RAN Architecture

[0075] New radio (NR) may refer to radios configured to operate according to a new air interface (e.g., other than Orthogonal Frequency Divisional Multiple Access (OFDMA)-based air interfaces) or fixed transport layer (e.g., other than Internet Protocol **(IP)).** NR may utilize OFDM with a CP on the uplink and downlink and include support for half-duplex operation using TDD. NR may include Enhanced Mobile Broadband (eMBB) service targeting wide bandwidth (e.g. 80 MHz beyond), millimeter wave (mmW) targeting high carrier frequency (e.g. 60 GHz), massive MTC (mMTC) targeting non-backward compatible MTC techniques, and/or mission critical targeting ultra reliable low latency communications (URLLC) service.

[0076] A single component carrier (CC) bandwidth of 100 MHZ may be supported. NR RBs may span 12 sub-carriers with a sub-carrier bandwidth of 75 kHz over a 0.1 ms duration. Each radio frame may consist of 50 subframes with a length of 10 ms. Consequently, each subframe may have a length of 0.2 ms. Each subframe may indicate a link direction (e.g., DL or UL) for data transmission and the link direction for each subframe may be dynamically switched. Each subframe may include DL/UL data as well as DL/UL control data. UL and DL subframes for NR may be as described in more detail below with respect to FIGs. 9 and 10.

[0077] Beamforming may be supported and beam direction may be dynamically configured. MIMO transmissions with precoding may also be supported. MIMO configurations in the DL may support up to 8 transmit antennas with multi-layer DL transmissions up to 8 streams and up to 2 streams per UE. Multi-layer transmissions with up to 2 streams per UE may be supported. Aggregation of multiple cells may be supported with up to 8 serving cells. Alternatively, NR may support a different air interface, other than an OFDM-based interface. NR networks may include entities such central units (CUs) or distributed units (DUs).

[0078] The NR RAN may include a CU and DUs. A NR BS (e.g., a NB, an eNB, a gNB, a 5G NB, a TRP, an AP, etc.) may correspond to one or multiple BSs. NR cells can be configured as access cells (ACells) or data only cells (DCe!ls). For example, the RAN (e.g., a CU or DU) can configure the cells. DCelfs may be cells used for carrier aggregation or dual connectivity, but not used for initial access, cell selection/reselection, or handover. In some cases DCells may not transmit synchronization signals—in some case cases DCells may transmit synchronization signals.

[0079] FIG. 7 illustrates an example logical architecture 700 of a distributed RAN, according to aspects of the present disclosure. 5G access node 706 may include access node controller (ANC) 702. ANC 702 may be a CU of the distributed RAN. The backhaul interface to the next generation core network (NG-CN) 704 may terminate at ANC 702. The backhaul interface to neighboring next generation access nodes (NG-ANs) 710 may terminate at ANC 702. ANC 702 may include one or more TRPs 708. As described above, TRP may be used interchangeably with "cell", BS, NR BS, NB, eNB, 5G NB, gNB, AP, etc.

[0080] TRPs 708 may comprise a DU. TRPs 708 may be connected to one ANC (e.g., ANC 702) or more than one ANC (not illustrated). For example, for RAN sharing, radio as a service (RaaS), and service specific AND deployments, TRP 708 may be connected to more than one ANC. TRP 708 may include one or more antenna ports. TRPs 708 may be configured to individually (e.g., dynamic selection) or jointly (e.g., joint transmission) serve traffic to a UE.

[0081] Logical architecture 700 may be used to illustrate fronthaul definition. The architecture may be defined that support fronthauling solutions across different deployment types. For example, logical architecture 700 may be based on transmit network capabilities **(e.g.,** bandwidth, latency, and/or jitter). Logical architecture 700 may share features and/or components with LTE. According to aspects, NG-AN 710 may support dual connectivity with NR. NG-AN 710 may share a common fronthaul for LTE and NR. Logical architecture 700 may enable cooperation between and among TRPs 708. For example, cooperation may be preset within a TRP and/or across TRPs via ANC 702. in some cases, no inter-TRP interface may be needed/present.

[0082] A dynamic configuration of split logical functions may be present within logical architecture 700. The packet data convergence protocol (PDCP), radio link control (RLC), and medium access control (MAC) protocols may be adaptably placed at ANC 702 or TRP 708.

[0083] FIG. 8 illustrates an example physical architecture 800 of a distributed RAN, according to aspects of the present disclosure. Centralized core network unit (C-CU) 802 may host core network functions. C-CU 802 may be centrally deployed. C-CU 802 functionality may he offloaded (e.g., to advanced wireless services (AWS)), in an effort to handle peak capacity.

[0084] Centralized RAN unit (C-RU) 804 may host one or more ANC functions. Optionally, C-RU 804 may host core network functions locally. C-RU 804 may have distributed deployment. C-RU 804 may be closer to the network edge.

[0085] DU 806 may host one or more TRPs. DU 806 may he located at edges of the network with radio frequency (RF) functionality.

[0086] FIG. 9 is a diagram showdng an example of a DL-centric subframe 900. DL-centric subframe 900 may include control portion 902. Control portion 902 may exist in the initial or beginning portion of DL-centric subframe 900. Control portion 902 may include various scheduling information and/or control information corresponding to various portions of DL-centric subframe 900. In some configurations, control portion 902 may be a physical DL control channel (PDCCH), as shown in FIG. 9. DL-centric subframe 900 may also include DL data portion 904. DL data portion 904 may sometimes be referred to as the payload of DL-centric subframe 900. DL data portion 904 may include the communication resources utilized to communicate DL data from the scheduling entity (e.g., UE or BS) to the subordinate entity (e.g., UE). In some configurations, DL data portion 904 may be a physical DL shared channel (PDSCH).

[0087] DL-centric subframe 900 may also include common UL portion 906. Common UL portion 906 may sometimes be referred to as an UL burst, a common UL burst, and/or various other suitable terms. Common UL portion 906 may include feedback information corresponding to various other portions of DL-centric subframe 900. For example, common UL portion 906 may include feedback information corresponding to control portion 902. Non-limiting examples of feedback information may include an acknowledgment (ACK) signal, a negative acknowledgment (NACK) signal, a HARQ indicator, and/or various other suitable types of information. Common UL portion 906 may include additional or alternative information, such as information pertaining to random access channel (RAC.H) procedures, scheduling requests (SRs), and various other suitable types of information. As illustrated in FIG. 9, the end of DL data portion 904 may be separated in time from the beginning of common UL portion 906. This time separation may sometimes be referred to as a gap, a guard period, a guard interval, and/or various other suitable terms. This separation provides time for the switch-over from DL communication (e.g., reception operation by the subordinate entity) to UL communication (e.g., transmission by the subordinate entity). One of ordinary skill in the art will understand that the foregoing is merely one example of a DL-centric subframe and alternative structures having similar features may exist without necessarily deviating from the aspects described herein.

[0088] FIG. 10 is a diagram showing an example of an UL-centric subframe 1000. UL-centric subframe 1000 may include control portion 1002. Control portion 1002 may exist in the initial or beginning portion of UL-centric subframe 1000. Control portion 1002 in FIG. 10 may be similar to control portion 1002 described above with reference to FIG. 9. UL-centric subframe 1000 may also include UL data portion 1004. UL data portion 1004 may sometimes be referred to as the payload of UL-centric subframe 1000. The UL portion may refer to the communication resources utilized to communicate UL data from the subordinate entity (e.g., UE) to the scheduling entity (e.g., UE or BS). In some configurations, control portion 1002 may be a PDCCH. In some configurations, the data portion may be a physical uplink shared channel (PUSCH).

[0089] As illustrated in FIG. 10, the end of control portion 1002 may be separated in time from the beginning of UL data portion 1004. This time separation may sometimes be referred to as a gap, guard period, guard interval, and/or various other suitable terms. This separation provides time for the switch-over from DL communication (e.g., reception operation by the scheduling entity) to UL communication (e.g., transmission by the scheduling entity). UL-centric subframe 1000 may also include common UL portion 1006. Common UL portion 1006 in FIG. 10 may be similar to common UL portion 906 described above with reference to FIG. 9. Common UL portion 1006 may additionally or alternatively include information pertaining to CQI, sounding reference signals (SRSs), and various other suitable types of information. One of ordinary skill in the art will understand that the foregoing is merely one example of an UL-centric subframe and alternative structures having similar features may exist without necessarily deviating from the aspects described herein.

[0090] In some circumstances, two or more subordinate entities (e.g., UEs) may communicate with each other using sidelink signals. Real-world applications of such sidelink communications may include public safety, proximity services, UE-to-network relaying, vehicle-to-vehicle (V2V) communications, Internet of Everything (loE) communications, IoT communications, mission-critical mesh, and/or various other suitable applications. Generally, a sidelink signal may refer to a signal communicated from one subordinate entity (e.g., UE1) to another subordinate entity (e.g., UE2) without relaying that communication through the scheduling entity (e.g., UE or BS), even though the scheduling entity may be utilized for scheduling and/or control purposes. In some examples, the sidelink signals may be communicated using a licensed spectrum (unlike wireless local area networks, which typically use an unlicensed spectrum).

[0091] A UE may operate in various radio resource configurations, including a configuration associated with transmitting pilots using a dedicated set of resources (e.g., a radio resource control (RRC) dedicated state, etc.) or a configuration associated with transmitting pilots using a common set of resources (e.g., an RRC common state, etc.). When operating in the RRC dedicated state, the UE may select a dedicated set of resources for transmitting a pilot signal to a network. When operating in the RRC common state, the UE may select a common set of resources for transmitting a pilot signal to the network. In either case, a pilot signal transmitted by the UE may be received by one or more network access devices, such as an AN, a DU, or portions thereof. Each receiving network access device may be configured to receive and measure pilot signals transmitted on the common set of resources, and also receive and measure pilot signals transmitted on dedicated sets of resources allocated to the UEs for which the network access device is a member of a monitoring set of network access devices for the UE. One or more of the receiving network access devices, or a CU to which receiving network access deviee(s) transmit the measurements of the pilot signals, may use the measurements to identify serving cells for the UEs, or to initiate a change of serving cell for one or more of the UEs.

[00512] As mentioned, certain systems (e.g., Release 13 or later eMTC systems), may support narrowband operation. For example, the narrowband operation may include support for communications on a 6 RB band and half-duplex operation (e.g., capability to transmit and receive, but not both simultaneously) for up to, e.g., 15 dB coverage enhancements. These systems may reserve a portion of the system bandwidth for control, which may be an MTC physical downlink control channel (MPDCCH). The MPDCCH may be transmitted in a narrowband, may use at least one subframe, and may rely on demodulation reference signal (DMRS) demodulation for decoding of the control channel. Coverage may be increased by performing repetition/bundling of signals.

[0093] Certain systems (e.g., Release 13 or later NB-IoT systems) may support narrowband Intemet-of-things operation (NB-IOT). NB-IoT may use 180 kHz bandwidth. NB-IoT may offer standalone, in-band, or guard band deployment scenarios. Standalone deployment may use new' bandwidth, whereas guard band deployment may be done using bandwidth typically reserved in the guard band of an existing network, such as long term evolution (LTE). In-band deployment on the other hand may use the same resource blocks in the LTE carrier of the existing LTE network. NB-IoT may offer increased coverage. NB-IoT may define a new narrowband control channel (e.g., Narrowband PDCCH (NPDCCH)), data, and references signals that fit in 1 RB.

EXAMPLE CE LEVEL RESELECTION

[0094] CE operation may be categorized into four CE levels (e.g., levels 0, 1, 2, 3) according to standard. CE levels 0 and 1 may correspond to CE Mode A, and CE levels 2 and 3 may correspond to CE Mode B. CE Mode A is designed for moderate coverage conditions, and CE Mode B is designed for more extreme coverage conditions and may be applicable for CINR < -6 dB to -18 dB. For example, according to TS 36.213 version 13.7.0, if the most recent PRACH CE level for a UE is 0 or 1, contents of the random access response grant are interpreted according to CE Mode A, and if the most recent PRACH CE level for a UE is 2 or 3, contents of the random access response grant are interpreted according to CE Mode B. For example, CE levels may be related to PRACH resources (e.g., which ones to select), repetition/hopping parameters, etc. As CE) levels increase, for example, amount of repetitions (e.g., of DL/UL transmissions), amount of transmission attempts, or transmission power, etc., may increase to provide enhanced coverage. CE levels may be chosen during, e.g., initial access or handover (HO).

[00515] For example, during initial access, CE thresholds may be provided/configured by serving base station, e.g., in SIB-2 in radioResourceConfigCommon (e.g., *rsrp-ThresholdsPrachlnfoList* information element). During HO, CE thresholds may be provided in mobility related information such as mobilityControllnfo element.

[0096] During initial access, depending on the threshold and measured DL channel condition (e.g., RSRP), UE may choose its CE level. The CE levels supported by a network may be indicated in an element of SIB-2 common configuration/dedicated configuration (e.g., HO), such as in rach-CE-LevelInfoList-rl3. CE levels supported by UE are indicated to network via messages/information elements, e.g., via RRC UECapabilitylnformation response. For example, if DL channel condition (e.g., RSRP, etc.) threshold for CE level 3 is configured and if measured DL channel conditions (e.g., of the serving base station) are worse than that threshold, UE may consider itself to be in CE level 3, if it supports CE level 3. Otherwise, if DL channel condition threshold for CE level 2 is configured and if measured DL channel conditions are worse than that threshold, UE may consider itself to be in CE level 2, if it supports CE level 2. Otherwise, if DL channel condition threshold for CE level 1 is configured and if measured DL channel conditions are worse than that threshold, UE may consider itself to be in CE level 1, if it supports CE level 1. Otherwise, UE may consider itself to be in CE level 0.

[0097] During HO (e.g., connected mode mobility) of UEs (e.g., eMTC, other low cost (LC)/bandwidth limited (BL) devices, or other devices in coverage enhancement) to a target cell, the CE level may be determined or selected in two ways. First, the UE may determine the CE level as during initial access, e.g., with the help of DL channel condition threshold information provided in, e.g., SIB-2. Second, the network may determine the CE level and provide start or initial CE Level in, e.g., SIB-2 or mobility control related information element, such as MobilityControllnfo of *RRCConnectionReconfiguration* message, via, for example, initial-CE-ievel-rlS parameter. When a parameter indicating initial CE level has been provided (e.g., as aforementioned or indicated by a PDCCH order, e.g., which initiated a random access procedure), the UE considers itself to be in the indicated CE level, regardless of any downlink channel conditions it measures.

[0098] Aspects of this disclosure provide an efficient algorithm for an UE (e.g., a UE in extended coverage to dynamically reselect its CE level (e.g., change from one CE level to another CE level). UEs in extended coverage, for example, include UEs that are in coverage enhancement modes A or B. Currently, for an extended coverage UE, CE level reselection is supported during RACH initiation. CE level is selected at RACH initialization based on, e.g., RSRP condition and threshold configured by the network, as mentioned. Once CE level is selected UE may remain in same CE level until the maximum RACH retry attempts are achieved before moving to next higher CE level. With each attempt, a RACH attempt counter (e.g., preamble transmission counter) may be incremented, and the associated transmit power may be increased. Upon reaching its maximum CE level, UE will remain in that CE level until the maximum RACH attempts are achieved before declaring RACH failure to higher layers (e.g., RRC).

[0099] Channel condition may be highly dynamic in nature, and currently, with each RACH try extending up to 0.5 seconds or more (e.g., 2 to 3 seconds) based on the repetitions configured by network and a UE remaining in same CE level until maximum RACH attempts, the UE may take longer time to move to the right CE level for communication. This procedure may cause delay and consume additional CPU utilization to pick the CE level, for example, when the channel condition/signal quality (e.g., RSRP, RSRQ, etc.) changes between RACH attempts. Aspects of this disclosure provide techniques to reduce the number of RACHs triggered, as well as time and power utilization by UE, which enhance efficiency and improve battery life.

[00100] In an aspect of the disclosure, UE physical layer evaluates and shares radio channel condition to MAC (media access control) layer upon every RACH attempt problem or failure (e.g., upon determination that failure to receive a random access response (RAR) from a BS occurred). For example, determining that failure to receive a RAR from the BS occurred may be based on at least one of: no reception of random access response (RAR) from the BS, no reception of physical downlink control channel (PDCCH) scheduling RAR within a RAR window, or no reception a RAR containing a random access preamble identifier corresponding to the transmitted random access preamble.

[00101] For example, UE (e.g, MAC layer) may consider reselecting CE level between every RACH attempt based on signal quality (e.g., RSRP, RSRQ) evaluation done at physical layer for every' RACH attempt problem or failure. UE (e.g,, MAC layer) may apply a new CE level (e.g., the next higher CE level, the CE level that is two levels higher, the next lower CE level, the CE level that is two levels lower, etc., depending on

application) and continue RACH attempt procedure and still may continue with the maximum RACH attempt counter for the new CE level.

[00102] FIG. 11 is a flow diagram illustrating example operations 1100, according to aspects described herein. Operations 1100 may be performed, for example, by a UE (e.g., UE 120) which may be a low cost, NB, IoT device, or other device that's in coverage enhancement. For example, the UE may be an eMTC UE, a NB-IoT UE, or another type of UE in coverage enhancement. Operations 1100 may begin, at 1102, by attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS). In an aspect, attempting the RACH procedure may include selecting a random access preamble based, at least on part, on the first CE level and transmitting the random access preamble at a first power.

[00103] At 1104, the UE determines a failure to receive random access response (RAR) from the BS occurred. As mentioned, determining a failure to receive a RAR from the BS occurred may be based on at least one of: determining that the RAR from the BS is not received, determining that a physical downlink control channel (PDCCH) transmission scheduling RAR within a RAR window is not received, or determining that a RAR containing a random access preamble identifier corresponding to the transmitted random access preamble is not received.

[00104] At 1106, the UE measures signal quality of the BS observed at the UE in response to the determined RAR reception failure. In an aspect, the signal quality may be reference signal received power (RSRP), reference signal received quality (RSRQ), etc.

[00105] At 1108, the UE determines whether to adjust the first CPI level to a second CE level based at least in part on the measured signal quality. In an aspect, determining whether to adjust the first CE level may include at least one of: determining not to adjust the first CE level, if the first CE level is a maximum CE level, or comparing the measured signal quality with a signal quality threshold corresponding to the first CE level, determining to adjust the first CE level to the second CE level if the measured signal quality is lower than the signal quality threshold for the first CE level, and determining to not adjust the first CPI level if the measured signal quality is higher than or equal to the signal quality threshold for the first CE level. The second CE level may be higher than

the first CE level (e.g., the second CE level may be 2, and first CE level may be 1; the second CE level may be 3, and the first CE level may be 2, etc.). In some instances, e.g., when the measured signal quality is lower than the signal quality threshold for the first CE level by a certain margin (e.g., the margin may be pre-determined or dynamically determined), the UE may skip one or more of the next CE levels and go directly to a CE level that may be more suited for the current channel conditions (e.g., the second CE level may be 3, and the first CE level may be 1). In an aspect, the signal quality threshold for the first CE level is based on rsrp-ThresholdsPrachInfoList-rl3 information element of system information block type-2 (SIB-2).

[00106] At 1110, the UE starts a next RACH procedure attempt, at the first CE level or the second CE level, with the BS. As mentioned in the examples above, the UE may determine to remain at the first CE level or may determine to adjust the first CE level to the second CE level, and it may start the next RACH procedure attempt, at the first CE level or the second CE level.

EXAMPLE TRANSMIT POWER DETERMINATION

[00107] Currently, even if a RSRP measurement by a UE falls just within a range for a CE level x but close to the threshold for a higher CE level y, UE starts the RACH attempt at the initial RACH attempt counter value for CE level x and perform RACH attempts till maximum number of attempts for CE level x is reached in search of a successful RACH. Since transmit power is determined based on RACH attempt counter value at each CE level, the issue of delay and additional power utilization by UE is present in this example scenario as well.

[00108] In an aspect of the disclosure, based on the configured signal quality (e.g., RSRP, RSRQ, etc.) threshold and RACH attempt counter, UE may distribute RACH attempts based on threshold and counter across a CE level and pick an optimized RACH attempt counter value for the CE level and start RACH at that counter value instead of starting the RACH from the initial RACH counter value. For example, CE level 1 may have RSRP threshold 40 and RACH attempt counter 10, CE level 2 may have RSRP threshold 30 and RACH attempt counter 10, CE level 3 may have RSRP threshold 20 and RACH attempt counter 10. For example, if determined serving BS RSRP as observed at the UE (e.g., measured by physical layer) falls just inside of the edge of CE level 2 that

is next to CE level 3, here 21, then UE may determine to start RACK attempt within CE level 2 with RACK counter as 9, with the transmit power corresponding to RACK counter value at 9. This techniques leads to more efficient transmit power selection, as less RACH attempts are needed for a successful RACH procedure.

[00109] FIG. 12 is a flow diagram illustrating example operations 1200, according to aspects described herein. Operations 1200 may be performed, for example, by a UE (e.g., UE 120) which may be a low cost, NB, IoT device, or other device that's in coverage enhancement. For example, the UE may be an eMTC UE, a NB-IoT UE, or another type of UE in coverage enhancement. Operations 1200 may be performed by the UE preparing for a RACH procedure with a base station (BS). In an aspect, attempting the RACH procedure may include selecting a random access preamble and transmitting the random access preamble at a first power.

[00110] Operations 1200 may begin, at 1202, by measuring signal quality of the BS observed at the UE. In an aspect, the signal quality may be reference signal received power (RSRP), reference signal received quality (RSRQ), etc.

[00111] At 1204, the UE determines a coverage enhancement (CE) level and a counter value (e.g., a RACH attempt counter value, such as preamble transmission counter value) based at least in part of the measured signal quality.

[00112] In an aspect, as operations 1300 of FIG. 13 illustrates, determining the CE level includes comparing the measured signal quality with at least one signal quality threshold corresponding to a CE level of a set of CE levels (e.g., starting with a signal quality threshold corresponding to a maximum CE level of the set of CE levels and moving to a next CE level of the set of CE levels in decreasing order) (1302). In response to a comparison result that the measured signal quality is higher than or equal to the signal quality threshold being compared with, the UE may determine whether there is a next CE level (e.g., next higher CE level) (1304). If Yes, the UE compares the measured signal quality with a signal quality threshold corresponding to the next CE level and repeat until a comparison result indicating that the measured signal quality is lower than the signal quality threshold being compared with, or until the UE determines that an end of the set of the CE levels has been reached (there is no next CE level). In response to a comparison result that the measured signal quality is lower than the signal quality threshold being

compared with or the determination that the end of the set of the CE levels is reached, the UE may determine the CE level to be the CE level corresponding to the signal quality threshold being compared with (1306). In an aspect, the at least one signal quality threshold is based on rsrp-ThresholdsPrachInfoList-rl3 information element of system information block type-2 (SIB-2).

[00113] In an aspect, determining the counter value may include determining a difference between the measured signal quality and a signal quality threshold corresponding to the determined CE level, and adaptively determining the counter value based on the difference. Adaptively determining the counter value based on the difference may include increasing the counter value towards its maximum value when the difference gets smaller and decreasing counter value away from its maximum value when the difference gets bigger.

[00114] At 1206, the UE attempts the RACK procedure based at least in part on the determined CE level and counter value. For example, the UE may attempt the RACK procedure at a CE level that is set to the determined CE level and at a counter value that is set to the determined counter value.

[00115] In an aspect, various techniques illustrated by FIGs. 11 and 12 may be combined depending on application. As one example, in addition to determining whether to reselect CE level between every' RACK attempt, the UE may also determine whether to adjust the RACK attempt counter value more than the normal amount between every RACK attempt.

[00116] Since an extended coverage UE may need to perform RACK to send initial data or new data, the provided techniques may help UE avoid additional RACH procedure until the maximum RACH attempts is reached every' time before it can RACH attempt in higher CE level, in its search for the right CE level. They reduce delay in the RACH procedure, which in turn reduces latency, and as mentioned, they also increase power efficiency, which is an important consideration for UEs, especially loT UEs expected to operate for years on battery power without charging, and UEs in coverage enhancement areas (e.g., basements, remote regions, etc.), leading to enhanced performance and maximizing coverage of the UEs.

[00117] As used herein, the term “identifying” encompasses a wide variety of actions. For example, “identifying” may include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, “identifying” may include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, “identifying” may include resolving, selecting, choosing, establishing and the like.

[00118] Moreover, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or.” That is, unless specified otherwise, or clear from the context, the phrase, for example, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, for example the phrase “X employs A or B” is satisfied by any of the following instances: X employs A; X employs B; or X employs both A and B. As used herein, reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” For example, the articles “a” and “an” as used in this application and the appended claims should generally be constated to mean “one or more” unless specified otherwise or clear from the context to be directed to a singular form. Unless specifically stated otherwise, the term “some” refers to one or more. A phrase referring to “at least one of' a list of items refers to any combination of those items, including single members. As an example, “at least one of: *a*, *b*, or c” is intended to cover: *a*, *b*, *c*, *a-b*, *a-c*, *b-c*, *and a-b-c*, as well as any combination with multiples of the same element (e.g., a-a, a-a-a, a-a-b, a-a-c, a-b-b, a-c-c, b-b, b-b-b, b-b-c, c-c, and c-c-c or any other ordering of a, b, and c). As used herein, including in the claims, the term “and/or,” when used in a list of two or more items, means that any one of the listed items can be employed by itself, or any combination of two or more of the listed items can be employed. For example, if a composition is described as containing components A, B, and/or C, the composition can contain A alone; B alone; C alone; A and B in combination; A and C in combination; B and C in combination; or A, B, and C in combination.

[00119] In some cases, rather than actually communicating a frame, a device may have an interface to communicate a frame for transmission or reception. For example, a processor may output a frame, via a bus interface, to an RF front end for transmission. Similarly, rather than actually receiving a frame, a device may have an interface to obtain a frame received from another device. For example, a processor may obtain (or receive)

a frame, via a bus interface, from an RF front end for transmission.

[00120] The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

[00121] The various operations of methods described above may be performed by any suitable means capable of performing the corresponding functions. The means may include various hardware and/or software component(s) and/or module(s), including, but not limited to a circuit, an application specific integrated circuit (ASIC), or processor. Generally, where there are operations illustrated in Figures, those operations may be performed by any suitable corresponding counterpart means-plus-function components.

[00122] For example, means for determining, means for attempting, means for measuring, means for starting, means for selecting, means for transmitting, means for receiving, means for sending, means for comparing, means for repeating, means for increasing, and/or means for decreasing may include one or more processors/controllers, transmitters, receivers, antennas, and/or other elements of the user equipment 120 and/or the base station 110 illustrated in FIG. 2.

[00123] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or combinations thereof.

[00124] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the disclosure herein may be implemented as hardware, software, or combinations thereof. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or

software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[00125] The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. One or more aforementioned devices or processors may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[00126] The steps of a method or algorithm described in connection with the disclosure herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination thereof. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory', EEPROM memory, phase change memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[00127] In one or more exemplary designs, the functions described may be implemented in hardware, software, or combinations thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD/DVD or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy-disk and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[00128] The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WHAT IS CLAIMED IS:

CLAIMS

// Method 1: CE level reselection

1. A method of wireless communications by a user equipment (UE), comprising:

attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS);

determining a failure to receive a random access response (RAR) from the BS occurred;

measuring signal quality of the BS observed at the UE in response to the determined RAR reception failure;

determining whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality; and

starting a next RACH procedure attempt, at the first CE level or the second CE level, with the BS.

2. The method of claim 1, wherein attempting the RACH procedure comprises selecting a random access preamble based at least on part on the first CE level and transmitting the random access preamble at a first power.

3. The method of claim 1, wherein determining the failure to receive a RAR from the BS occurred is based on at least one of:

determining that the RAR from the BS is not received,

determining that a physical downlink control channel (PDCCH) transmission scheduling RAR within a RAR window' is not received, or

determining that a RAR containing a random access preamble identifier corresponding to the transmitted random access preamble is not received.

4. The method of claim 1, wherein determining whether to adjust the first CE level comprises at least one of:

determining not to adjust the first CE level, if the first CE level is a maximum CE level; or

comparing the measured signal quality with a signal quality threshold for the first CE level, determining to adjust the first CE level to the second CE level if the measured signal quality is lower than the signal quality threshold for the first CE level, and determining to not adjust the first CE level if the measured signal quality is higher than or equal to the signal quality threshold for the first CE level.

5. The method of claim 4, wherein the second CE level is higher than the first CE level.

6. The method of claim 4, wherein the signal quality comprises reference signal received power (RSRP).

7. The method of claim 4, wherein the signal quality threshold for the first CE level is based on rsrp-ThresholdsPrachInfoList-rl3 information element of system information block type-2 (SIB-2).

8. The method of claim 1, wherein the HE is at least one of: an enhanced machine type communication (eMTC) UE, a narrowband internet of things (NB-IoT) UE, or another type of UE in coverage enhancement.

i! Method 2: RACH Tx power (adaptively select CE RACH attempt counter based on RSRP)

9. A method of wireless communications by a user equipment (UE) preparing for a random access channel (RACH) procedure with abase station (BS), comprising:

measuring signal quality of the BS observed at the UE;

determining a coverage enhancement (CE) level and a RACH attempt counter value based at least in part on the measured signal quality; and

attempting the RACH procedure based at least in part on the determined CE level and RACH attempt counter value.

10. The method of claim 9, wherein attempting the RACH procedure comprises selecting a random access preamble and transmitting the random access preamble at a first power.

// claim 11 is about determining CE level based on signal quality (e.g., RSRP). For example, if DL channel condition (e.g., RSRP, etc.) threshold for CE level 3 is configured and if measured DL channel conditions (e.g., of the base station) are worse than that threshold, UE may consider itself to be in CE level 3. Otherwise, if DL channel condition threshold for CE level 2 is configured and if measured DL channel conditions are worse than that threshold, UE may consider itself to be in CE level 2. Otherwise, if DL channel condition threshold for CE level 1 is configured and if measured DL channel conditions are worse than that threshold, UE may consider itself to be in CE level 1. Otherwise, UE may consider itself to be in CE level 0 //

11. The method of claim 9, wherein determining the CE level comprises:

comparing the measured signal quality with at least one signal quality threshold corresponding to a CE level of a set of CE levels, starting with a signal quality threshold corresponding to a maximum CE level of the set of CE levels and moving to a next CE level of the set of CE levels in decreasing order;

in response to a comparison result that the measured signal quality is higher than or equal to the signal quality threshold being compared with, comparing the measured signal quality with a signal quality threshold corresponding to the next CE level and repeating until a comparison result that the measured signal quality is lower than the signal quality threshold being compared with or until determining that an end of the set of the CE levels is reached; and

in response to the comparison result that the measured signal quality is lower than the signal quality threshold being compared with or the determination that the end of the set of the CE levels is reached, determining the CE level to be the CE level corresponding to the signal quality threshold being compared with.

12. The method of claim 11, wherein determining the RACH attempt counter value comprises:

determining a difference between the measured signal quality and a signal quality threshold corresponding to the determined CE level; and

adaptively determining the RACH attempt counter value based on the difference.

13. The method of claim 12, wherein adaptively determining the RACH attempt counter value based on the difference comprises:

increasing the counter value towards its maximum value when the difference gets smaller and decreasing the counter value away from its maximum value when the difference gets bigger.

14. The method of claim 9, wherein the signal quality comprises reference signal received power (RSRP).

15. The method of claim 11, wherein the at least one signal quality threshold is based on rsrp-ThresholdsPrachInfoList-rl3 information element of system information block type-2 (SIB-2).

16. The method of claim 9, wherein the RACH attempt counter value comprises a preamble transmission counter value.

17. The method of claim 9, wherein the UE is at least one of: an enhanced machine type communication (eMTC) UE, a narrowband internet of things (NB-IoT) UE, or another type of UE in coverage enhancement.

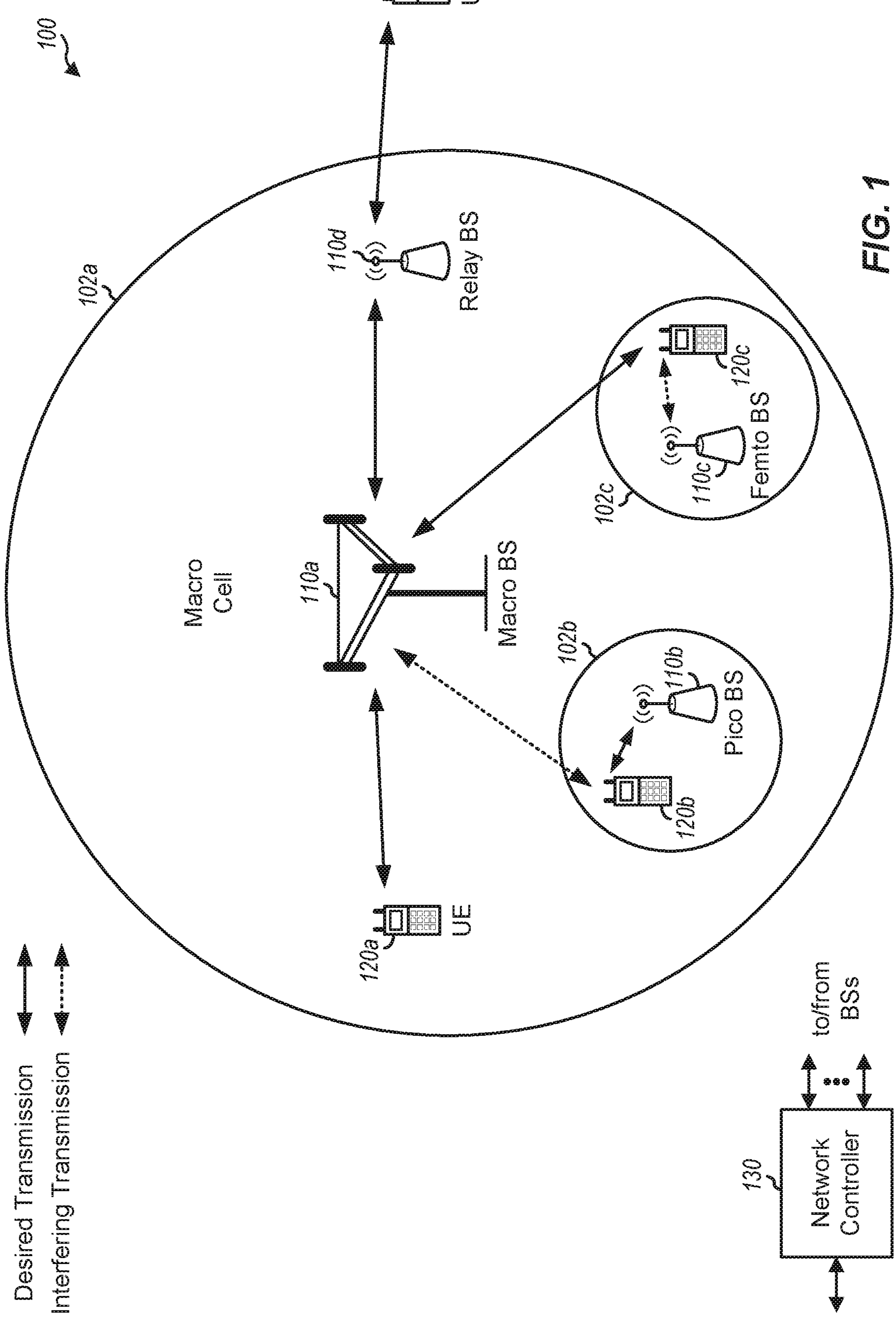

100
Desired Transmission
Interfering Transmission
102a
Macro Cell
110a
Macro BS
110d
Relay BS
120d
UE
120a
UE
102b
110b
Pico BS
120b
102c
110c
Femto BS
120c
130
Network Controller
to/from BSs

FIG. 1

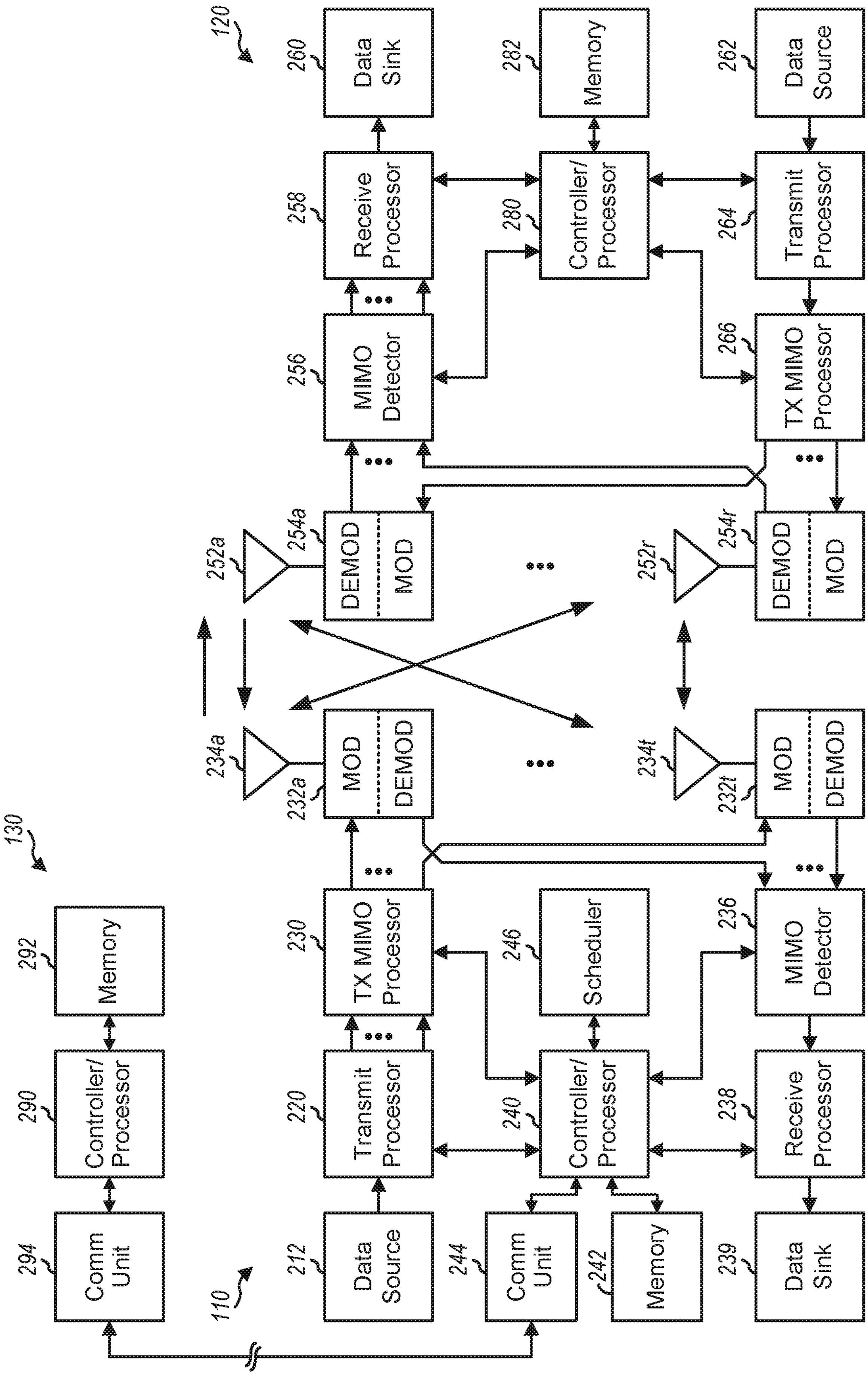

120
260
Data Sink
282
Memory
262
Data Source
258
Receive Processor
280
Controller/ Processor
264
Transmit Processor
256
MIMO Detector
266
TX MIMO Processor
252a
254a
DEMOD
MOD
252r
254r
DEMOD
MOD
234a
232a
MOD
DEMOD
234t
232t
MOD
DEMOD
130
292
Memory
290
Controller/ Processor
294
Comm Unit
230
TX MIMO Processor
246
Scheduler
236
MIMO Detector
220
Transmit Processor
240
Controller/ Processor
238
Receive Processor
110
212
Data Source
244
Comm Unit
242
Memory
239
Data Sink

FIG. 2

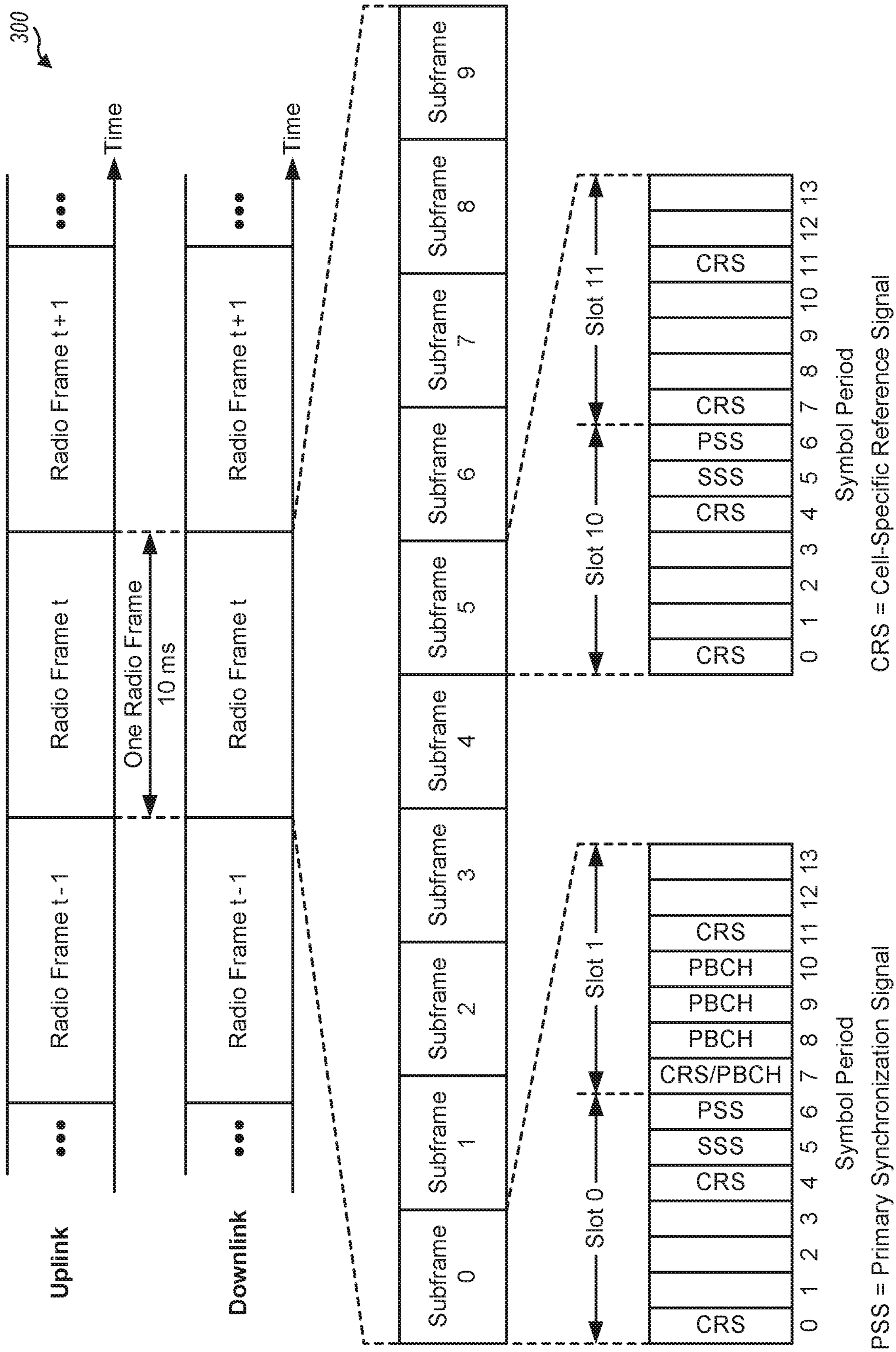
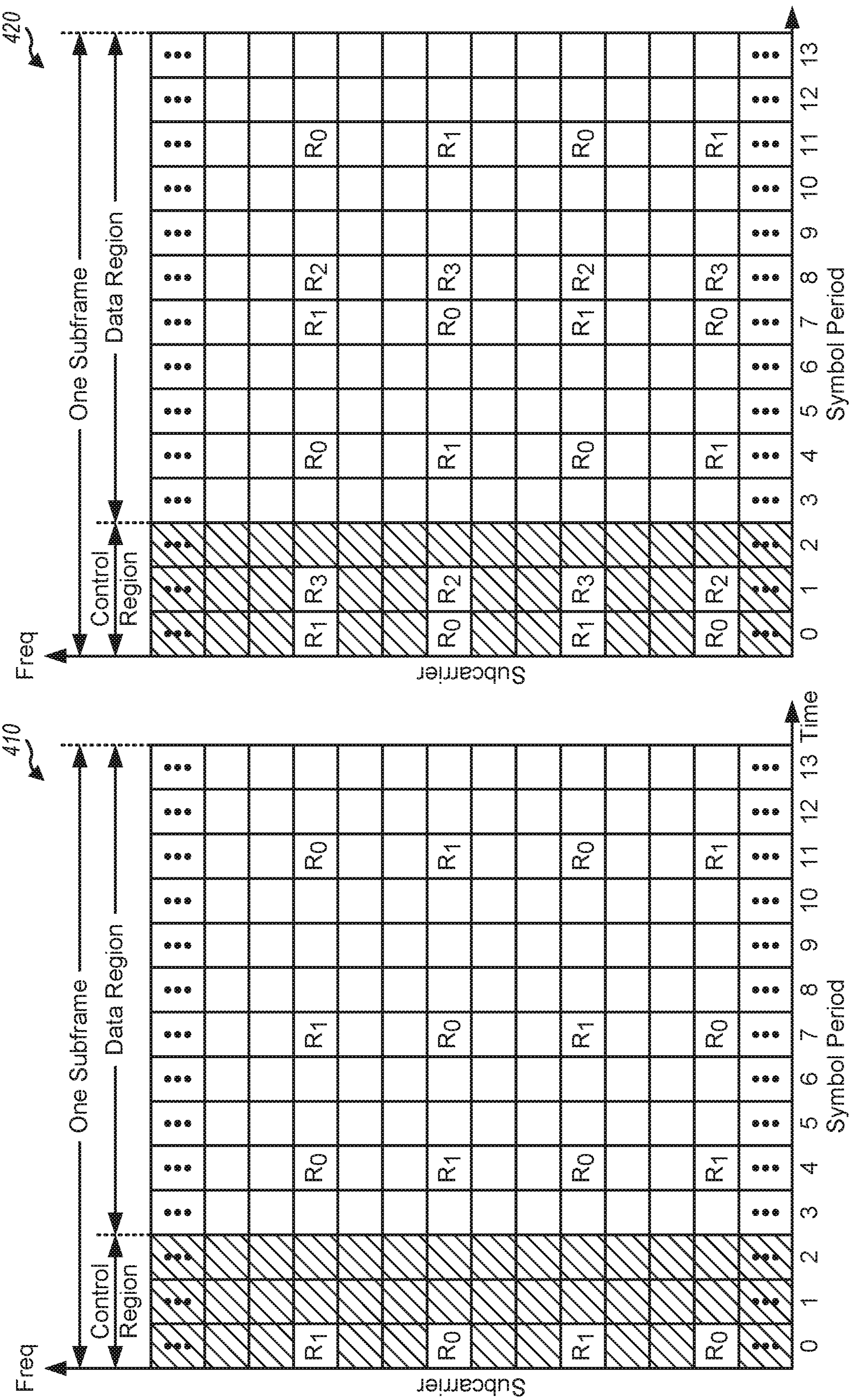


FIG. 3

PSS = Primary Synchronization Signal
SSS = Secondary Synchronization Signal

CRS = Cell-Specific Reference Signal
PBCH = Physical Broadcast Channel



R_a Reference symbol for antenna a

FIG. 4

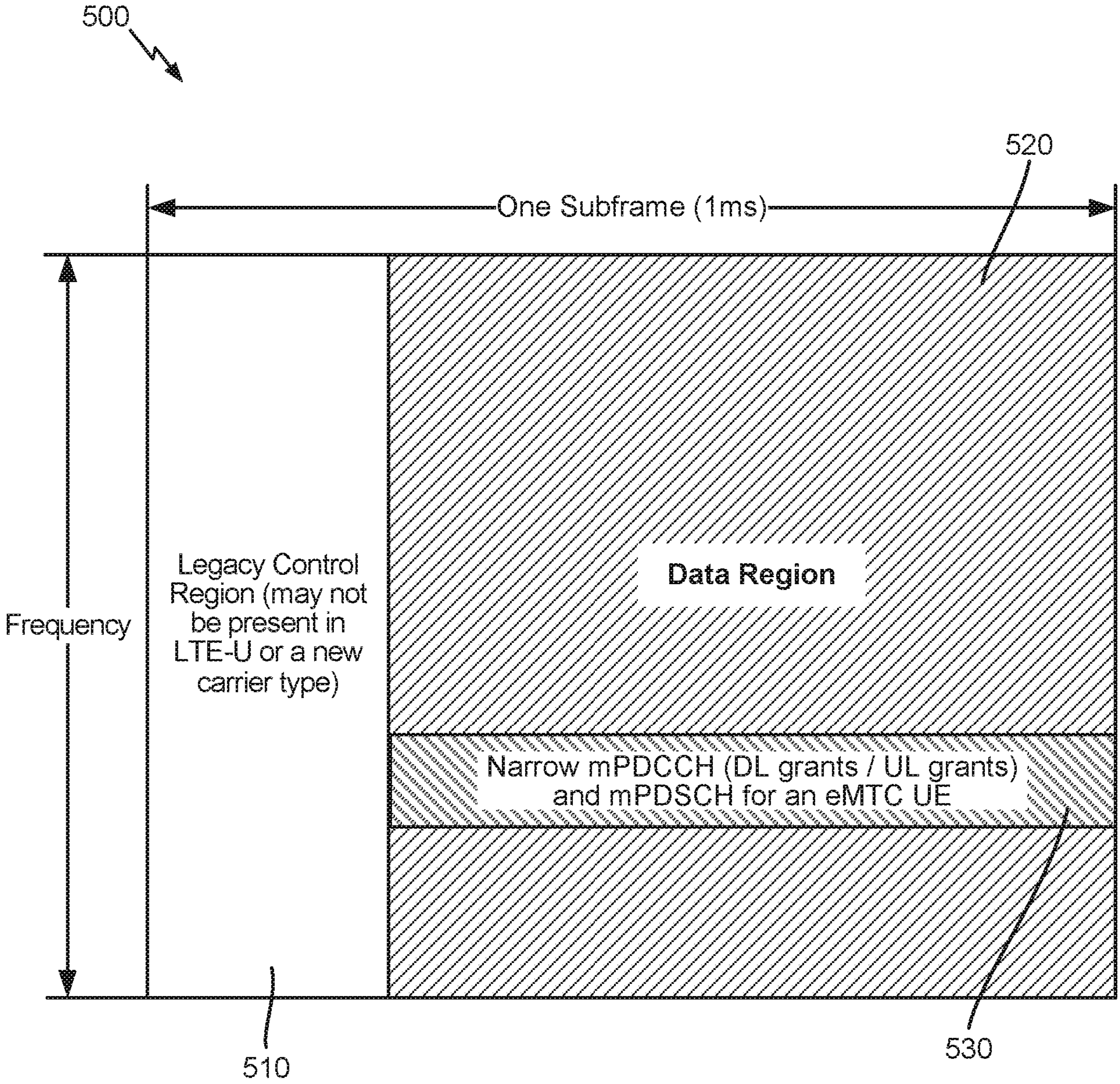

500
520
One Subframe (1ms)
Frequency
Legacy Control Region (may not be present in LTE-U or a new carrier type)
Data Region
Narrow mPDCCH (DL grants / UL grants) and mPDSCH for an eMTC UE
510
530

FIG. 5

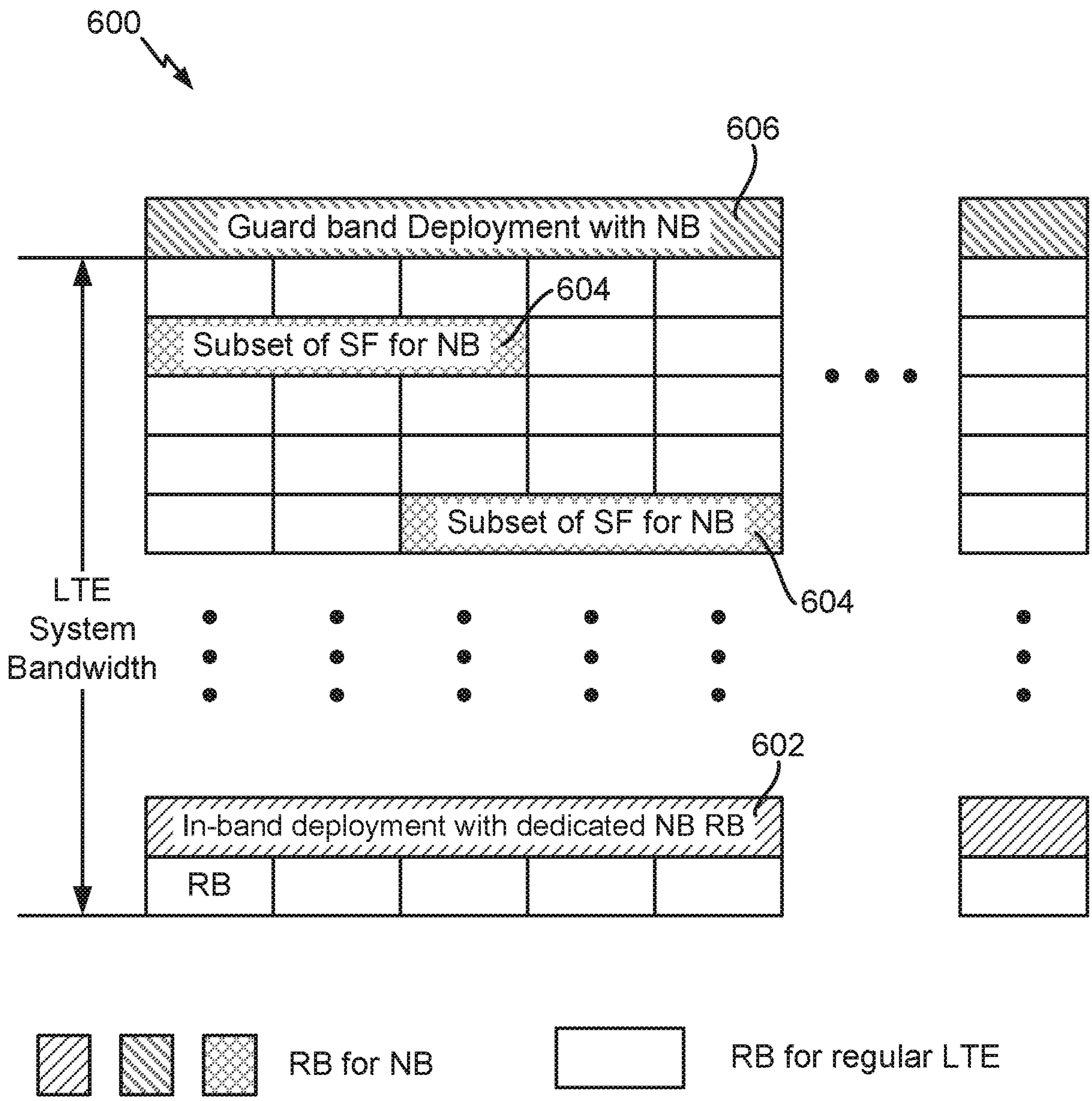

600
606
Guard band Deployment with NB
604
Subset of SF for NB
Subset of SF for NB
604
LTE
System
Bandwidth
602
In-band deployment with dedicated NB RB
RB
RB for NB
RB for regular LTE

FIG. 6

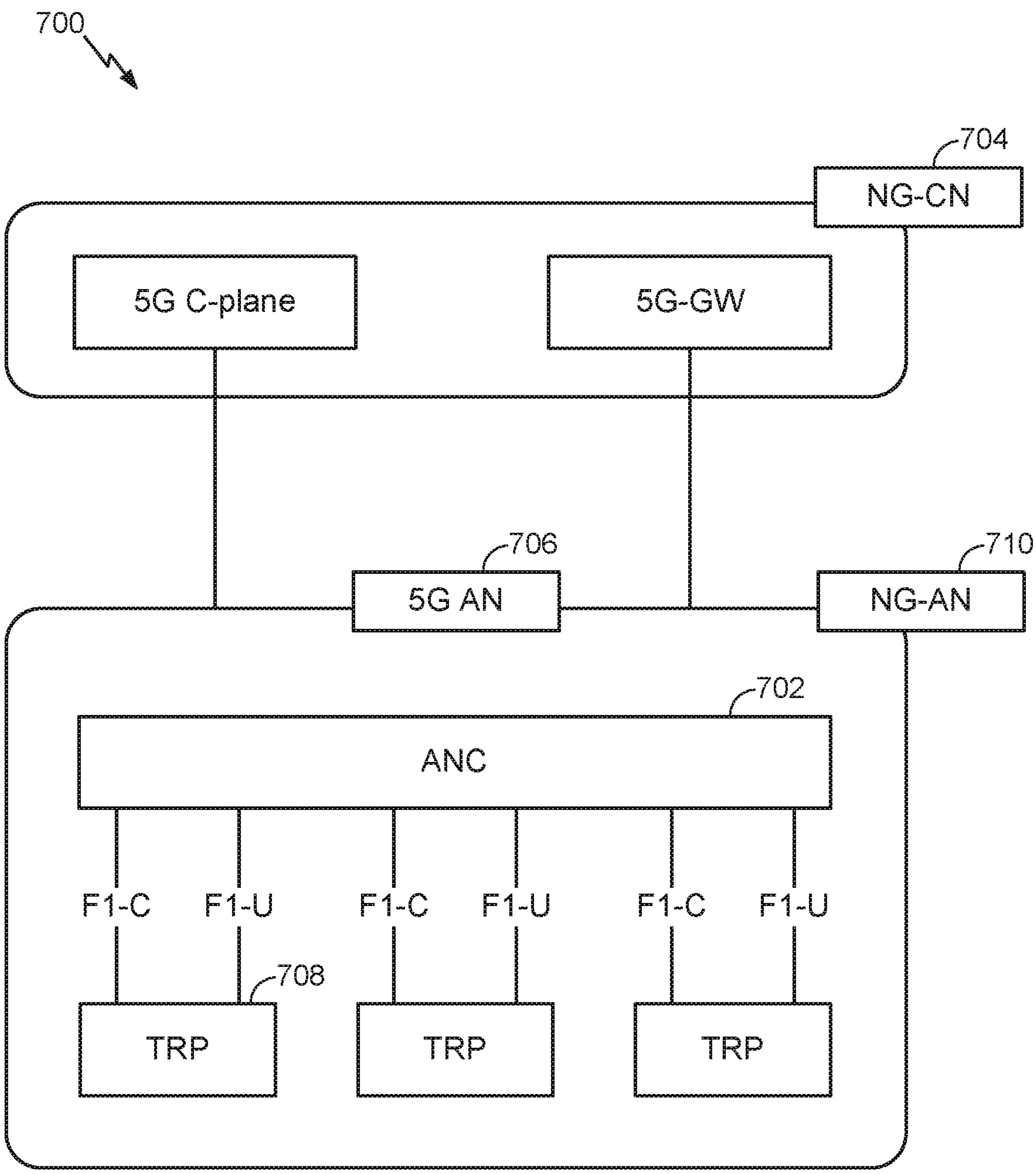

700
704
NG-CN
5G C-plane
5G-GW
706
5G AN
710
NG-AN
702
ANC
F1-C
F1-U
F1-C
F1-U
F1-C
F1-U
708
TRP
TRP
TRP

FIG. 7

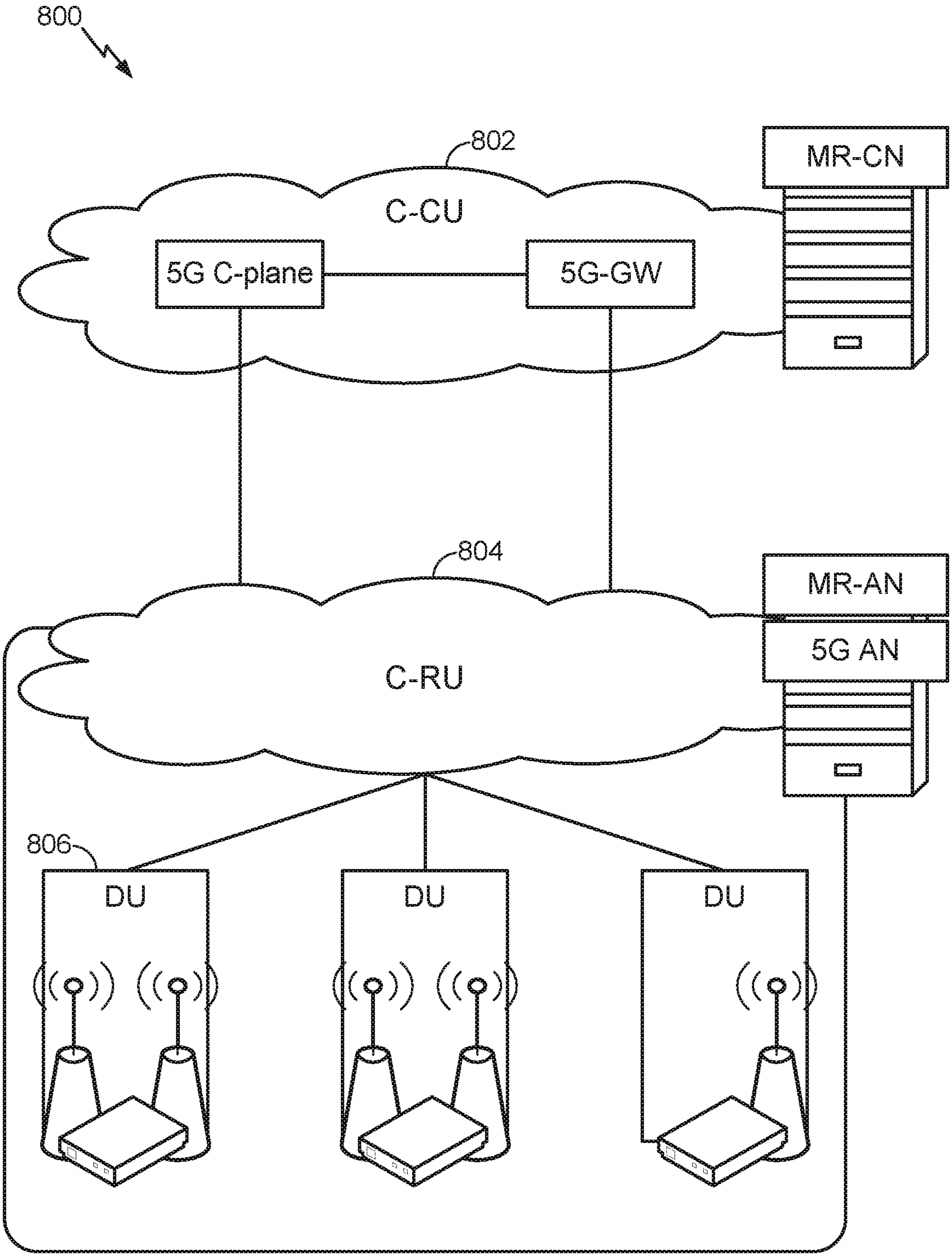


FIG. 8

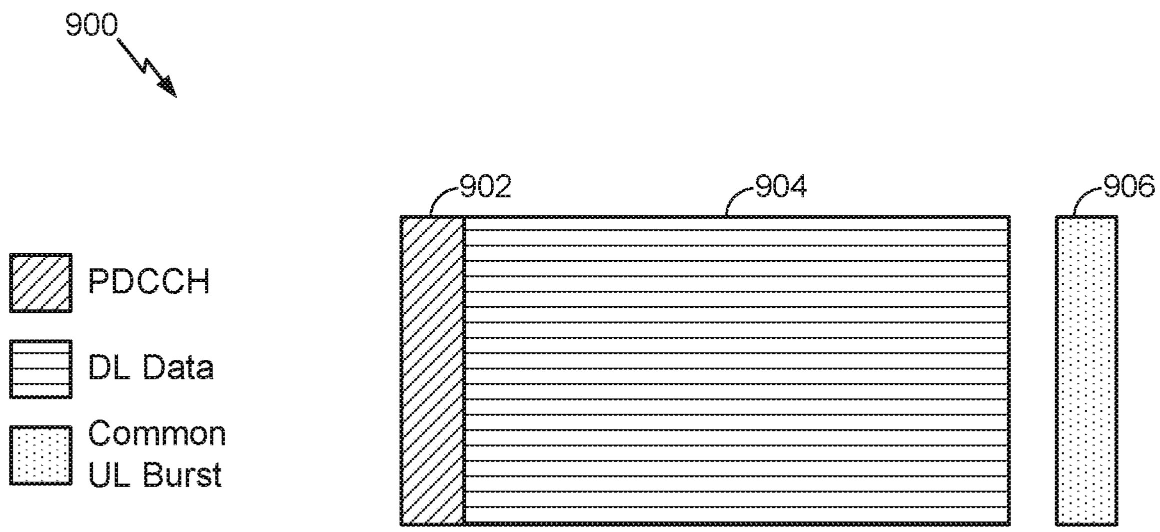

900
PDCCH
DL Data
Common UL Burst
902
904
906

FIG. 9

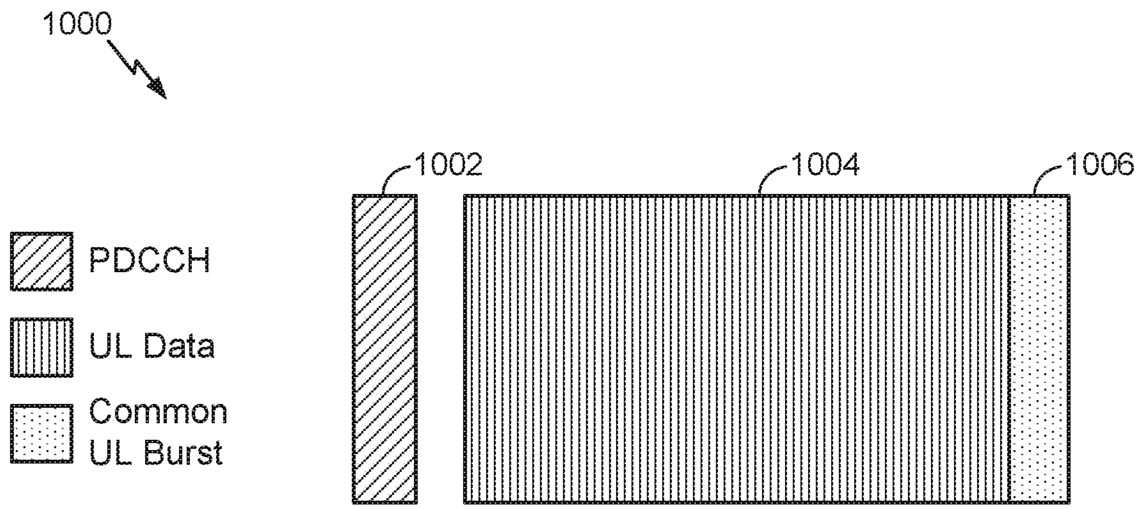

1000
PDCCH
UL Data
Common UL Burst
1002
1004
1006

FIG. 10

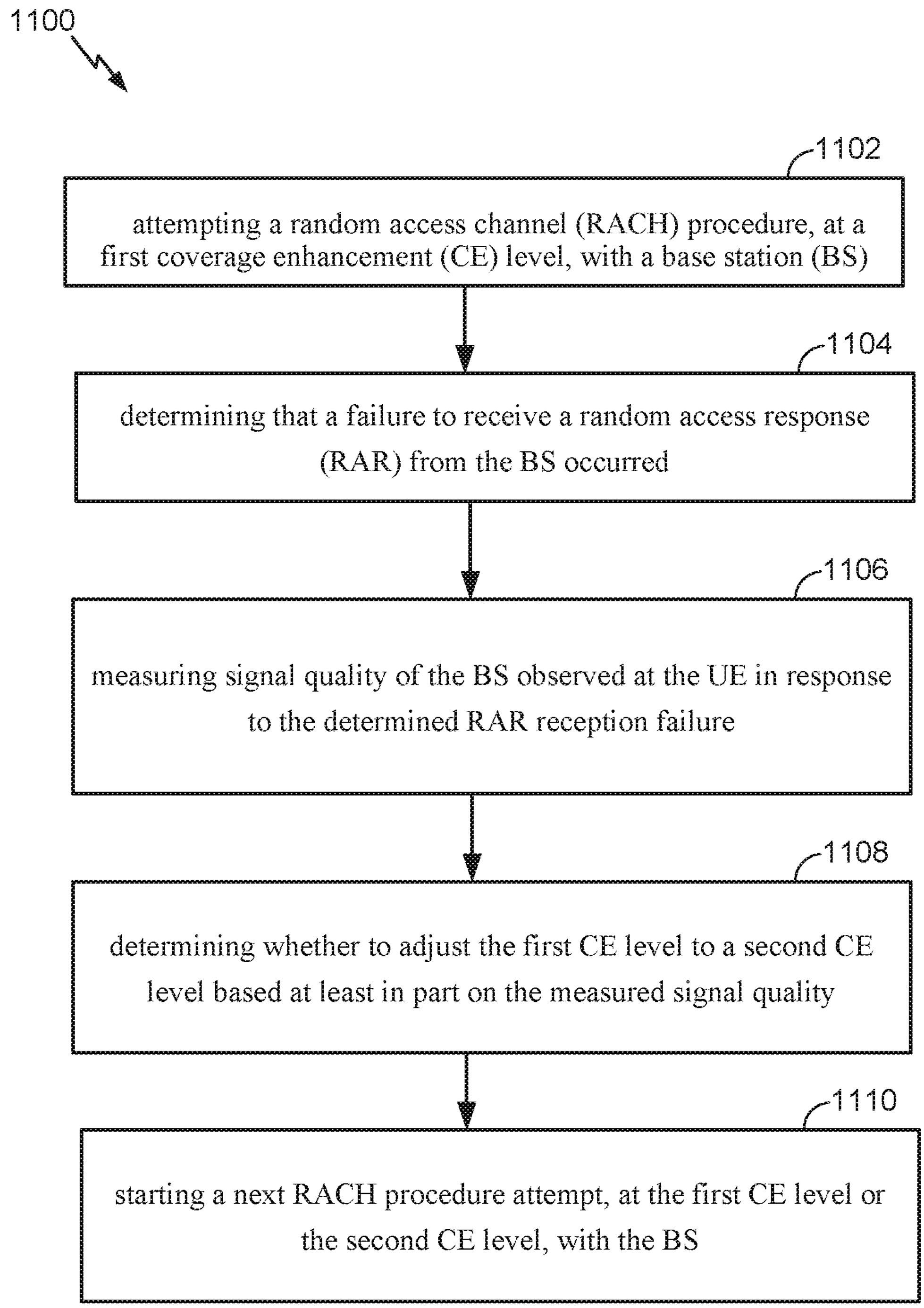

1100
1102
attempting a random access channel (RACH) procedure, at a first coverage enhancement (CE) level, with a base station (BS)
1104
determining that a failure to receive a random access response (RAR) from the BS occurred
1106
measuring signal quality of the BS observed at the UE in response to the determined RAR reception failure
1108
determining whether to adjust the first CE level to a second CE level based at least in part on the measured signal quality
1110
starting a next RACH procedure attempt, at the first CE level or the second CE level, with the BS

FIG. 11

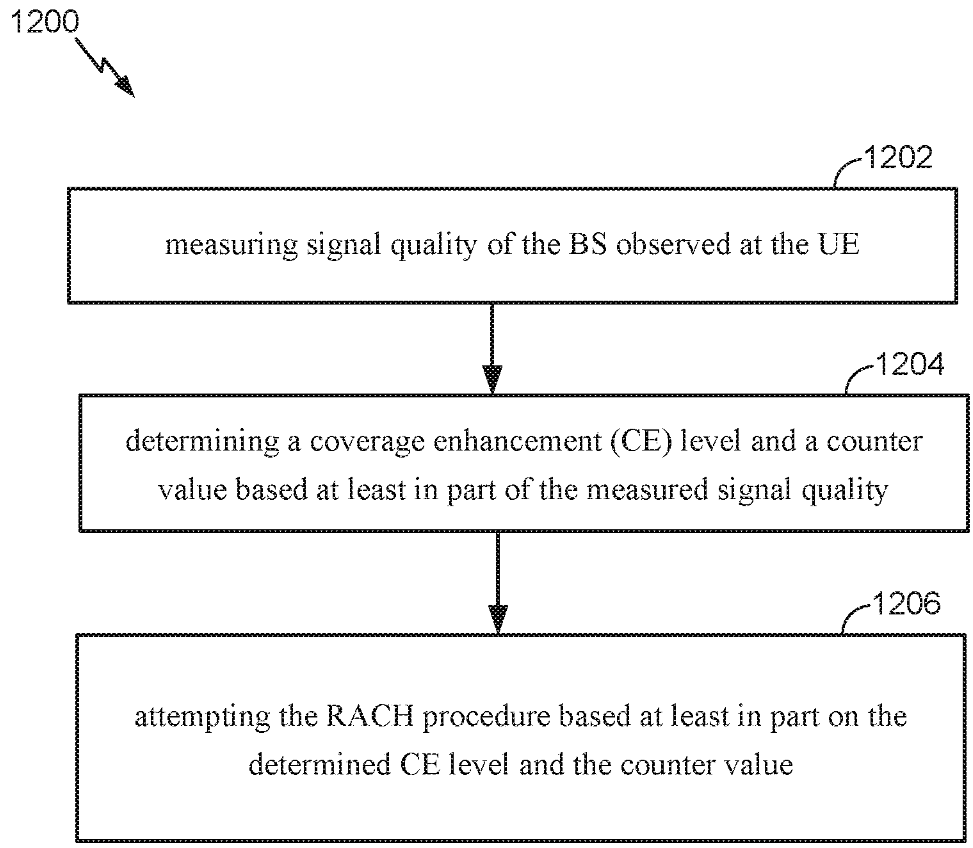

1200
1202
measuring signal quality of the BS observed at the UE
1204
determining a coverage enhancement (CE) level and a counter value based at least in part of the measured signal quality
1206
attempting the RACH procedure based at least in part on the determined CE level and the counter value

FIG. 12

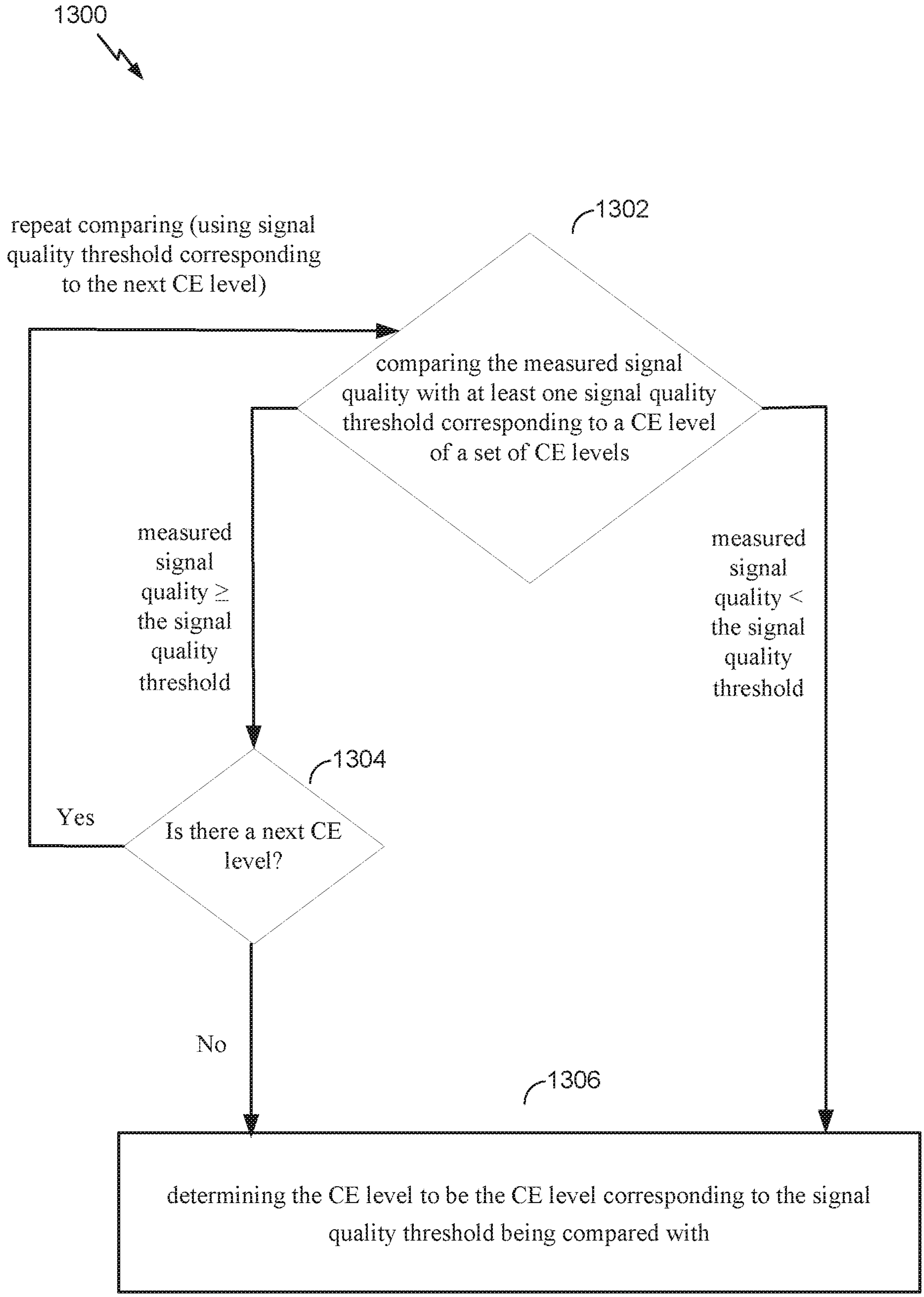

1300
1302
repeat comparing (using signal quality threshold corresponding to the next CE level)
comparing the measured signal quality with at least one signal quality threshold corresponding to a CE level of a set of CE levels
measured signal quality ≥ the signal quality threshold
measured signal quality < the signal quality threshold
1304
Yes
Is there a next CE level?
No
1306
determining the CE level to be the CE level corresponding to the signal quality threshold being compared with

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/078280

A. CLASSIFICATION OF SUBJECT MATTER

H04W 52/48(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W; H04L

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

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

CNABS, CNTXT, CNKI, WOTXT, USTXT, EPTXT, VEN: CE, coverage, enhanced, level, RACH， random access channel， RAR, random access reponse, fail+, quality, adjust+, determin+, preamble, power

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016302234 A1 (INTEL IP CORP.) 13 October 2016 (2016-10-13) the description， paragraphs [0041]-[0047] and figure 2	1-17
A	CN 105556994 A (INTEL IP CORP.) 04 May 2016 (2016-05-04) the whole document	1-17
A	CN 107771406 A (QUALCOMM INC.) 06 March 2018 (2018-03-06) the whole document	1-17
A	CN 107431986 A (INTEL IP CORP.) 01 December 2017 (2017-12-01) the whole document	1-17

☐ 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
19 November 2018	**28 November 2018**

Name and mailing address of the ISA/CN	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2018/078280

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