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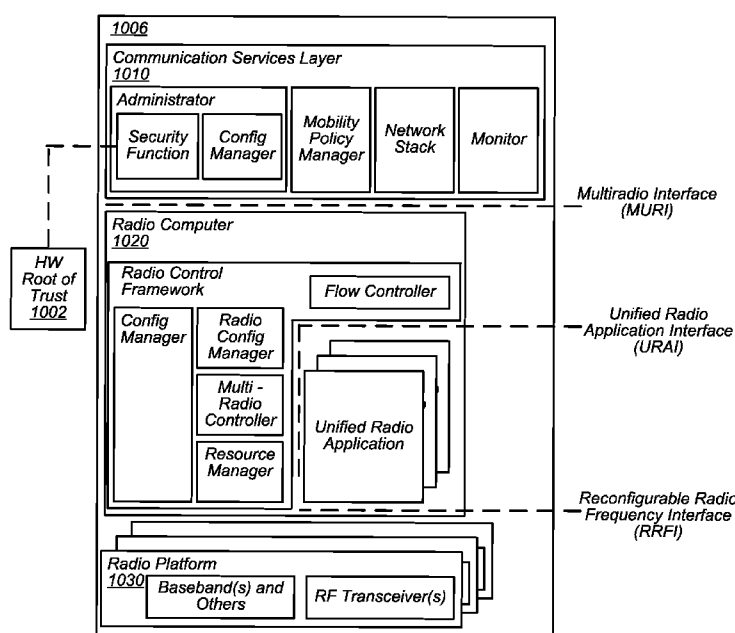


FIG. 10

(57) Abstract: Apparatuses, systems, and methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers. A wireless device may be configured to associate a first application with a first radio computer and a second application with a second radio computer. The second application may perform a different function than the first application. The UE may be configured to exchange, via a multiradio interface, data between a communication services layer of the wireless device and the first and second radio computers. In some instances, the first application may be a safety related application and/or a safety critical related application and the second application may be a non-safety related application and/or a non-safety critical application.

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MULTI-RADIO INTERFACE FOR MULTIPLE RADIO COMPUTERS**FIELD**

[0001] The present application relates to wireless communications, and more particularly to apparatuses, systems, and methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers.

DESCRIPTION OF THE RELATED ART

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

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

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

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

[0006] Additionally, LTE defines a Physical Uplink Shared Channel (PUSCH) as a UL channel shared by all devices (user equipment, UE) in a radio cell to transmit user data to the network. The scheduling for all UEs is under control of the LTE base station (enhanced Node B, or eNB). The

eNB uses the uplink scheduling grant (DCI format 0) to inform the UE about resource block (RB) assignment, and the modulation and coding scheme to be used. PUSCH typically supports QPSK and quadrature amplitude modulation (QAM). In addition to user data, the PUSCH also carries any control information necessary to decode the information, such as transport format indicators and multiple-in multiple-out (MIMO) parameters. Control data is multiplexed with information data prior to digital Fourier transform (DFT) spreading.

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

SUMMARY

[0008] Embodiments relate to apparatuses, systems, and methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers.

[0009] In some embodiments, a wireless device, e.g., such as a user equipment device (UE), may be configured to associate a first application with a first radio computer and a second application with a second radio computer. The second application may perform a different function than the first application. Additionally, the UE may be configured to exchange, via a generalized multiradio interface (gMURI or MURI), data between a communication services layer (CSL) of the UE and the first and second radio computers. In some embodiments, the first application may be a safety related application and/or a safety critical related application and the second application may be a non-safety related application and/or a non-safety critical application. In some embodiments, the first radio computer may be supported by a first radio operating system (ROS) and the second radio computer may be supported by a second ROS independent from the first ROS.

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

[0011] This Summary is intended to provide a brief overview of some of the subject matter described in this document. Accordingly, it will be appreciated that the above-described features are merely examples and should not be construed to narrow the scope or spirit of the subject matter

described herein in any way. Other features, aspects, and advantages of the subject matter described herein will become apparent from the following Detailed Description, Figures, and Claims.

[0012] Note that the following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail. For the purposes of the present document, the phrase “A or B” means (A), (B), or (A and B). An architecture includes, but is not limited to, a network topology. Examples of an architecture include, but is not limited to, a network, a network topology, and a system. Examples of a network include, but is not limited to, a time sensitive network (TSN), a core network (CN), any other suitable network known in the field of wireless communications, or any combination thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A better understanding of the present subject matter can be obtained when the following detailed description of various embodiments is considered in conjunction with the following drawings, in which:

[0014] Figure 1A illustrates an example wireless communication system according to some embodiments.

[0015] Figure 1B illustrates an example of a base station (BS) and an access point in communication with a user equipment (UE) device according to some embodiments.

[0016] Figure 2 illustrates an example simplified block diagram of a WLAN Access Point (AP), according to some embodiments.

[0017] Figure 3 illustrates an example block diagram of a UE according to some embodiments.

[0018] Figure 4 illustrates an example block diagram of a BS according to some embodiments.

[0019] Figure 5 illustrates an example block diagram of cellular communication circuitry, according to some embodiments.

[0020] Figure 6A illustrates an example of connections between an EPC network, an LTE base station (eNB), and a 5G NR base station (gNB).

[0021] Figure 6B illustrates an example of a protocol stack for an eNB and a gNB.

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

[0023] Figure 7B illustrates an example of a 5G network architecture that incorporates both dual 3GPP (e.g., LTE and 5G NR) access and non-3GPP access to the 5G CN, according to some embodiments.

[0024] Figure 8 illustrates an example of a baseband processor architecture for a UE, according to some embodiments.

[0025] Figure 9 illustrates an example of a generalized system architecture for a mobile device, according to some embodiments.

[0026] Figure 10 illustrates an example of a generalized radio equipment architecture for a mobile device, according to some embodiments.

[0027] Figure 11 illustrates an example of a generalized radio equipment architecture for a mobile device that includes multiple radio computers, according to some embodiments.

[0028] Figure 12 illustrates an example of a generalized radio equipment architecture for a mobile device that includes multiple radio computers and multiple radio platforms, according to some embodiments.

[0029] Figure 13 illustrates an example of ETSI EN 303 146-1 V1.3.1 Figure 5.1 which defines interconnection between CSL and an RCF using a MURI for a reconfigurable mobile device.

[0030] Figure 14 illustrates an example of a generalized radio equipment architecture for a mobile device may include multiple MURIs for supporting multiple radio control functions, according to some embodiments.

[0031] Figure 15 illustrates an example of a generalized radio equipment architecture for a mobile device may a MURI for supporting multiple radio control functions, according to some embodiments.

[0032] Figure 16 illustrates a block diagram of an example of a method for attachment of an RCF to the MURI, according to some embodiments.

[0033] Figure 17 illustrates an example of reference points for a reconfigurable mobile device as defined in ETSI EN 303 095 V1.3.1 Figure 5.1.

[0034] Figure 18 illustrates an example of reference points for a reconfigurable mobile device including a multiplexing entity between a CSL and multiple RCFs, according to some embodiments.

[0035] Figure 19 illustrates a block diagram of an example of a method for of using a generalized multiradio interface (gMURI) for managing multiple radio computers, according to some embodiments.

[0036] Figure 20 illustrates an example architecture of a network, according to some embodiments.

[0037] Figure 21 illustrates an example architecture of a system including a core network, according to some embodiments.

[0038] Figure 22 illustrates another example of an architecture of a system including a core network, according to some embodiments.

[0039] Figure 23 illustrates an example of infrastructure equipment, according to some embodiments.

[0040] Figure 24 illustrates an example of a platform, according to some embodiments.

[0041] Figure 25 illustrates example components of baseband circuitry and radio front end modules (RFEM), according to some embodiments.

[0042] Figure 26 illustrates examples of various protocol functions that may be implemented in a wireless communication device, according to some embodiments.

[0043] Figure 27 illustrates examples of components of a core network, according to some embodiments.

[0044] Figure 28 is an example of a block diagram illustrating components of a system to support NFV, according to some embodiments.

[0045] Figure 29 is an example of a block diagram illustrating components able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein, according to some embodiments.

[0046] While the features described herein may be susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to be limiting to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the subject matter as defined by the appended claims.

DETAILED DESCRIPTION

Terms

[0047] The following is a glossary of terms used in this disclosure:

[0048] Memory Medium – Any of various types of non-transitory memory devices or storage devices. The term “memory medium” is intended to include an installation medium, e.g., a CD-ROM, floppy disks, or tape device; a computer system memory or random access memory such as DRAM, DDR RAM, SRAM, EDO RAM, Rambus RAM, etc.; a non-volatile memory such as a Flash, magnetic media, e.g., a hard drive, or optical storage; registers, or other similar types of memory elements, etc. The memory medium may include other types of non-transitory memory as well or combinations thereof. In addition, the memory medium may be located in a first computer system in which the programs are executed, or may be located in a second different computer system which connects to the first computer system over a network, such as the Internet. In the latter instance, the second computer system may provide program instructions to the first computer for execution. The term “memory medium” may include two or more memory mediums which may reside in different locations, e.g., in different computer systems that are connected over a network. The memory medium may store program instructions (e.g., embodied as computer programs) that may be executed by one or more processors.

[0049] Carrier Medium – a memory medium as described above, as well as a physical transmission medium, such as a bus, network, and/or other physical transmission medium that conveys signals such as electrical, electromagnetic, or digital signals.

[0050] Programmable Hardware Element - includes various hardware devices comprising multiple programmable function blocks connected via a programmable interconnect. Examples include FPGAs (Field Programmable Gate Arrays), PLDs (Programmable Logic Devices), FPOAs (Field Programmable Object Arrays), and CPLDs (Complex PLDs). The programmable function blocks may range from fine grained (combinatorial logic or look up tables) to coarse grained (arithmetic logic units or processor cores). A programmable hardware element may also be referred to as "reconfigurable logic".

[0051] Computer System – any of various types of computing or processing systems, including a personal computer system (PC), mainframe computer system, workstation, network appliance, Internet appliance, personal digital assistant (PDA), television system, grid computing system, or other device or combinations of devices. In general, the term "computer system" can be broadly defined to encompass any device (or combination of devices) having at least one processor that executes instructions from a memory medium.

[0052] User Equipment (UE) (or “UE Device”) – any of various types of computer systems devices which are mobile or portable and which performs wireless communications. Examples of UE devices include mobile telephones or smart phones (e.g., iPhone™, Android™-based phones), portable gaming devices (e.g., Nintendo DS™, PlayStation Portable™, Gameboy Advance™, iPhone™), laptops, wearable devices (e.g. smart watch, smart glasses), PDAs, portable Internet

devices, music players, data storage devices, or other handheld devices, etc. In general, the term “UE” or “UE device” can be broadly defined to encompass any electronic, computing, and/or telecommunications device (or combination of devices) which is easily transported by a user and capable of wireless communication.

[0053] Base Station – The term "Base Station" has the full breadth of its ordinary meaning, and at least includes a wireless communication station installed at a fixed location and used to communicate as part of a wireless telephone system or radio system.

[0054] Processing Element – refers to various elements or combinations of elements that are capable of performing a function in a device, such as a user equipment or a cellular network device. Processing elements may include, for example: processors and associated memory, portions or circuits of individual processor cores, entire processor cores, processor arrays, circuits such as an ASIC (Application Specific Integrated Circuit), programmable hardware elements such as a field programmable gate array (FPGA), as well any of various combinations of the above.

[0055] Channel - a medium used to convey information from a sender (transmitter) to a receiver. It should be noted that since characteristics of the term “channel” may differ according to different wireless protocols, the term “channel” as used herein may be considered as being used in a manner that is consistent with the standard of the type of device with reference to which the term is used. In some standards, channel widths may be variable (e.g., depending on device capability, band conditions, etc.). For example, LTE may support scalable channel bandwidths from 1.4 MHz to 20MHz. In contrast, WLAN channels may be 22MHz wide while Bluetooth channels may be 1Mhz wide. Other protocols and standards may include different definitions of channels. Furthermore, some standards may define and use multiple types of channels, e.g., different channels for uplink or downlink and/or different channels for different uses such as data, control information, etc.

[0056] Band - The term "band" has the full breadth of its ordinary meaning, and at least includes a section of spectrum (e.g., radio frequency spectrum) in which channels are used or set aside for the same purpose.

[0057] Automatically – refers to an action or operation performed by a computer system (e.g., software executed by the computer system) or device (e.g., circuitry, programmable hardware elements, ASICs, etc.), without user input directly specifying or performing the action or operation. Thus the term "automatically" is in contrast to an operation being manually performed or specified by the user, where the user provides input to directly perform the operation. An automatic procedure may be initiated by input provided by the user, but the subsequent actions that are performed “automatically” are not specified by the user, i.e., are not performed “manually”, where the user specifies each action to perform. For example, a user filling out an

electronic form by selecting each field and providing input specifying information (e.g., by typing information, selecting check boxes, radio selections, etc.) is filling out the form manually, even though the computer system must update the form in response to the user actions. The form may be automatically filled out by the computer system where the computer system (e.g., software executing on the computer system) analyzes the fields of the form and fills in the form without any user input specifying the answers to the fields. As indicated above, the user may invoke the automatic filling of the form, but is not involved in the actual filling of the form (e.g., the user is not manually specifying answers to fields but rather they are being automatically completed). The present specification provides various examples of operations being automatically performed in response to actions the user has taken.

[0058] Approximately - refers to a value that is almost correct or exact. For example, approximately may refer to a value that is within 1 to 10 percent of the exact (or desired) value. It should be noted, however, that the actual threshold value (or tolerance) may be application dependent. For example, in some embodiments, “approximately” may mean within 0.1% of some specified or desired value, while in various other embodiments, the threshold may be, for example, 2%, 3%, 5%, and so forth, as desired or as required by the particular application.

[0059] Concurrent – refers to parallel execution or performance, where tasks, processes, or programs are performed in an at least partially overlapping manner. For example, concurrency may be implemented using “strong” or strict parallelism, where tasks are performed (at least partially) in parallel on respective computational elements, or using “weak parallelism”, where the tasks are performed in an interleaved manner, e.g., by time multiplexing of execution threads.

[0060] Various components may be described as “configured to” perform a task or tasks. In such contexts, “configured to” is a broad recitation generally meaning “having structure that” performs the task or tasks during operation. As such, the component can be configured to perform the task even when the component is not currently performing that task (e.g., a set of electrical conductors may be configured to electrically connect a module to another module, even when the two modules are not connected). In some contexts, “configured to” may be a broad recitation of structure generally meaning “having circuitry that” performs the task or tasks during operation. As such, the component can be configured to perform the task even when the component is not currently on. In general, the circuitry that forms the structure corresponding to “configured to” may include hardware circuits.

[0061] Various components may be described as performing a task or tasks, for convenience in the description. Such descriptions should be interpreted as including the phrase “configured to.” Reciting a component that is configured to perform one or more tasks is expressly intended not to invoke 35 U.S.C. § 112(f) interpretation for that component.

Figures 1A and 1B - Communication Systems

[0062] Figure 1A illustrates a simplified example wireless communication system, according to some embodiments. It is noted that the system of Figure 1 is merely one example of a possible system, and that features of this disclosure may be implemented in any of various systems, as desired.

[0063] As shown, the example wireless communication system includes a base station 102A which communicates over a transmission medium with one or more user devices 106A, 106B, etc., through 106N. Each of the user devices may be referred to herein as a “user equipment” (UE). Thus, the user devices 106 are referred to as UEs or UE devices.

[0064] The base station (BS) 102A may be a base transceiver station (BTS) or cell site (a “cellular base station”) and may include hardware that enables wireless communication with the UEs 106A through 106N.

[0065] The communication area (or coverage area) of the base station may be referred to as a “cell.” The base station 102A and the UEs 106 may be configured to communicate over the transmission medium using any of various radio access technologies (RATs), also referred to as wireless communication technologies, or telecommunication standards, such as GSM, UMTS (associated with, for example, WCDMA or TD-SCDMA air interfaces), LTE, LTE-Advanced (LTE-A), 5G new radio (5G NR), HSPA, 3GPP2 CDMA2000 (e.g., 1xRTT, 1xEV-DO, HRPD, eHRPD), etc. Note that if the base station 102A is implemented in the context of LTE, it may alternately be referred to as an ‘eNodeB’ or ‘eNB’. Note that if the base station 102A is implemented in the context of 5G NR, it may alternately be referred to as ‘gNodeB’ or ‘gNB’.

[0066] As shown, the base station 102A may also be equipped to communicate with a network 100 (e.g., a core network of a cellular service provider, a telecommunication network such as a public switched telephone network (PSTN), and/or the Internet, among various possibilities). Thus, the base station 102A may facilitate communication between the user devices and/or between the user devices and the network 100. In particular, the cellular base station 102A may provide UEs 106 with various telecommunication capabilities, such as voice, SMS and/or data services.

[0067] Base station 102A and other similar base stations (such as base stations 102B...102N) operating according to the same or a different cellular communication standard may thus be provided as a network of cells, which may provide continuous or nearly continuous overlapping service to UEs 106A-N and similar devices over a geographic area via one or more cellular communication standards.

[0068] Thus, while base station 102A may act as a “serving cell” for UEs 106A-N as illustrated in Figure 1, each UE 106 may also be capable of receiving signals from (and possibly within communication range of) one or more other cells (which might be provided by base stations 102B-N and/or any other base stations), which may be referred to as “neighboring cells”. Such cells may also be capable of facilitating communication between user devices and/or between user devices and the network 100. Such cells may include “macro” cells, “micro” cells, “pico” cells, and/or cells which provide any of various other granularities of service area size. For example, base stations 102A-B illustrated in Figure 1 might be macro cells, while base station 102N might be a micro cell. Other configurations are also possible.

[0069] In some embodiments, base station 102A may be a next generation base station, e.g., a 5G New Radio (5G NR) base station, or “gNB”. In some embodiments, a gNB may be connected to a legacy evolved packet core (EPC) network and/or to a NR core (NRC) network. In addition, a gNB cell may include one or more transition and reception points (TRPs). In addition, a UE capable of operating according to 5G NR may be connected to one or more TRPs within one or more gNBs.

[0070] Note that a UE 106 may be capable of communicating using multiple wireless communication standards. For example, the UE 106 may be configured to communicate using a wireless networking (e.g., Wi-Fi) and/or peer-to-peer wireless communication protocol (e.g., Bluetooth, Wi-Fi peer-to-peer, etc.) in addition to at least one cellular communication protocol (e.g., GSM, UMTS (associated with, for example, WCDMA or TD-SCDMA air interfaces), LTE, LTE-A, 5G NR, HSPA, 3GPP2 CDMA2000 (e.g., 1xRTT, 1xEV-DO, HRPD, eHRPD), etc.). The UE 106 may also or alternatively be configured to communicate using one or more global navigational satellite systems (GNSS, e.g., GPS or GLONASS), one or more mobile television broadcasting standards (e.g., ATSC-M/H or DVB-H), and/or any other wireless communication protocol, if desired. Other combinations of wireless communication standards (including more than two wireless communication standards) are also possible.

[0071] Figure 1B illustrates user equipment 106 (e.g., one of the devices 106A through 106N) in communication with a base station 102 and an access point 112, according to some embodiments. The UE 106 may be a device with both cellular communication capability and non-cellular communication capability (e.g., Bluetooth, Wi-Fi, and so forth) such as a mobile phone, a hand-held device, a computer or a tablet, or virtually any type of wireless device.

[0072] The UE 106 may include a processor that is configured to execute program instructions stored in memory. The UE 106 may perform any of the method embodiments described herein by executing such stored instructions. Alternatively, or in addition, the UE 106 may include a programmable hardware element such as an FPGA (field-programmable gate array) that is

configured to perform any of the method embodiments described herein, or any portion of any of the method embodiments described herein.

[0073] The UE 106 may include one or more antennas for communicating using one or more wireless communication protocols or technologies. In some embodiments, the UE 106 may be configured to communicate using, for example, CDMA2000 (1xRTT / 1xEV-DO / HRPD / eHRPD), LTE/LTE-Advanced, or 5G NR using a single shared radio and/or GSM, LTE, LTE-Advanced, or 5G NR using the single shared radio. The shared radio may couple to a single antenna, or may couple to multiple antennas (e.g., for MIMO) for performing wireless communications. In general, a radio may include any combination of a baseband processor, analog RF signal processing circuitry (e.g., including filters, mixers, oscillators, amplifiers, etc.), or digital processing circuitry (e.g., for digital modulation as well as other digital processing). Similarly, the radio may implement one or more receive and transmit chains using the aforementioned hardware. For example, the UE 106 may share one or more parts of a receive and/or transmit chain between multiple wireless communication technologies, such as those discussed above.

[0074] In some embodiments, the UE 106 may include separate transmit and/or receive chains (e.g., including separate antennas and other radio components) for each wireless communication protocol with which it is configured to communicate. As a further possibility, the UE 106 may include one or more radios which are shared between multiple wireless communication protocols, and one or more radios which are used exclusively by a single wireless communication protocol. For example, the UE 106 might include a shared radio for communicating using either of LTE or 5G NR (or LTE or 1xRTT or LTE or GSM), and separate radios for communicating using each of Wi-Fi and Bluetooth. Other configurations are also possible.

Figure 2 – Access Point Block Diagram

[0075] Figure 2 illustrates an exemplary block diagram of an access point (AP) 112. It is noted that the block diagram of the AP of Figure 2 is only one example of a possible system. As shown, the AP 112 may include processor(s) 204 which may execute program instructions for the AP 112. The processor(s) 204 may also be coupled (directly or indirectly) to memory management unit (MMU) 240, which may be configured to receive addresses from the processor(s) 204 and to translate those addresses to locations in memory (e.g., memory 260 and read only memory (ROM) 250) or to other circuits or devices.

[0076] The AP 112 may include at least one network port 270. The network port 270 may be configured to couple to a wired network and provide a plurality of devices, such as UEs 106, access to the Internet. For example, the network port 270 (or an additional network port) may be configured to couple to a local network, such as a home network or an enterprise network. For

example, port 270 may be an Ethernet port. The local network may provide connectivity to additional networks, such as the Internet.

[0077] The AP 112 may include at least one antenna 234, which may be configured to operate as a wireless transceiver and may be further configured to communicate with UE 106 via wireless communication circuitry 230. The antenna 234 communicates with the wireless communication circuitry 230 via communication chain 232. Communication chain 232 may include one or more receive chains, one or more transmit chains or both. The wireless communication circuitry 230 may be configured to communicate via Wi-Fi or WLAN, e.g., 802.11. The wireless communication circuitry 230 may also, or alternatively, be configured to communicate via various other wireless communication technologies, including, but not limited to, 5G NR, Long-Term Evolution (LTE), LTE Advanced (LTE-A), Global System for Mobile (GSM), Wideband Code Division Multiple Access (WCDMA), CDMA2000, etc., for example when the AP is co-located with a base station in case of a small cell, or in other instances when it may be desirable for the AP 112 to communicate via various different wireless communication technologies.

[0078] In some embodiments, as further described below, an AP 112 may be configured to perform methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers as further described herein.

Figure 3 – Block Diagram of a UE

[0079] Figure 3 illustrates an example simplified block diagram of a communication device 106, according to some embodiments. It is noted that the block diagram of the communication device of Figure 3 is only one example of a possible communication device. According to embodiments, communication device 106 may be a user equipment (UE) device, a mobile device or mobile station, a wireless device or wireless station, a desktop computer or computing device, a mobile computing device (e.g., a laptop, notebook, or portable computing device), a tablet and/or a combination of devices, among other devices. As shown, the communication device 106 may include a set of components 300 configured to perform core functions. For example, this set of components may be implemented as a system on chip (SOC), which may include portions for various purposes. Alternatively, this set of components 300 may be implemented as separate components or groups of components for the various purposes. The set of components 300 may be coupled (e.g., communicatively; directly or indirectly) to various other circuits of the communication device 106.

[0080] For example, the communication device 106 may include various types of memory (e.g., including NAND flash 310), an input/output interface such as connector I/F 320 (e.g., for connecting to a computer system; dock; charging station; input devices, such as a microphone,

camera, keyboard; output devices, such as speakers; etc.), the display 360, which may be integrated with or external to the communication device 106, and cellular communication circuitry 330 such as for 5G NR, LTE, GSM, etc., and short to medium range wireless communication circuitry 329 (e.g., Bluetooth™ and WLAN circuitry). In some embodiments, communication device 106 may include wired communication circuitry (not shown), such as a network interface card, e.g., for Ethernet.

[0081] The cellular communication circuitry 330 may couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 335 and 336 as shown. The short to medium range wireless communication circuitry 329 may also couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 337 and 338 as shown. Alternatively, the short to medium range wireless communication circuitry 329 may couple (e.g., communicatively; directly or indirectly) to the antennas 335 and 336 in addition to, or instead of, coupling (e.g., communicatively; directly or indirectly) to the antennas 337 and 338. The short to medium range wireless communication circuitry 329 and/or cellular communication circuitry 330 may include multiple receive chains and/or multiple transmit chains for receiving and/or transmitting multiple spatial streams, such as in a multiple-input multiple output (MIMO) configuration.

[0082] In some embodiments, as further described below, cellular communication circuitry 330 may include dedicated receive chains (including and/or coupled to, e.g., communicatively; directly or indirectly. dedicated processors and/or radios) for multiple RATs (e.g., a first receive chain for LTE and a second receive chain for 5G NR). In addition, in some embodiments, cellular communication circuitry 330 may include a single transmit chain that may be switched between radios dedicated to specific RATs. For example, a first radio may be dedicated to a first RAT, e.g., LTE, and may be in communication with a dedicated receive chain and a transmit chain shared with an additional radio, e.g., a second radio that may be dedicated to a second RAT, e.g., 5G NR, and may be in communication with a dedicated receive chain and the shared transmit chain.

[0083] The communication device 106 may also include and/or be configured for use with one or more user interface elements. The user interface elements may include any of various elements, such as display 360 (which may be a touchscreen display), a keyboard (which may be a discrete keyboard or may be implemented as part of a touchscreen display), a mouse, a microphone and/or speakers, one or more cameras, one or more buttons, and/or any of various other elements capable of providing information to a user and/or receiving or interpreting user input.

[0084] The communication device 106 may further include one or more smart cards 345 that include SIM (Subscriber Identity Module) functionality, such as one or more UICC(s) (Universal Integrated Circuit Card(s)) cards 345.

[0085] As shown, the SOC 300 may include processor(s) 302, which may execute program instructions for the communication device 106 and display circuitry 304, which may perform graphics processing and provide display signals to the display 360. The processor(s) 302 may also be coupled to memory management unit (MMU) 340, which may be configured to receive addresses from the processor(s) 302 and translate those addresses to locations in memory (e.g., memory 306, read only memory (ROM) 350, NAND flash memory 310) and/or to other circuits or devices, such as the display circuitry 304, short to medium range wireless communication circuitry 329, cellular communication circuitry 330, connector I/F 320, and/or display 360. The MMU 340 may be configured to perform memory protection and page table translation or set up. In some embodiments, the MMU 340 may be included as a portion of the processor(s) 302.

[0086] As noted above, the communication device 106 may be configured to communicate using wireless and/or wired communication circuitry. The communication device 106 may be configured to perform methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers as further described herein.

[0087] As described herein, the communication device 106 may include hardware and software components for implementing the above features for a communication device 106 to communicate a scheduling profile for power savings to a network. The processor 302 of the communication device 106 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 302 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 302 of the communication device 106, in conjunction with one or more of the other components 300, 304, 306, 310, 320, 329, 330, 340, 345, 350, 360 may be configured to implement part or all of the features described herein.

[0088] In addition, as described herein, processor 302 may include one or more processing elements. Thus, processor 302 may include one or more integrated circuits (ICs) that are configured to perform the functions of processor 302. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processor(s) 302.

[0089] Further, as described herein, cellular communication circuitry 330 and short to medium range wireless communication circuitry 329 may each include one or more processing elements. In other words, one or more processing elements may be included in cellular communication circuitry 330 and, similarly, one or more processing elements may be included in short to medium range wireless communication circuitry 329. Thus, cellular communication circuitry 330 may

include one or more integrated circuits (ICs) that are configured to perform the functions of cellular communication circuitry 330. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of cellular communication circuitry 330. Similarly, the short to medium range wireless communication circuitry 329 may include one or more ICs that are configured to perform the functions of short to medium range wireless communication circuitry 329. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of short to medium range wireless communication circuitry 329.

Figure 4 – Block Diagram of a Base Station

[0090] Figure 4 illustrates an example block diagram of a base station 102, according to some embodiments. It is noted that the base station of Figure 4 is merely one example of a possible base station. As shown, the base station 102 may include processor(s) 404 which may execute program instructions for the base station 102. The processor(s) 404 may also be coupled to memory management unit (MMU) 440, which may be configured to receive addresses from the processor(s) 404 and translate those addresses to locations in memory (e.g., memory 460 and read only memory (ROM) 450) or to other circuits or devices.

[0091] The base station 102 may include at least one network port 470. The network port 470 may be configured to couple to a telephone network and provide a plurality of devices, such as UE devices 106, access to the telephone network as described above in Figures 1 and 2.

[0092] The network port 470 (or an additional network port) may also or alternatively be configured to couple to a cellular network, e.g., a core network of a cellular service provider. The core network may provide mobility related services and/or other services to a plurality of devices, such as UE devices 106. In some cases, the network port 470 may couple to a telephone network via the core network, and/or the core network may provide a telephone network (e.g., among other UE devices serviced by the cellular service provider).

[0093] In some embodiments, base station 102 may be a next generation base station, e.g., a 5G New Radio (5G NR) base station, or “gNB”. In such embodiments, base station 102 may be connected to a legacy evolved packet core (EPC) network and/or to a NR core (NRC) network. In addition, base station 102 may be considered a 5G NR cell and may include one or more transmission and reception points (TRPs). In addition, a UE capable of operating according to 5G NR may be connected to one or more TRPs within one or more gNBs.

[0094] The base station 102 may include at least one antenna 434, and possibly multiple antennas. The at least one antenna 434 may be configured to operate as a wireless transceiver and may be further configured to communicate with UE devices 106 via radio 430. The antenna 434

communicates with the radio 430 via communication chain 432. Communication chain 432 may be a receive chain, a transmit chain or both. The radio 430 may be configured to communicate via various wireless communication standards, including, but not limited to, 5G NR, LTE, LTE-A, GSM, UMTS, CDMA2000, Wi-Fi, etc.

[0095] The base station 102 may be configured to communicate wirelessly using multiple wireless communication standards. In some instances, the base station 102 may include multiple radios, which may enable the base station 102 to communicate according to multiple wireless communication technologies. For example, as one possibility, the base station 102 may include an LTE radio for performing communication according to LTE as well as a 5G NR radio for performing communication according to 5G NR. In such a case, the base station 102 may be capable of operating as both an LTE base station and a 5G NR base station. As another possibility, the base station 102 may include a multi-mode radio which is capable of performing communications according to any of multiple wireless communication technologies (e.g., 5G NR and Wi-Fi, LTE and Wi-Fi, LTE and UMTS, LTE and CDMA2000, UMTS and GSM, etc.).

[0096] As described further subsequently herein, the BS 102 may include hardware and software components for implementing or supporting implementation of features described herein. The processor 404 of the base station 102 may be configured to implement or support implementation of part or all of the methods described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively, the processor 404 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit), or a combination thereof. Alternatively (or in addition) the processor 404 of the BS 102, in conjunction with one or more of the other components 430, 432, 434, 440, 450, 460, 470 may be configured to implement or support implementation of part or all of the features described herein.

[0097] In addition, as described herein, processor(s) 404 may be comprised of one or more processing elements. In other words, one or more processing elements may be included in processor(s) 404. Thus, processor(s) 404 may include one or more integrated circuits (ICs) that are configured to perform the functions of processor(s) 404. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processor(s) 404.

[0098] Further, as described herein, radio 430 may be comprised of one or more processing elements. In other words, one or more processing elements may be included in radio 430. Thus, radio 430 may include one or more integrated circuits (ICs) that are configured to perform the functions of radio 430. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of radio 430.

Figure 5: Block Diagram of Cellular Communication Circuitry

[0099] Figure 5 illustrates an example simplified block diagram of cellular communication circuitry, according to some embodiments. It is noted that the block diagram of the cellular communication circuitry of Figure 5 is only one example of a possible cellular communication circuit. According to embodiments, cellular communication circuitry 330 may be included in a communication device, such as communication device 106 described above. As noted above, communication device 106 may be a user equipment (UE) device, a mobile device or mobile station, a wireless device or wireless station, a desktop computer or computing device, a mobile computing device (e.g., a laptop, notebook, or portable computing device), a tablet and/or a combination of devices, among other devices.

[00100] The cellular communication circuitry 330 may couple (e.g., communicatively; directly or indirectly) to one or more antennas, such as antennas 335a-b and 336 as shown (in Figure 3). In some embodiments, cellular communication circuitry 330 may include dedicated receive chains (including and/or coupled to, e.g., communicatively; directly or indirectly. dedicated processors and/or radios) for multiple RATs (e.g., a first receive chain for LTE and a second receive chain for 5G NR). For example, as shown in Figure 5, cellular communication circuitry 330 may include a modem 510 and a modem 520. Modem 510 may be configured for communications according to a first RAT, e.g., such as LTE or LTE-A, and modem 520 may be configured for communications according to a second RAT, e.g., such as 5G NR.

[00101] As shown, modem 510 may include one or more processors 512 and a memory 516 in communication with processors 512. Modem 510 may be in communication with a radio frequency (RF) front end 530. RF front end 530 may include circuitry for transmitting and receiving radio signals. For example, RF front end 530 may include receive circuitry (RX) 532 and transmit circuitry (TX) 534. In some embodiments, receive circuitry 532 may be in communication with downlink (DL) front end 550, which may include circuitry for receiving radio signals via antenna 335a.

[00102] Similarly, modem 520 may include one or more processors 522 and a memory 526 in communication with processors 522. Modem 520 may be in communication with an RF front end 540. RF front end 540 may include circuitry for transmitting and receiving radio signals. For example, RF front end 540 may include receive circuitry 542 and transmit circuitry 544. In some embodiments, receive circuitry 542 may be in communication with DL front end 560, which may include circuitry for receiving radio signals via antenna 335b.

[00103] In some embodiments, a switch 570 may couple transmit circuitry 534 to uplink (UL) front end 572. In addition, switch 570 may couple transmit circuitry 544 to UL front end 572. UL front end 572 may include circuitry for transmitting radio signals via antenna 336. Thus, when

cellular communication circuitry 330 receives instructions to transmit according to the first RAT (e.g., as supported via modem 510), switch 570 may be switched to a first state that allows modem 510 to transmit signals according to the first RAT (e.g., via a transmit chain that includes transmit circuitry 534 and UL front end 572). Similarly, when cellular communication circuitry 330 receives instructions to transmit according to the second RAT (e.g., as supported via modem 520), switch 570 may be switched to a second state that allows modem 520 to transmit signals according to the second RAT (e.g., via a transmit chain that includes transmit circuitry 544 and UL front end 572).

[00104] In some embodiments, the cellular communication circuitry 330 may be configured to perform methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers as further described herein.

[00105] As described herein, the modem 510 may include hardware and software components for implementing the above features or for time division multiplexing UL data for NSA NR operations, as well as the various other techniques described herein. The processors 512 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 512 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 512, in conjunction with one or more of the other components 530, 532, 534, 550, 570, 572, 335 and 336 may be configured to implement part or all of the features described herein.

[00106] In addition, as described herein, processors 512 may include one or more processing elements. Thus, processors 512 may include one or more integrated circuits (ICs) that are configured to perform the functions of processors 512. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processors 512.

[00107] As described herein, the modem 520 may include hardware and software components for implementing the above features for communicating a scheduling profile for power savings to a network, as well as the various other techniques described herein. The processors 522 may be configured to implement part or all of the features described herein, e.g., by executing program instructions stored on a memory medium (e.g., a non-transitory computer-readable memory medium). Alternatively (or in addition), processor 522 may be configured as a programmable hardware element, such as an FPGA (Field Programmable Gate Array), or as an ASIC (Application Specific Integrated Circuit). Alternatively (or in addition) the processor 522, in conjunction with

one or more of the other components 540, 542, 544, 550, 570, 572, 335 and 336 may be configured to implement part or all of the features described herein.

[00108] In addition, as described herein, processors 522 may include one or more processing elements. Thus, processors 522 may include one or more integrated circuits (ICs) that are configured to perform the functions of processors 522. In addition, each integrated circuit may include circuitry (e.g., first circuitry, second circuitry, etc.) configured to perform the functions of processors 522.

5G NR Architecture with LTE

[00109] In some implementations, fifth generation (5G) wireless communication will initially be deployed concurrently with current wireless communication standards (e.g., LTE). For example, dual connectivity between LTE and 5G new radio (5G NR or NR) has been specified as part of the initial deployment of NR. Thus, as illustrated in Figures 6A-B, evolved packet core (EPC) network 600 may continue to communicate with current LTE base stations (e.g., eNB 602). In addition, eNB 602 may be in communication with a 5G NR base station (e.g., gNB 604) and may pass data between the EPC network 600 and gNB 604. Thus, EPC network 600 may be used (or reused) and gNB 604 may serve as extra capacity for UEs, e.g., for providing increased downlink throughput to UEs. In other words, LTE may be used for control plane signaling and NR may be used for user plane signaling. Thus, LTE may be used to establish connections to the network and NR may be used for data services.

[00110] Figure 6B illustrates a proposed protocol stack for eNB 602 and gNB 604. As shown, eNB 602 may include a medium access control (MAC) layer 632 that interfaces with radio link control (RLC) layers 622a-b. RLC layer 622a may also interface with packet data convergence protocol (PDCP) layer 612a and RLC layer 622b may interface with PDCP layer 612b. Similar to dual connectivity as specified in LTE-Advanced Release 12, PDCP layer 612a may interface via a master cell group (MCG) bearer with EPC network 600 whereas PDCP layer 612b may interface via a split bearer with EPC network 600.

[00111] Additionally, as shown, gNB 604 may include a MAC layer 634 that interfaces with RLC layers 624a-b. RLC layer 624a may interface with PDCP layer 612b of eNB 602 via an X₂ interface for information exchange and/or coordination (e.g., scheduling of a UE) between eNB 602 and gNB 604. In addition, RLC layer 624b may interface with PDCP layer 614. Similar to dual connectivity as specified in LTE-Advanced Release 12, PDCP layer 614 may interface with EPC network 600 via a secondary cell group (SCG) bearer. Thus, eNB 602 may be considered a master node (MeNB) while gNB 604 may be considered a secondary node (SgNB). In some scenarios, a UE may be required to maintain a connection to both an MeNB and a SgNB. In such scenarios,

the MeNB may be used to maintain a radio resource control (RRC) connection to an EPC while the SgNB may be used for capacity (e.g., additional downlink and/or uplink throughput).

5G Core Network Architecture – Interworking with Wi-Fi

[00112] In some embodiments, the 5G core network (CN) may be accessed via (or through) a cellular connection/interface (e.g., via a 3GPP communication architecture/protocol) and a non-cellular connection/interface (e.g., a non-3GPP access architecture/protocol such as Wi-Fi connection). Figure 7A illustrates an example of a 5G network architecture that incorporates both 3GPP (e.g., cellular) and non-3GPP (e.g., non-cellular) access to the 5G CN, according to some embodiments. As shown, a user equipment device (e.g., such as UE 106) may access the 5G CN through both a radio access network (RAN, e.g., such as gNB or base station 604) and an access point, such as AP 112. The AP 112 may include a connection to the Internet 700 as well as a connection to a non-3GPP inter-working function (N3IWF) 702 network entity. The N3IWF may include a connection to a core access and mobility management function (AMF) 704 of the 5G CN. The AMF 704 may include an instance of a 5G mobility management (5G MM) function associated with the UE 106. In addition, the RAN (e.g., gNB 604) may also have a connection to the AMF 704. Thus, the 5G CN may support unified authentication over both connections as well as allow simultaneous registration for UE 106 access via both gNB 604 and AP 112. As shown, the AMF 704 may include one or more functional entities associated with the 5G CN (e.g., network slice selection function (NSSF) 720, short message service function (SMSF) 722, application function (AF) 724, unified data management (UDM) 726, policy control function (PCF) 728, and/or authentication server function (AUSF) 730). Note that these functional entities may also be supported by a session management function (SMF) 706a and an SMF 706b of the 5G CN. The AMF 706 may be connected to (or in communication with) the SMF 706a. Further, the gNB 604 may in communication with (or connected to) a user plane function (UPF) 708a that may also be communication with the SMF 706a. Similarly, the N3IWF 702 may be communicating with a UPF 708b that may also be communicating with the SMF 706b. Both UPFs may be communicating with the data network (e.g., DN 710a and 710b) and/or the Internet 700 and IMS core network 710.

[00113] Figure 7B illustrates an example of a 5G network architecture that incorporates both dual 3GPP (e.g., LTE and 5G NR) access and non-3GPP access to the 5G CN, according to some embodiments. As shown, a user equipment device (e.g., such as UE 106) may access the 5G CN through both a radio access network (RAN, e.g., such as gNB or base station 604 or eNB or base station 602) and an access point, such as AP 112. The AP 112 may include a connection to the Internet 700 as well as a connection to the N3IWF 702 network entity. The N3IWF may include a

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

[00114] Note that in various embodiments, one or more of the above described network entities may be configured for software reconfiguration of a multi-radio wireless device that includes multiple radio computers, e.g., as further described herein.

[00115] Figure 8 illustrates an example of a baseband processor architecture for a UE (e.g., such as UE 106), according to some embodiments. The baseband processor architecture 800 described in Figure 8 may be implemented on one or more radios (e.g., radios 329 and/or 330 described above) or modems (e.g., modems 510 and/or 520) as described above. As shown, the non-access stratum (NAS) 810 may include a 5G NAS 820 and a legacy NAS 850. The legacy NAS 850 may include a communication connection with a legacy access stratum (AS) 870. The 5G NAS 820 may include communication connections with both a 5G AS 840 and a non-3GPP AS 830 and Wi-Fi AS 832. The 5G NAS 820 may include functional entities associated with both access stratum. Thus, the 5G NAS 820 may include multiple 5G MM entities 826 and 828 and 5G session management (SM) entities 822 and 824. The legacy NAS 850 may include functional entities such as short message service (SMS) entity 852, evolved packet system (EPS) session management (ESM) entity 854, session management (SM) entity 856, EPS mobility management (EMM) entity 858, and mobility management (MM)/ GPRS mobility management (GMM) entity 860. In

addition, the legacy AS 870 may include functional entities such as LTE AS 872, UMTS AS 874, and/or GSM/GPRS AS 876.

[00116] Thus, the baseband processor architecture 800 allows for a common 5G-NAS for both 5G cellular and non-cellular (e.g., non-3GPP access). Note that as shown, the 5G MM may maintain individual connection management and registration management state machines for each connection. Additionally, a device (e.g., UE 106) may register to a single PLMN (e.g., 5G CN) using 5G cellular access as well as non-cellular access. Further, it may be possible for the device to be in a connected state in one access and an idle state in another access and vice versa. Finally, there may be common 5G-MM procedures (e.g., registration, de-registration, identification, authentication, as so forth) for both accesses.

[00117] Note that in various embodiments, one or more of the above described functional entities of the 5G NAS and/or 5G AS may be configured to perform methods for software reconfiguration of a multi-radio wireless device that includes multiple radio computers, e.g., as further described herein.

Multi-Radio Interface (MURI) for Multiple Radio Computers

[00118] The European Commission currently prepares a Delegated Act (DA) and Implementing Act (IA) for Article 3(3)(i) of the Radio Equipment Directive (RED). In Article 3(3)(i), rules for Software (SW) based changes related to essential requirements of the RED are defined. In the future, it will thus be possible to have (third party) software altering radio related parameters similar to how Android™ applications allow portable, but non-radio related, software to be written by third parties.

[00119] In addition, the ETSI TC RRS standards committee has finalized a Software Reconfiguration framework targeting the modification of Mobile Devices: ETSI EN 303 095 (European Norm 303 095). This standard introduces a Software Reconfiguration architecture that includes four distinct interfaces. These interfaces are defined in EN 303 146-1, -2, -3 and -4, respectively. The so-called “Multiradio Interface (MURI)” is defined in EN 303 146-1 and includes mechanisms for (i) software provision, (ii) software installation, (iii) software execution, and (iv) software de-installation. However, it does not contain any provisions for “software update.” In this context, a mobile device was assumed to have a single radio computer for such purposes. Further, ETSI RRS is extending this framework to the reconfiguration of wireless equipment in general. In this context, the architecture framework is also generalized and multiple radio computers are made possible in the new framework. However, EN 303 146-1 does not address a platform offering multiple Radio Computers (e.g. one for safety related/critical applications and another one for non-safety related/critical applications).

[00120] Further, the corresponding system architecture (e.g., for the SW Reconfiguration framework specified in ETSI EN 303 095) is generalized in ETSI TS 103 648 (including the generalization of the mobile device architecture in ETSI EN 302 095). Additionally, ETSI TS 103 648 also defines a generalized radio equipment architecture. Note that in order to address multiple radio computers, the “Multiradio Interface (MURI)” as defined in EN 303 146-1 is currently being reworked towards an evolved version called “generalized Multiradio Interface (gMURI)” that will accommodate multiple radio computers in a target platform. gMURI is also defined in ETSI EN 303 146-1.

[00121] Embodiments described herein address extensions to the “Multiradio Interface (MURI)” defined in EN 303 146-1 to allow for multiple radio computers in a target system. For example, some embodiments described herein are directed to a platform that hosts at least two applications. In some embodiments, a platform may host two applications, where:

(a) a first application may be a safety related/critical application and a second application may be a non-safety related/critical application;

(b) a first application may affect the health/life of a patient (e.g., remote surgery and so forth.) and other application may not (e.g., transfer of video information and so forth);

(c) a first application may affect the functioning of a machine (e.g., robot in an industrial automation environment) while the second application does not (e.g., surveillance of the factory environment);

(d) a first application may affect the integrity of a machine (e.g., an agricultural machine, such as a tractor or similar) while the second one does not (e.g., video transfer, transfer on data on the processed farming surface, etc.); and/or

(e) a first application may be time sensitive (e.g., real time gaming, time sensitive networking, and so forth) while the second one is not (e.g., video transfer, audio transfer, and so forth.).

In some embodiments, the safety related/critical application and the non-safety related/critical application may need to be strictly separated, hence, the target system may include two independent radio computers building on independent radio operating systems. In some embodiments, assigning two distinct radio computers to each application may help to keep operations independent of each other, e.g., as in the case of a first application affecting the health/life of a patient, as in the case of a first application affecting the functioning of a machine, as in the case of a first application affecting the integrity of a machine, and/or as in the case of a first application being time sensitive.

[00122] In some embodiments, for example, as illustrated by Figure 9, a generalized system architecture for a mobile device may be defined. As shown, a reconfigurable wireless device 906

(e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106, may include a multiradio interface (MURI) (e.g., for interfacing with a communication service layer of wireless device 906) and a unified radio application interface (URAI) (e.g., for interfacing a unified radio application with a radio control framework). Below the MURI, the reconfigurable wireless device 906 may include radio storage 910, one or more radio computers 920a-n, and a radio platform 930 (e.g., which may include baseband processor(s) and/or radio frequency transceivers). The radio computers 920a-n may work under radio operating system control and may execute unified radio applications (URAs) and/or radio applications (e.g., software which enforce generation of transmit radio frequency signals and/or decoding of received radio frequency signals) which may be stored in radio storage 910. In addition, radio computers 920a-n may each include one or more programable processors, hardware accelerators, peripherals, and so forth. Further, each of radio computers 920a-n may include a radio virtual machine (RVM) (e.g., an abstract machine which may support reactive and/or concurrent executions and may be implemented as a controlled execution environment which may allow selection of a trade-off between flexibility of base band code development and/or required (re-)certification efforts), a native radio library (e.g., a library of stand functional blocks (SFBs) that may be provided by a platform vendor in a form of platform-specific executable code), and a back end (BE) compiler. Note that in at least some embodiments, the radio library and/or BE compiler may be provided at a cloud outside a radio computer.

[00123] In some embodiments, for example, as illustrated by Figure 10, a generalized radio equipment architecture for a mobile device may be defined. As shown, a reconfigurable wireless device 1006 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless device 906, may include a communication services layer 1010, a radio computer 1020, and a radio platform 1030. As shown, communication services layer 1010 may include administrator functions (including at least a security function, which interfaces with hardware root of trust 1002, e.g., which may provide security services, such as secure storage, with a high level of security assurance and a configuration manager), a mobility policy manager, a network stack, and a monitor function. Communication services layer 1010 may interface via a MURI with radio computer 1020. Radio computer 1020 may include a flow controller, a radio configuration manger, a multi-radio controller, and/or a resource manager. The radio computer 1020 may interface with one or more unified radio applications via a URAI. Radio platform(s) 1030 (e.g., which may include baseband processor(s) and/or radio frequency

transceivers) may also interface with the one or more unified radio applications via a reconfigurable radio frequency interface (RRFI).

[00124] In some embodiments, for example, as illustrated by Figure 11, a generalized radio equipment architecture for a mobile device may include multiple radio computers. As shown, a reconfigurable wireless device 1106 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless devices 906 and 1006, may include a communication services layer 1110, multiple radio computers 1120a-n, and a radio platform 1130. As shown, communication services layer 1110 may include administrator functions (including at least a security function, which interfaces with hardware root of trust 1102, e.g., which may provide security services, such as secure storage, with a high level of security assurance and a configuration manager), a mobility policy manager, a network stack, and a monitor function. Communication services layer 1110 may interface via a MURI with radio computers 1120a-n. Each radio computer 1120a-n may include a flow controller, a radio configuration manger, a multi-radio controller, and/or a resource manager. In addition, each radio control framework may have a dedicated radio operating system. Thus, if there are one or more issues (e.g., a malfunction, an exception, and so forth) of one radio operating system and/or radio control function, the issue(s) will not affect other radio operating systems and/or radio control functions, thereby protecting related applications. Each radio computer 1120a-n may interface with one or more unified radio applications via a URAI. Radio platform(s) 1130 (e.g., which may include baseband processor(s) and/or radio frequency transceivers) may also interface with respective one or more unified radio applications for each radio computer 1120a-n via an RRFI.

[00125] In some embodiments, for example, as illustrated by Figure 12, a generalized radio equipment architecture for a mobile device may include multiple radio computers as well as corresponding multiple radio platforms. As shown, a reconfigurable wireless device 1206 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless devices 906 and 1006, may include a communication services layer 1210, multiple radio computers 1220a-n, and multiple radio platforms 1230a-n. As shown, communication services layer 1210 may include administrator functions (including at least a security function, which interfaces with hardware root of trust 1202, e.g., which may provide security services, such as secure storage, with a high level of security assurance and a configuration manager), a mobility policy manager, a network stack, and a monitor function. Communication services layer 1210 may interface via a MURI with radio computers 1220a-n. Each radio computer 1220a-n may include a flow controller, a radio configuration manger, a multi-radio controller,

and/or a resource manager. In addition, each radio control framework may have a dedicated radio operating system. Thus, if there are one or more issues (e.g., a malfunction, an exception, and so forth) of one radio operating system and/or radio control function, the issue(s) will not affect other radio operating systems and/or radio control functions, thereby protecting related applications. Each radio computer 1220a-n may interface with one or more unified radio applications via a URAI. Radio platforms 1230a-n (e.g., which may include baseband processor(s) and/or radio frequency transceivers) may correspond to computer radios 1220a-n and may also interface with respective one or more unified radio applications for respective radio computers 1220a-n via respective RRFIs.

[00126] In some embodiments, the architectures described in Figures 11 and 12 may be combined and/or mixed. For example, a portion of the radio computers may be orchestrated (supported) by a single radio platform while another portion of radio computers may have independent radio platforms. As another example, radio computers may be grouped such that a first group of radio computers is supported by a first radio platform and a second group of radio computers is supported by a second radio platform. In some embodiments, such configurations may also be combined.

[00127] As shown in Figure 13, ETSI EN 303 146-1 Figure 5.1 defines interconnection between a communication service layer (CSL) and a radio control function (RCF) using a MURI for a reconfigurable mobile device. As shown, reconfigurable mobile device 1300 may include a CSL and a radio computer that includes a MURI and an RCF. The MURI may be defined to support three services between the CSL and RCF – administrative services, access control services, and data flow services. Administrative services may be used by some device configuration applications, e.g., such as an administrator function included in the CSL to (un)install a new URA into the reconfigurable mobile device and/or to create/delete an instance of the URA. Access control services may be used by the mobility policy manager to maintain user policies and preferences related to usage of different RATs and/or to make a selection between them. Data flow services may be used by a networking stack of the reconfigurable mobile device, such as a TCP/IP stack and may represent a set of (logical) link layer services, which are provided in a uniform manner regardless of which URAs may be active.

[00128] In some embodiments, for example, as illustrated by Figure 14, a generalized radio equipment architecture for a mobile device may include multiple MURIs for supporting multiple radio control functions. As shown, a reconfigurable wireless device 1406 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless devices 906, 1006, 1106, and/or 1206, may include a communication services layer 1410,

multiple radio computers 1420a-n. As shown, communication services layer 1410 may have interfaces with a MURI to support administrative services, access control services, and/or data flow services. Additionally, communication services layer 1410 may interface with radio computers 1420a-n via MURIs 1422a-n to exchange service information (e.g., in support of administrative services, access control services, and/or data flow services) with radio control frameworks 1424a-n. Thus, each radio control framework 1424a-n may have a dedicated MURI (e.g., MURIs 1422a-n). In some embodiments, there may be one or more groups of radio control functions, each group including one or more radio control functions and supported by a dedicated MURI.

[00129] In some embodiments, for example, as illustrated by Figure 15, a generalized radio equipment architecture for a mobile device may a MURI for supporting multiple radio control functions. As shown, a reconfigurable wireless device 1506 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless devices 906, 1006, 1106, and/or 1206, may include a communication services layer 1510, multiple radio computers 1520a-n. As shown, communication services layer 1510 may have interfaces with a MURI to support administrative services, access control services, and/or data flow services. Additionally, communication services layer 1510 may interface with radio computers 1520a-n via MURI 1522 to exchange service information (e.g., in support of administrative services, access control services, and/or data flow services) with radio control frameworks 1524a-n. Thus, MURI messages may be multiplexed to each radio control framework 1524a-n. In some embodiments, there may be one or more groups of radio control functions, each group including one or more radio control functions and supported by a dedicated MURI via multiplexing.

[00130] In some embodiments, a unique identifier (ID) may be assigned to each radio control function (RCF) (e.g., each RCF orchestrating (supporting) one or multiple radio computers) and a multiplexing entity may be provided at the interaction between the MURI and the various RCFs such that a message can be transported to an intended RCF. In some embodiments, when a message is transported from a specific RCF with a given ID to the MURI, the ID may aid the MURI in differentiating a source and indicate the source to the entities of the CSL (e.g., administrator, mobility policy manager, networking stack and monitor). In some embodiments, messages handled by the MURI may contain an ID field. In such embodiments, when a maximum number of RCFs is defined, a corresponding number of bits may be allocated to the ID field (e.g., when the maximum number is 255, then 8 bits will be allocated.)

[00131] Figure 16 illustrates a block diagram of an example of a method for attachment of an RCF to the MURI, according to some embodiments. The method shown in Figure 16 may be used

in conjunction with any of the systems, methods, or devices shown in the Figures, among other devices. In various embodiments, some of the method elements shown may be performed concurrently, in a different order than shown, or may be omitted. Additional method elements may also be performed as desired. As shown, this method may operate as follows.

[00132] At 1602, a MURI, e.g., as described herein, may receive an attachment request from a radio control function (RCF). In other words, the RCF may initiate an attachment request.

[00133] At 1604, the MURI may forward the attachment request to a communication service layer (CSL). In some embodiments, the attachment request may be handled (e.g., processed) by an administrator function (or entity) of the CSL. In some embodiments, the administrator function (or other entity) may determine an (unique) identifier (ID) to associate with the RCF. Alternatively, the administrator may reject the attachment request.

[00134] At 1606, the determination (accept or reject) may be received from the CSL. In other words, the determination (accept or reject) may be passed from the CSL to the MURI.

[00135] At 1608, the MURI may provide the determination (e.g., either by providing a rejection message or indicating the assigned ID) to the RCF.

[00136] In some embodiments, if attachment is accepted, the RCF may initiate termination (or detachment) through a corresponding request. In such instances, the RCF may be detached from the CSL and the assigned ID may be allocated to another RCF.

[00137] In some embodiments, when a single RCF is related to a single radio computer, a single unique ID may relate to (e.g., identify) both. In some embodiments, a unique ID may be attached to the RCF and the single radio computer related to the RCF may be uniquely identified through the same ID. In some embodiments, a unique ID may be attached to the radio computer and the single RCF related to the radio computer may be uniquely identified through the same ID. In some embodiments, a unique ID may be attached to both the RCF and the radio computer.

[00138] In some embodiments, when a single RCF is related to multiple radio computers, a unique ID may be assigned to each radio computer. In such embodiments, when there are multiple RCFs, each RCF may be related to a multitude of unique IDs. In some embodiments, a multiplexing entity between a MURI and a specific RCF may identify the target RCF for a given radio computer ID.

[00139] In some embodiments, each RCF may be assigned a unique ID called an RCF-ID and each radio computer may be assigned a unique ID called a RadioComputer-ID. In such embodiments, any instructions, commands, and/or data from the CSL may indicate a target RCF's RCF-ID and a target radio computer's RadioComputer-ID.

[00140] In some embodiments, data exchange between radio computers may be supported via a CSL. In some embodiments, a single radio computer that has a first unique ID may communicate to the CSL and request that a message is transferred to a different radio computer of a second ID.

[00141] As described herein, a CSL is introduced that includes specific functionalities. Note, however, that other embodiments are not so limited. In other words, the specific functionalities of the CSL described herein are just examples of the possible functionalities offered by a CSL. The embodiments described herein are applicable to any type of layer on top of the radio/hardware management (typically just on top of the radio operating system). Additionally, as described herein, an RCF is introduced that includes specific functionalities. Note, however, that other embodiments are not so limited. In other words, the specific functionalities of the RCF described herein are just examples of the possible functionalities offered by an RCF. The embodiments described herein are applicable to any type of layer on top of the radio/hardware management (typically just on top of the radio operating system).

[00142] Figure 17 illustrates the architecture of reference points for a reconfigurable mobile device 1700 as defined in ETSI EN 303 095 V1.3.1 Figure 5.1. Note that a solid line between two blocks denotes a reference point (e.g., a logical or physical interface) defined between the two blocks through which direct interaction(s) between the two blocks is(are) performed. Note further that a dotted line between two blocks denotes that interaction(s) between the two blocks is performed through a radio operating system (ROS) based on a command(s) issued by a corresponding block. Additionally, blocks in the RCF, e.g., configuration manager, radio configuration manager, multi-radio controller, and the resource manager may issue the command for the interaction(s) to take place at the unified radio application (URA) through the ROS. In addition, each reference point may be based on three kinds of interfaces, e.g. MURI which are interfaces between entities of CSL and that of RCF, URAI which are interfaces between URA and entities of RCF, and RRFI which are interfaces between URA and Radio Frequency (RF) part. In addition to MURI, URAI, and RRFI, interfaces between entities of RCF have also been defined as reference points. These reference points are fully defined by ETSI EN 303 095 V1.3.1 Sections 5.2-5.13. In particular, the MURI may support connections between the CSL and the RCF for reference points CF1, CF2, CTRL1, CTRL4, DCTRL1, and CII.

[00143] In some embodiments, for example as illustrated by Figure 18, reference points between the CSL and RCF(s) may be complemented by a corresponding multiplexing entity such that the CSL can communicate with multiple RCFs. As shown, a reconfigurable wireless device 1806 (e.g., a mobile device with radio communication capabilities providing support for radio reconfiguration), which may be similar to and/or include features as described in reference to UE 106 as well as reconfigurable wireless devices 906, 1006, 1106, and/or 1206, may include a

communication services layer 1810 and multiple radio computers 1820a-n. As shown, communication services layer 1810 may have interfaces with a MURI to support administrative services, access control services, and/or data flow services. Additionally, communication services layer 1810 may interface with radio computers 1820a-n via MURI supported by multiplexing entity 1815 to exchange service information (e.g., in support of administrative services, access control services, and/or data flow services) with radio computers 1820a-n. Thus, MURI messages may be multiplexed to each radio control framework. In some embodiments, there may be one or more groups of radio control functions, each group including one or more radio control functions and supported by a dedicated MURI via multiplexing. In addition, radio computers 1820a-n may interface with radio platforms 1830a-n via independent RRFIs. As shown, various RCFs may be assigned respective IDs and multiplexing entity 1815 may forward messages to the concerned RCF in function of the ID indicated in the respective messages. For example, the multiplexing entity may connect the administrator to the configuration manager of the RCF of radio computer 1820a if the messages to be conveyed include an identifier associated with the RCF of radio computer 1820a. In some embodiments, multiplexing entity 1815 (e.g., which may be associated with and/or including in a MURI) may support connections from CSL 1810 and RCFs of radio computers 1820a-n for reference points CF1, CF2, CTRL1, CTRL4, DCTRL1, and/or CII. For example, for interactions between an administrator (e.g., in CSL 1810) and a configuration manager (e.g., in one of the RCFs of radio computers 1820a-n), multiplexer entity 1815 (e.g., for the direction from CSL 1810 to the RCFs) and/or de-multiplexer entity 1815 (e.g., for the direction from the RCFs to CSL 1810) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to/from a CF1 reference point of a radio computer of the given ID. As another example, for interactions between a mobility policy manager (e.g., in the CSL 1810) and a configuration manager (e.g., in one of the RCFs), the multiplexer entity 1815 may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CF2 reference point of the radio computer of the given ID. As yet a further example, for interactions between a mobility policy manager (e.g., in CSL 1810) and a radio configuration manager (e.g., in one of the RCFs), multiplexer entity 1815 may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CTRL1 reference point of the radio computer of the given ID. As another example, for interactions between a network (or networking) stack (e.g., in CSL 1810) and a flow controller (e.g., in one of the RCFs), multiplexer

entity 1815 may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CTRL4 reference point and/or to a DCTRL1 reference point of the radio computer of the given ID. As another example, for interactions between a monitor (e.g., in CSL 1810) and one of unified radio applications, the multiplexer entity may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CII reference point reference point of the radio computer of the given ID.

[00144] In some embodiments, a class definition for a radio computer, such as radio computers described herein may be as defined by Table 1, e.g.:

Class RadioComputer	
This class contains all URA related information about resources and interactions related to hardware and software of a reconfigurable MD.	
DERIVED FROM	
ATTRIBUTES	
CONTAINED IN	
CONTAINS	RCCapabilities [*], RCConfiguration [*], RCMeasurements [*], Channel [*], RCProfile [*], RadioAPP [*], RadioOS [*]
SUPPORTED EVENTS	

Table 1: Radio Computer Class

Thus, each parameter (e.g., RCCapabilities, RCConfiguration, RCMeasurements, Channel, RCProfile, RadioAPP, and/or RadioOS) may have zero or more instances.

[00145] In some embodiments, each interface class related to the MURI may be defined as illustrated in the following tables. Table 2 illustrates an example definition for an Administrative Services Class, Table 3 illustrates an example definition for an Access Control Services Class, and Table 4 illustrates an example definition for a Data Flow Services Class.

Class I Administrative Services		
This class describes interfaces supporting Administrative Services.		
OPERATIONS		
installRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is related to the installation of an URA.		
uninstallRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
<i>This operation is related to the uninstallation of an URA</i>		
updateRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is related to the update of an URA		
createRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is related to the creation of an instance of an URA.		
delRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is related to the deletion of an instance of an URA.		
getRadioAppParameters	<i>Return type:</i> RadioAppParameters	<i>Value type:</i> InputItem
This operation is needed for retrieving URA parameters.		
setRadioAppParameters	<i>Return type:</i> BOOLEAN	<i>Value type:</i> InputItem
This operation is needed for setting URA parameters.		
getListOfRadioApps	<i>Return type:</i> RadioAppsList	<i>Value type:</i> InputItem
This operation is needed for getting a list of the installed/instantiated/activated URA(s).		

Table 2: Administrative Services Class

ClassIAccessControlServices		
This class describes interfaces supporting Access Control Services.		
OPERATIONS		
activateRadioApps	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is needed for activating a URA.		
deactivateRadioApps	<i>Return type:</i> BOOLEAN	<i>Value type:</i> InputItem
This operation is needed for deactivating a URA.		
getListOfRadioApps	<i>Return type:</i> RadioAppsList	<i>Value type:</i> InputItem
This operation is needed for getting a list of the installed/instantiated/activated URA(s).		
startRadioMeasurement	<i>Return type:</i> BOOLEAN	<i>Value type:</i> InputItem
This operation starts the measurements related to radio environments and MD capabilities.		
stopRadioMeasurement	<i>Return type:</i> RadioMeasurementsList	<i>Value type:</i> InputItem
This operation stops the measurements related to radio environments and MD capabilities.		
createAssociation	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation is related to the creation of a network association.		
terminateAssociation	<i>Return type:</i> BOOLEAN	<i>Value type:</i> InputItem
This operation terminates a network association previously created.		
createDataFlow	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation creates a data flow.		
terminateDataFlow	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation terminates a data flow.		

changeDataFlow	<i>Return type:</i> INTEGER	<i>Value type:</i> InputItem
This operation move/separate/combine data flow.		
reportErrors	<i>Return type:</i> Void	<i>Value type:</i> InputItem
This operation is needed for reporting errors.		

Table 3: Access Control Services Class

ClassIDataFlowServices		
This class describes interfaces supporting Data Flow Services.		
OPERATIONS		
sendUserData	<i>Return type:</i> BOOLEAN	<i>Value type:</i> InputItem
This operation is needed for sending user data.		
receiveUserData	<i>Return type:</i> UserData	<i>Value type:</i> InputItem
This operation is needed for receiving user data.		

Table 4: Data Flow Services Class

Thus, as shown, value types for all of parameters in these service classes may considered an “input item” instead of a public. In other words, these parameters’ value type may be configurable, at least in some embodiments.

[00146] Figure 19 illustrates a block diagram of an example of a method for of using a generalized multiradio interface (gMURI) for managing multiple radio computers, according to some embodiments. The method Figure 19 illustrates a block diagram of an example of a method for of using a generalized multiradio interface (gMURI) for managing multiple radio computers, according to some embodiments. shown in Figure 19 may be used in conjunction with any of the systems, methods, or devices shown in the Figures, among other devices. In various embodiments, some of the method elements shown may be performed concurrently, in a different order than shown, or may be omitted. Additional method elements may also be performed as desired. As shown, this method may operate as follows.

[00147] At 1902, a first radio computer (e.g., first radio) may be associated or caused to associate with a first application and a second radio computer (e.g., a second radio) may be associated or caused to associate with a second application. In some embodiments, the first and second applications may perform different functions (and/or services).

[00148] At 1904, data between a communication services layer (CSL) and the first and second radio computers may be communicated (e.g., exchanged).

[00149] In some embodiments, to communicate the data, the data may be communicated between the CSL and a first gMURI. Additionally, the data may be communicated between the first gMURI and a first radio control framework (RCF), where the RCF manages the first radio computer. In some embodiments, to communicate the data, the data may be communicated between the CSL and a second gMURI. Additionally, the data may be communicated between the second gMURI and a second RCF, where the RCF manages the second radio computer. In some embodiments, the first and/or second RCFs may be assigned unique identifiers (IDs). In some embodiments, a first set of data may be communicated between the CSL and the first radio computer based on the first RCF's unique ID. In some embodiments, a second set of data may be communicated between the CSL and the second radio computer based on the second RCF's unique ID. In some embodiments, the first and/or second radio computers may be assigned unique identifiers (IDs). In some embodiments, a first set of data may be communicated between the CSL and the first radio computer based on the first radio computer's unique ID. In some embodiments, a second set of data may be communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00150] In some embodiments, to communicate the data, the data may be communicated between the CSL and a gMURI. Additionally, the data may be communicated between the gMURI and a first RCF, where the first RCF manages the first radio computer. In some embodiments, the data may be communicated between the gMURI and a second RCF, where the second RCF manages the second radio computer. In some embodiments, the first and/or second RCFs may be assigned unique identifiers (IDs). In some embodiments, a first set of data may be communicated between the CSL and the first radio computer based on the first RCF's unique ID. In some embodiments, a second set of data may be communicated between the CSL and the second radio computer based on the second RCF's unique ID. In some embodiments, the first and/or second radio computers may be assigned unique identifiers (IDs). In some embodiments, a first set of data may be communicated between the CSL and the first radio computer based on the first radio computer's unique ID. In some embodiments, a second set of data may be communicated between the CSL and the second radio computer based on the second radio computer's unique ID. In some embodiments, the data may be multiplexed prior to the gMURI communicating the data with the first and second RCFs.

Exemplary Systems

[00151] Figures 20 to 29 illustrate and describe various additional exemplary systems and devices that may be used to implement the embodiments described herein.

[00152] Figure 20 illustrates an example architecture of a system 2000 of a network, in accordance with various embodiments. The following description is provided for an example system 2000 that operates in conjunction with the LTE system standards and 5G or NR system standards as provided by 3GPP technical specifications. However, the example embodiments are not limited in this regard and the described embodiments may apply to other networks that benefit from the principles described herein, such as future 3GPP systems (e.g., Sixth Generation (6G)) systems, IEEE 802.16 protocols (e.g., WMAN, WiMAX, etc.), or the like.

[00153] As shown by Figure 20, the system 2000 includes UE 2001a and UE 2001b (collectively referred to as “UEs 2001” or “UE 2001”, each of which may be a UE 106 as described herein). In this example, UEs 2001 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as consumer electronics devices, cellular phones, smartphones, feature phones, tablet computers, wearable computer devices, personal digital assistants (PDAs), pagers, wireless handsets, desktop computers, laptop computers, in-vehicle infotainment (IVI), in-car entertainment (ICE) devices, an Instrument Cluster (IC), head-up display (HUD) devices, onboard diagnostic (OBD) devices, dashtop mobile equipment (DME), mobile data terminals (MDTs), Electronic Engine Management System (EEMS), electronic/engine control units (ECUs), electronic/engine control modules (ECMs), embedded systems, microcontrollers, control modules, engine management systems (EMS), networked or “smart” appliances, MTC devices, M2M, IoT devices, and/or the like.

[00154] In some embodiments, any of the UEs 2001 may be IoT UEs, which may comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as M2M or MTC for exchanging data with an MTC server or device via a PLMN, ProSe or D2D communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[00155] The UEs 2001 may be configured to connect, for example, communicatively couple, with an or RAN 2010. In embodiments, the RAN 2010 may be an NG RAN or a 5G RAN, an E-UTRAN, or a legacy RAN, such as a UTRAN or GERAN. As used herein, the term “NG RAN” or the like may refer to a RAN 2010 that operates in an NR or 5G system 2000, and the term “E-UTRAN” or the like may refer to a RAN 2010 that operates in an LTE or 4G system 2000. The

UEs 2001 utilize connections (or channels) 2003 and 2004, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[00156] In this example, the connections 2003 and 2004 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a GSM protocol, a CDMA network protocol, a PTT protocol, a POC protocol, a UMTS protocol, a 3GPP LTE protocol, a 5G protocol, a NR protocol, and/or any of the other communications protocols discussed herein. In embodiments, the UEs 2001 may directly exchange communication data via a ProSe interface 2005. The ProSe interface 2005 may alternatively be referred to as a SL interface 2005 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[00157] The UE 2001b is shown to be configured to access an AP 2006 (also referred to as “WLAN node 2006,” “WLAN 2006,” “WLAN Termination 2006,” “WT 2006” or the like) via connection 2007. The connection 2007 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 2006 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 2006 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below). In various embodiments, the UE 2001b, RAN 2010, and AP 2006 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 2001b in RRC_CONNECTED being configured by a RAN node 2011a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 2001b using WLAN radio resources (e.g., connection 2007) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 2007. IPsec tunneling may include encapsulating the entirety of original IP packets and adding a new packet header, thereby protecting the original header of the IP packets.

[00158] The RAN 2010 can include one or more AN nodes or RAN nodes 2011a and 2011b (collectively referred to as “RAN nodes 2011” or “RAN node 2011”, each of which may be a base station 106 as described herein) that enable the connections 2003 and 2004. As used herein, the terms “access node,” “access point,” or the like may describe equipment that provides the radio baseband functions for data and/or voice connectivity between a network and one or more users. These access nodes can be referred to as BS, gNBs, RAN nodes, eNBs, NodeBs, RSUs, TRxPs or TRPs, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). As used herein, the term “NG RAN node” or the like may refer to a RAN node 2011 that operates in an NR or 5G system 2000 (for example, a gNB), and the term “E-UTRAN node” or the like may refer to a RAN node 2011 that operates in an LTE or 4G system 2000 (e.g., an eNB). According to various embodiments, the RAN nodes 2011 may be implemented as one or more of a dedicated physical device such as a

macrocell base station, and/or a low power (LP) base station for providing femtocells, picocells or other like cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells.

[00159] In some embodiments, all or parts of the RAN nodes 2011 may be implemented as one or more software entities running on server computers as part of a virtual network, which may be referred to as a CRAN and/or a virtual baseband unit pool (vBBUP). In these embodiments, the CRAN or vBBUP may implement a RAN function split, such as a PDCP split wherein RRC and PDCP layers are operated by the CRAN/vBBUP and other L2 protocol entities are operated by individual RAN nodes 2011; a MAC/PHY split wherein RRC, PDCP, RLC, and MAC layers are operated by the CRAN/vBBUP and the PHY layer is operated by individual RAN nodes 2011; or a “lower PHY” split wherein RRC, PDCP, RLC, MAC layers and upper portions of the PHY layer are operated by the CRAN/vBBUP and lower portions of the PHY layer are operated by individual RAN nodes 2011. This virtualized framework allows the freed-up processor cores of the RAN nodes 2011 to perform other virtualized applications. In some implementations, an individual RAN node 2011 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 20). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 23), and the gNB-CU may be operated by a server that is located in the RAN 2010 (not shown) or by a server pool in a similar manner as the CRAN/vBBUP. Additionally or alternatively, one or more of the RAN nodes 2011 may be next generation eNBs (ng-eNBs), which are RAN nodes that provide E-UTRA user plane and control plane protocol terminations toward the UEs 2001, and are connected to a 5GC (e.g., CN 2220 of Figure 22) via an NG interface (discussed infra).

[00160] In V2X scenarios one or more of the RAN nodes 2011 may be or act as RSUs. The term “Road Side Unit” or “RSU” may refer to any transportation infrastructure entity used for V2X communications. An RSU may be implemented in or by a suitable RAN node or a stationary (or relatively stationary) UE, where an RSU implemented in or by a UE may be referred to as a “UE-type RSU,” an RSU implemented in or by an eNB may be referred to as an “eNB-type RSU,” an RSU implemented in or by a gNB may be referred to as a “gNB-type RSU,” and the like. In one example, an RSU is a computing device coupled with radio frequency circuitry located on a roadside that provides connectivity support to passing vehicle UEs 2001 (vUEs 2001). The RSU may also include internal data storage circuitry to store intersection map geometry, traffic statistics, media, as well as applications/software to sense and control ongoing vehicular and pedestrian traffic. The RSU may operate on the 5.9 GHz Direct Short-Range Communications (DSRC) band to provide very low latency communications required for high speed events, such as crash avoidance, traffic warnings, and the like. Additionally or alternatively, the RSU may operate on

the cellular V2X band to provide the aforementioned low latency communications, as well as other cellular communications services. Additionally or alternatively, the RSU may operate as a Wi-Fi hotspot (2.4 GHz band) and/or provide connectivity to one or more cellular networks to provide uplink and downlink communications. The computing device(s) and some or all of the radiofrequency circuitry of the RSU may be packaged in a weatherproof enclosure suitable for outdoor installation, and may include a network interface controller to provide a wired connection (e.g., Ethernet) to a traffic signal controller and/or a backhaul network.

[00161] Any of the RAN nodes 2011 can terminate the air interface protocol and can be the first point of contact for the UEs 2001. In some embodiments, any of the RAN nodes 2011 can fulfill various logical functions for the RAN 2010 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[00162] In embodiments, the UEs 2001 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 2011 over a multicarrier communication channel in accordance with various communication techniques, such as, but not limited to, an OFDMA communication technique (e.g., for downlink communications) or a SC-FDMA communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[00163] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 2011 to the UEs 2001, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[00164] According to various embodiments, the UEs 2001, 2002 and the RAN nodes 2011, 2012 communicate data (for example, transmit and receive) data over a licensed medium (also referred to as the “licensed spectrum” and/or the “licensed band”) and an unlicensed shared medium (also

referred to as the “unlicensed spectrum” and/or the “unlicensed band”). The licensed spectrum may include channels that operate in the frequency range of approximately 400 MHz to approximately 3.8 GHz, whereas the unlicensed spectrum may include the 5 GHz band.

[00165] To operate in the unlicensed spectrum, the UEs 2001, 2002 and the RAN nodes 2011, 2012 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 2001, 2002 and the RAN nodes 2011, 2012 may perform one or more known medium-sensing operations and/or carrier-sensing operations in order to determine whether one or more channels in the unlicensed spectrum is unavailable or otherwise occupied prior to transmitting in the unlicensed spectrum. The medium/carrier sensing operations may be performed according to a listen-before-talk (LBT) protocol.

[00166] LBT is a mechanism whereby equipment (for example, UEs 2001, 2002, RAN nodes 2011, 2012, etc.) senses a medium (for example, a channel or carrier frequency) and transmits when the medium is sensed to be idle (or when a specific channel in the medium is sensed to be unoccupied). The medium sensing operation may include CCA, which utilizes at least ED to determine the presence or absence of other signals on a channel in order to determine if a channel is occupied or clear. This LBT mechanism allows cellular/LAA networks to coexist with incumbent systems in the unlicensed spectrum and with other LAA networks. ED may include sensing RF energy across an intended transmission band for a period of time and comparing the sensed RF energy to a predefined or configured threshold.

[00167] Typically, the incumbent systems in the 5 GHz band are WLANs based on IEEE 802.11 technologies. WLAN employs a contention-based channel access mechanism, called CSMA/CA. Here, when a WLAN node (e.g., a mobile station (MS) such as UE 2001 or 2002, AP 2006, or the like) intends to transmit, the WLAN node may first perform CCA before transmission. Additionally, a backoff mechanism is used to avoid collisions in situations where more than one WLAN node senses the channel as idle and transmits at the same time. The backoff mechanism may be a counter that is drawn randomly within the CWS, which is increased exponentially upon the occurrence of collision and reset to a minimum value when the transmission succeeds. The LBT mechanism designed for LAA is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions, respectively, may have an LAA contention window that is variable in length between X and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for LAA. In one example, the minimum CWS for an LAA transmission may be 9 microseconds (μ s); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[00168] The LAA mechanisms are built upon CA technologies of LTE-Advanced systems. In CA, each aggregated carrier is referred to as a CC. A CC may have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five CCs can be aggregated, and therefore, a maximum aggregated bandwidth is 100 MHz. In FDD systems, the number of aggregated carriers can be different for DL and UL, where the number of UL CCs is equal to or lower than the number of DL component carriers. In some cases, individual CCs can have a different bandwidth than other CCs. In TDD systems, the number of CCs as well as the bandwidths of each CC is usually the same for DL and UL.

[00169] CA also comprises individual serving cells to provide individual CCs. The coverage of the serving cells may differ, for example, because CCs on different frequency bands will experience different pathloss. A primary service cell or PCell may provide a PCC for both UL and DL, and may handle RRC and NAS related activities. The other serving cells are referred to as SCells, and each SCell may provide an individual SCC for both UL and DL. The SCCs may be added and removed as required, while changing the PCC may require the UE 2001, 2002 to undergo a handover. In LAA, eLAA, and feLAA, some or all of the SCells may operate in the unlicensed spectrum (referred to as “LAA SCells”), and the LAA SCells are assisted by a PCell operating in the licensed spectrum. When a UE is configured with more than one LAA SCell, the UE may receive UL grants on the configured LAA SCells indicating different PUSCH starting positions within a same subframe.

[00170] The PDSCH carries user data and higher-layer signaling to the UEs 2001. The PDCCH carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 2001 about the transport format, resource allocation, and HARQ information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 2001b within a cell) may be performed at any of the RAN nodes 2011 based on channel quality information fed back from any of the UEs 2001. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 2001.

[00171] The PDCCH uses CCEs to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as REGs. Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the DCI and the channel condition. There can be four or more different

PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, $L=1, 2, 4$, or 8).

[00172] Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an EPDCCH that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more ECCEs. Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an EREGs. An ECCE may have other numbers of EREGs in some situations.

[00173] The RAN nodes 2011 may be configured to communicate with one another via interface 2012. In embodiments where the system 2000 is an LTE system (e.g., when CN 2020 is an EPC 2120 as in Figure 21), the interface 2012 may be an X2 interface 2012. The X2 interface may be defined between two or more RAN nodes 2011 (e.g., two or more eNBs and the like) that connect to EPC 2020, and/or between two eNBs connecting to EPC 2020. In some implementations, the X2 interface may include an X2 user plane interface (X2-U) and an X2 control plane interface (X2-C). The X2-U may provide flow control mechanisms for user data packets transferred over the X2 interface, and may be used to communicate information about the delivery of user data between eNBs. For example, the X2-U may provide specific sequence number information for user data transferred from a MeNB to an SeNB; information about successful in sequence delivery of PDCP PDUs to a UE 2001 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 2001; information about a current minimum desired buffer size at the SeNB for transmitting to the UE user data; and the like. The X2-C may provide intra-LTE access mobility functionality, including context transfers from source to target eNBs, user plane transport control, etc.; load management functionality; as well as inter-cell interference coordination functionality.

[00174] In embodiments where the system 2000 is a 5G or NR system (e.g., when CN 2020 is an 5GC 2220 as in Figure 22), the interface 2012 may be an Xn interface 2012. The Xn interface is defined between two or more RAN nodes 2011 (e.g., two or more gNBs and the like) that connect to 5GC 2020, between a RAN node 2011 (e.g., a gNB) connecting to 5GC 2020 and an eNB, and/or between two eNBs connecting to 5GC 2020. In some implementations, the Xn interface may include an Xn user plane (Xn-U) interface and an Xn control plane (Xn-C) interface. The Xn-U may provide non-guaranteed delivery of user plane PDUs and support/provide data forwarding and flow control functionality. The Xn-C may provide management and error handling functionality, functionality to manage the Xn-C interface; mobility support for UE 2001 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 2011. The mobility support may include context transfer from an old (source) serving RAN node 2011 to new (target) serving RAN node 2011;

and control of user plane tunnels between old (source) serving RAN node 2011 to new (target) serving RAN node 2011. A protocol stack of the Xn-U may include a transport network layer built on Internet Protocol (IP) transport layer, and a GTP-U layer on top of a UDP and/or IP layer(s) to carry user plane PDUs. The Xn-C protocol stack may include an application layer signaling protocol (referred to as Xn Application Protocol (Xn-AP)) and a transport network layer that is built on SCTP. The SCTP may be on top of an IP layer, and may provide the guaranteed delivery of application layer messages. In the transport IP layer, point-to-point transmission is used to deliver the signaling PDUs. In other implementations, the Xn-U protocol stack and/or the Xn-C protocol stack may be same or similar to the user plane and/or control plane protocol stack(s) shown and described herein.

[00175] The RAN 2010 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 2020. The CN 2020 may comprise a plurality of network elements 2022, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 2001) who are connected to the CN 2020 via the RAN 2010. The components of the CN 2020 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In some embodiments, NFV may be utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums (described in further detail below). A logical instantiation of the CN 2020 may be referred to as a network slice, and a logical instantiation of a portion of the CN 2020 may be referred to as a network sub-slice. NFV architectures and infrastructures may be used to virtualize one or more network functions, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[00176] Generally, the application server 2030 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS PS domain, LTE PS data services, etc.). The application server 2030 can also be configured to support one or more communication services (e.g., VoIP sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 2001 via the EPC 2020.

[00177] In embodiments, the CN 2020 may be a 5GC (referred to as “5GC 2020” or the like), and the RAN 2010 may be connected with the CN 2020 via an NG interface 2013. In embodiments, the NG interface 2013 may be split into two parts, an NG user plane (NG-U) interface 2014, which carries traffic data between the RAN nodes 2011 and a UPF, and the S1 control plane (NG-C)

interface 2015, which is a signaling interface between the RAN nodes 2011 and AMFs. Embodiments where the CN 2020 is a 5GC 2020 are discussed in more detail with regard to Figure 22.

[00178] In embodiments, the CN 2020 may be a 5G CN (referred to as “5GC 2020” or the like), while in other embodiments, the CN 2020 may be an EPC). Where CN 2020 is an EPC (referred to as “EPC 2020” or the like), the RAN 2010 may be connected with the CN 2020 via an S1 interface 2013. In embodiments, the S1 interface 2013 may be split into two parts, an S1 user plane (S1-U) interface 2014, which carries traffic data between the RAN nodes 2011 and the S-GW, and the S1-MME interface 2015, which is a signaling interface between the RAN nodes 2011 and MMEs. An example architecture wherein the CN 2020 is an EPC 2020 is shown by Figure 21.

[00179] Figure 21 illustrates an example architecture of a system 2100 including a first CN 2120, in accordance with various embodiments. In this example, system 2100 may implement the LTE standard wherein the CN 2120 is an EPC 2120 that corresponds with CN 2020 of Figure 20. Additionally, the UE 2101 may be the same or similar as the UEs 2001 of Figure 20, and the E-UTRAN 2110 may be a RAN that is the same or similar to the RAN 2010 of Figure 20, and which may include RAN nodes 2011 discussed previously. The CN 2120 may comprise MMEs 2121, an S-GW 2122, a P-GW 2123, an HSS 2124, and a SGSN 2125.

[00180] The MMEs 2121 may be similar in function to the control plane of legacy SGSN, and may implement MM functions to keep track of the current location of a UE 2101. The MMEs 2121 may perform various MM procedures to manage mobility aspects in access such as gateway selection and tracking area list management. MM (also referred to as “EPS MM” or “EMM” in E-UTRAN systems) may refer to all applicable procedures, methods, data storage, etc. that are used to maintain knowledge about a present location of the UE 2101, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 2101 and the MME 2121 may include an MM or EMM sublayer, and an MM context may be established in the UE 2101 and the MME 2121 when an attach procedure is successfully completed. The MM context may be a data structure or database object that stores MM-related information of the UE 2101. The MMEs 2121 may be coupled with the HSS 2124 via an S6a reference point, coupled with the SGSN 2125 via an S3 reference point, and coupled with the S-GW 2122 via an S11 reference point.

[00181] The SGSN 2125 may be a node that serves the UE 2101 by tracking the location of an individual UE 2101 and performing security functions. In addition, the SGSN 2125 may perform Inter-EPC node signaling for mobility between 2G/3G and E-UTRAN 3GPP access networks; PDN and S-GW selection as specified by the MMEs 2121; handling of UE 2101 time zone functions as specified by the MMEs 2121; and MME selection for handovers to E-UTRAN 3GPP

access network. The S3 reference point between the MMEs 2121 and the SGSN 2125 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[00182] The HSS 2124 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The EPC 2120 may comprise one or several HSSs 2124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 2124 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 2124 and the MMEs 2121 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 2120 between HSS 2124 and the MMEs 2121.

[00183] The S-GW 2122 may terminate the S1 interface 2103 ("S1-U" in Figure 21) toward the RAN 2110, and routes data packets between the RAN 2110 and the EPC 2120. In addition, the S-GW 2122 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The S11 reference point between the S-GW 2122 and the MMEs 2121 may provide a control plane between the MMEs 2121 and the S-GW 2122. The S-GW 2122 may be coupled with the P-GW 2123 via an S5 reference point.

[00184] The P-GW 2123 may terminate an SGi interface toward a PDN 2130. The P-GW 2123 may route data packets between the EPC 2120 and external networks such as a network including the application server 2030 (alternatively referred to as an "AF") via an IP interface 2025 (see e.g., Figure 20). In embodiments, the P-GW 2123 may be communicatively coupled to an application server (application server 2030 of Figure 20 or PDN 2130 in Figure 21) via an IP communications interface 2025 (see, e.g., Figure 20). The S5 reference point between the P-GW 2123 and the S-GW 2122 may provide user plane tunneling and tunnel management between the P-GW 2123 and the S-GW 2122. The S5 reference point may also be used for S-GW 2122 relocation due to UE 2101 mobility and if the S-GW 2122 needs to connect to a non-collocated P-GW 2123 for the required PDN connectivity. The P-GW 2123 may further include a node for policy enforcement and charging data collection (e.g., PCEF (not shown)). Additionally, the SGi reference point between the P-GW 2123 and the packet data network (PDN) 2130 may be an operator external public, a private PDN, or an intra operator packet data network, for example, for provision of IMS services. The P-GW 2123 may be coupled with a PCRF 2126 via a Gx reference point.

[00185] PCRF 2126 is the policy and charging control element of the EPC 2120. In a non-roaming scenario, there may be a single PCRF 2126 in the Home Public Land Mobile Network (HPLMN) associated with a UE 2101's Internet Protocol Connectivity Access Network (IP-CAN) session. In

a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE 2101's IP-CAN session, a Home PCRF (H-PCRF) within an HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 2126 may be communicatively coupled to the application server 2130 via the P-GW 2123. The application server 2130 may signal the PCRF 2126 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 2126 may provision this rule into a PCEF (not shown) with the appropriate TFT and QCI, which commences the QoS and charging as specified by the application server 2130. The Gx reference point between the PCRF 2126 and the P-GW 2123 may allow for the transfer of QoS policy and charging rules from the PCRF 2126 to PCEF in the P-GW 2123. An Rx reference point may reside between the PDN 2130 (or "AF 2130") and the PCRF 2126.

[00186] Figure 22 illustrates an architecture of a system 2200 including a second CN 2220 in accordance with various embodiments. The system 2200 is shown to include a UE 2201, which may be the same or similar to the UEs 2001 and UE 2101 discussed previously; a (R)AN 2210, which may be the same or similar to the RAN 2010 and RAN 2110 discussed previously, and which may include RAN nodes 2011 discussed previously; and a DN 2203, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 2220. The 5GC 2220 may include an AUSF 2222; an AMF 2221; a SMF 2224; a NEF 2223; a PCF 2226; an NRF 2225; a UDM 2227; an AF 2228; a UPF 2202; and a NSSF 2229.

[00187] The UPF 2202 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 2203, and a branching point to support multi-homed PDU session. The UPF 2202 may also perform packet routing and forwarding, perform packet inspection, enforce the user plane part of policy rules, lawfully intercept packets (UP collection), perform traffic usage reporting, perform QoS handling for a user plane (e.g., packet filtering, gating, UL/DL rate enforcement), perform Uplink Traffic verification (e.g., SDF to QoS flow mapping), transport level packet marking in the uplink and downlink, and perform downlink packet buffering and downlink data notification triggering. UPF 2202 may include an uplink classifier to support routing traffic flows to a data network. The DN 2203 may represent various network operator services, Internet access, or third-party services. DN 2203 may include, or be similar to, application server 2030 discussed previously. The UPF 2202 may interact with the SMF 2224 via an N4 reference point between the SMF 2224 and the UPF 2202.

[00188] The AUSF 2222 may store data for authentication of UE 2201 and handle authentication-related functionality. The AUSF 2222 may facilitate a common authentication framework for various access types. The AUSF 2222 may communicate with the AMF 2221 via an N12 reference point between the AMF 2221 and the AUSF 2222; and may communicate with the UDM 2227 via

an N13 reference point between the UDM 2227 and the AUSF 2222. Additionally, the AUSF 2222 may exhibit an Nausf service-based interface.

[00189] The AMF 2221 may be responsible for registration management (e.g., for registering UE 2201, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 2221 may be a termination point for the an N11 reference point between the AMF 2221 and the SMF 2224. The AMF 2221 may provide transport for SM messages between the UE 2201 and the SMF 2224, and act as a transparent proxy for routing SM messages. AMF 2221 may also provide transport for SMS messages between UE 2201 and an SMSF (not shown by Figure 22). AMF 2221 may act as SEAF, which may include interaction with the AUSF 2222 and the UE 2201, receipt of an intermediate key that was established as a result of the UE 2201 authentication process. Where USIM based authentication is used, the AMF 2221 may retrieve the security material from the AUSF 2222. AMF 2221 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 2221 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 2210 and the AMF 2221; and the AMF 2221 may be a termination point of NAS (N1) signaling, and perform NAS ciphering and integrity protection.

[00190] AMF 2221 may also support NAS signaling with a UE 2201 over an N3 IWF interface. The N3IWF may be used to provide access to untrusted entities. N3IWF may be a termination point for the N2 interface between the (R)AN 2210 and the AMF 2221 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 2210 and the UPF 2202 for the user plane. As such, the AMF 2221 may handle N2 signaling from the SMF 2224 and the AMF 2221 for PDU sessions and QoS, encapsulate/de-encapsulate packets for IPsec and N3 tunneling, mark N3 user-plane packets in the uplink, and enforce QoS corresponding to N3 packet marking taking into account QoS requirements associated with such marking received over N2. N3IWF may also relay uplink and downlink control-plane NAS signaling between the UE 2201 and AMF 2221 via an N1 reference point between the UE 2201 and the AMF 2221, and relay uplink and downlink user-plane packets between the UE 2201 and UPF 2202. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 2201. The AMF 2221 may exhibit a Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 2221 and an N17 reference point between the AMF 2221 and a 5G-EIR (not shown by Figure 22).

[00191] The UE 2201 may need to register with the AMF 2221 in order to receive network services. RM is used to register or deregister the UE 2201 with the network (e.g., AMF 2221), and establish a UE context in the network (e.g., AMF 2221). The UE 2201 may operate in an RM-

REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 2201 is not registered with the network, and the UE context in AMF 2221 holds no valid location or routing information for the UE 2201 so the UE 2201 is not reachable by the AMF 2221. In the RM-REGISTERED state, the UE 2201 is registered with the network, and the UE context in AMF 2221 may hold a valid location or routing information for the UE 2201 so the UE 2201 is reachable by the AMF 2221. In the RM-REGISTERED state, the UE 2201 may perform mobility Registration Update procedures, perform periodic Registration Update procedures triggered by expiration of the periodic update timer (e.g., to notify the network that the UE 2201 is still active), and perform a Registration Update procedure to update UE capability information or to re-negotiate protocol parameters with the network, among others.

[00192] The AMF 2221 may store one or more RM contexts for the UE 2201, where each RM context is associated with a specific access to the network. The RM context may be a data structure, database object, etc. that indicates or stores, inter alia, a registration state per access type and the periodic update timer. The AMF 2221 may also store a 5GC MM context that may be the same or similar to the (E)MM context discussed previously. In various embodiments, the AMF 2221 may store a CE mode B Restriction parameter of the UE 2201 in an associated MM context or RM context. The AMF 2221 may also derive the value, when needed, from the UE's usage setting parameter already stored in the UE context (and/or MM/RM context).

[00193] CM may be used to establish and release a signaling connection between the UE 2201 and the AMF 2221 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 2201 and the CN 2220, and comprises both the signaling connection between the UE and the AN (e.g., RRC connection or UE-N3IWF connection for non-3GPP access) and the N2 connection for the UE 2201 between the AN (e.g., RAN 2210) and the AMF 2221. The UE 2201 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 2201 is operating in the CM-IDLE state/mode, the UE 2201 may have no NAS signaling connection established with the AMF 2221 over the N1 interface, and there may be (R)AN 2210 signaling connection (e.g., N2 and/or N3 connections) for the UE 2201. When the UE 2201 is operating in the CM-CONNECTED state/mode, the UE 2201 may have an established NAS signaling connection with the AMF 2221 over the N1 interface, and there may be a (R)AN 2210 signaling connection (e.g., N2 and/or N3 connections) for the UE 2201. Establishment of an N2 connection between the (R)AN 2210 and the AMF 2221 may cause the UE 2201 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 2201 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 2210 and the AMF 2221 is released.

[00194] The SMF 2224 may be responsible for SM (e.g., session establishment, modify and release, including tunnel maintain between UPF and AN node); UE IP address allocation and management (including optional authorization); selection and control of UP function; configuring traffic steering at UPF to route traffic to proper destination; termination of interfaces toward policy control functions; controlling part of policy enforcement and QoS; lawful intercept (for SM events and interface to LI system); termination of SM parts of NAS messages; downlink data notification; initiating AN specific SM information, sent via AMF over N2 to AN; and determining SSC mode of a session. SM may refer to management of a PDU session, and a PDU session or “session” may refer to a PDU connectivity service that provides or enables the exchange of PDUs between a UE 2201 and a data network (DN) 2203 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 2201 request, modified upon UE 2201 and 5GC 2220 request, and released upon UE 2201 and 5GC 2220 request using NAS SM signaling exchanged over the N1 reference point between the UE 2201 and the SMF 2224. Upon request from an application server, the 5GC 2220 may trigger a specific application in the UE 2201. In response to receipt of the trigger message, the UE 2201 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 2201. The identified application(s) in the UE 2201 may establish a PDU session to a specific DNN. The SMF 2224 may check whether the UE 2201 requests are compliant with user subscription information associated with the UE 2201. In this regard, the SMF 2224 may retrieve and/or request to receive update notifications on SMF 2224 level subscription data from the UDM 2227.

[00195] The SMF 2224 may include the following roaming functionality: handling local enforcement to apply QoS SLAs (VPLMN); charging data collection and charging interface (VPLMN); lawful intercept (in VPLMN for SM events and interface to LI system); and support for interaction with external DN for transport of signaling for PDU session authorization/authentication by external DN. An N16 reference point between two SMFs 2224 may be included in the system 2200, which may be between another SMF 2224 in a visited network and the SMF 2224 in the home network in roaming scenarios. Additionally, the SMF 2224 may exhibit the Nsmf service-based interface.

[00196] The NEF 2223 may provide means for securely exposing the services and capabilities provided by 3GPP network functions for third party, internal exposure/re-exposure, Application Functions (e.g., AF 2228), edge computing or fog computing systems, etc. In such embodiments, the NEF 2223 may authenticate, authorize, and/or throttle the AFs. NEF 2223 may also translate information exchanged with the AF 2228 and information exchanged with internal network functions. For example, the NEF 2223 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 2223 may also receive information from other network functions

(NFs) based on exposed capabilities of other network functions. This information may be stored at the NEF 2223 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 2223 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 2223 may exhibit a Nnef service-based interface.

[00197] The NRF 2225 may support service discovery functions, receive NF discovery requests from NF instances, and provide the information of the discovered NF instances to the NF instances. NRF 2225 also maintains information of available NF instances and their supported services. As used herein, the terms “instantiate,” “instantiation,” and the like may refer to the creation of an instance, and an “instance” may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. Additionally, the NRF 2225 may exhibit the Nnrf service-based interface.

[00198] The PCF 2226 may provide policy rules to control plane function(s) to enforce them, and may also support unified policy framework to govern network behavior. The PCF 2226 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 2227. The PCF 2226 may communicate with the AMF 2221 via an N15 reference point between the PCF 2226 and the AMF 2221, which may include a PCF 2226 in a visited network and the AMF 2221 in case of roaming scenarios. The PCF 2226 may communicate with the AF 2228 via an N5 reference point between the PCF 2226 and the AF 2228; and with the SMF 2224 via an N7 reference point between the PCF 2226 and the SMF 2224. The system 2200 and/or CN 2220 may also include an N24 reference point between the PCF 2226 (in the home network) and a PCF 2226 in a visited network. Additionally, the PCF 2226 may exhibit a Npcf service-based interface.

[00199] The UDM 2227 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 2201. For example, subscription data may be communicated between the UDM 2227 and the AMF 2221 via an N8 reference point between the UDM 2227 and the AMF. The UDM 2227 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 22). The UDR may store subscription data and policy data for the UDM 2227 and the PCF 2226, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 2201) for the NEF 2223. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 2227, PCF 2226, and NEF 2223 to access a particular set of the stored data, as well as to read, update (e.g., add, modify), delete, and subscribe to notification of relevant data changes in the UDR. The UDM may include a UDM-FE, which is in charge of processing credentials, location management, subscription management and so on.

Several different front ends may serve the same user in different transactions. The UDM-FE accesses subscription information stored in the UDR and performs authentication credential processing, user identification handling, access authorization, registration/mobility management, and subscription management. The UDR may interact with the SMF 2224 via an N10 reference point between the UDM 2227 and the SMF 2224. UDM 2227 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 2227 may exhibit the Nudm service-based interface.

[00200] The AF 2228 may provide application influence on traffic routing, provide access to the NCE, and interact with the policy framework for policy control. The NCE may be a mechanism that allows the 5GC 2220 and AF 2228 to provide information to each other via NEF 2223, which may be used for edge computing implementations. In such implementations, the network operator and third-party services may be hosted close to the UE 2201 access point of attachment to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network. For edge computing implementations, the 5GC may select a UPF 2202 close to the UE 2201 and execute traffic steering from the UPF 2202 to DN 2203 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 2228. In this way, the AF 2228 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 2228 is considered to be a trusted entity, the network operator may permit AF 2228 to interact directly with relevant NFs. Additionally, the AF 2228 may exhibit a Naf service-based interface.

[00201] The NSSF 2229 may select a set of network slice instances serving the UE 2201. The NSSF 2229 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 2229 may also determine the AMF set to be used to serve the UE 2201, or a list of candidate AMF(s) 2221 based on a suitable configuration and possibly by querying the NRF 2225. The selection of a set of network slice instances for the UE 2201 may be triggered by the AMF 2221 with which the UE 2201 is registered by interacting with the NSSF 2229, which may lead to a change of AMF 2221. The NSSF 2229 may interact with the AMF 2221 via an N22 reference point between AMF 2221 and NSSF 2229; and may communicate with another NSSF 2229 in a visited network via an N31 reference point (not shown by Figure 22). Additionally, the NSSF 2229 may exhibit a Nnssf service-based interface.

[00202] As discussed previously, the CN 2220 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 2201 to/from other entities, such as an SMS-GMSC/IWMSC/SMS-router. The SMS may also interact with AMF 2221 and UDM 2227 for a notification procedure that the UE 2201 is available for SMS

transfer (e.g., set a UE not reachable flag, and notifying UDM 2227 when UE 2201 is available for SMS).

[00203] The CN 120 may also include other elements that are not shown by Figure 22, such as a Data Storage system/architecture, a 5G-EIR, a SEPP, and the like. The Data Storage system may include a SDSF, an UDSF, and/or the like. Any NF may store and retrieve unstructured data into/from the UDSF (e.g., UE contexts), via N18 reference point between any NF and the UDSF (not shown by Figure 22). Individual NFs may share a UDSF for storing their respective unstructured data or individual NFs may each have their own UDSF located at or near the individual NFs. Additionally, the UDSF may exhibit a Nudsf service-based interface (not shown by Figure 22). The 5G-EIR may be an NF that checks the status of PEI for determining whether particular equipment/entities are blacklisted from the network; and the SEPP may be a non-transparent proxy that performs topology hiding, message filtering, and policing on inter-PLMN control plane interfaces.

[00204] Additionally, there may be many more reference points and/or service-based interfaces between the NF services in the NFs; however, these interfaces and reference points have been omitted from Figure 22 for clarity. In one example, the CN 2220 may include a Nx interface, which is an inter-CN interface between the MME (e.g., MME 2121) and the AMF 2221 in order to enable interworking between CN 2220 and CN 2120. Other example interfaces/reference points may include an N5g-EIR service-based interface exhibited by a 5G-EIR, an N27 reference point between the NRF in the visited network and the NRF in the home network; and an N31 reference point between the NSSF in the visited network and the NSSF in the home network.

[00205] Figure 23 illustrates an example of infrastructure equipment 2300 in accordance with various embodiments. The infrastructure equipment 2300 (or “system 2300”) may be implemented as a base station, radio head, RAN node such as the RAN nodes 2011 and/or AP 2006 shown and described previously, application server(s) 2030, and/or any other element/device discussed herein. In other examples, the system 2300 could be implemented in or by a UE.

[00206] The system 2300 includes application circuitry 2305, baseband circuitry 2310, one or more radio front end modules (RFEMs) 2315, memory circuitry 2320, power management integrated circuitry (PMIC) 2325, power tee circuitry 2330, network controller circuitry 2335, network interface connector 2340, satellite positioning circuitry 2345, and user interface 2350. In some embodiments, the device 2300 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device. For example, said circuitries may be separately included in more than one device for CRAN, vBBU, or other like implementations.

[00207] Application circuitry 2305 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I2C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 2305 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 2300. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[00208] The processor(s) of application circuitry 2305 may include, for example, one or more processor cores (CPUs), one or more application processors, one or more graphics processing units (GPUs), one or more reduced instruction set computing (RISC) processors, one or more Acorn RISC Machine (ARM) processors, one or more complex instruction set computing (CISC) processors, one or more digital signal processors (DSP), one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, or any suitable combination thereof. In some embodiments, the application circuitry 2305 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein. As examples, the processor(s) of application circuitry 2305 may include one or more Intel Pentium®, Core®, or Xeon® processor(s); Advanced Micro Devices (AMD) Ryzen® processor(s), Accelerated Processing Units (APUs), or Epyc® processors; ARM-based processor(s) licensed from ARM Holdings, Ltd. such as the ARM Cortex-A family of processors and the ThunderX2® provided by Cavium(TM), Inc.; a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior P-class processors; and/or the like. In some embodiments, the system 2300 may not utilize application circuitry 2305, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[00209] In some implementations, the application circuitry 2305 may include one or more hardware accelerators, which may be microprocessors, programmable processing devices, or the like. The one or more hardware accelerators may include, for example, computer vision (CV) and/or deep learning (DL) accelerators. As examples, the programmable processing devices may be one or more a field-programmable devices (FPDs) such as field-programmable gate arrays

(FPGAs) and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such implementations, the circuitry of application circuitry 2305 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various embodiments discussed herein. In such embodiments, the circuitry of application circuitry 2305 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up-tables (LUTs) and the like.

[00210] The baseband circuitry 2310 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 2310 are discussed infra with regard to Figure 25.

[00211] User interface circuitry 2350 may include one or more user interfaces designed to enable user interaction with the system 2300 or peripheral component interfaces designed to enable peripheral component interaction with the system 2300. User interfaces may include, but are not limited to, one or more physical or virtual buttons (e.g., a reset button), one or more indicators (e.g., light emitting diodes (LEDs)), a physical keyboard or keypad, a mouse, a touchpad, a touchscreen, speakers or other audio emitting devices, microphones, a printer, a scanner, a headset, a display screen or display device, etc. Peripheral component interfaces may include, but are not limited to, a nonvolatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, etc.

[00212] The radio front end modules (RFEMs) 2315 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 25111 of Figure 25 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 2315, which incorporates both mmWave antennas and sub-mmWave.

[00213] The memory circuitry 2320 may include one or more of volatile memory including dynamic random access memory (DRAM) and/or synchronous dynamic random access memory (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory

(commonly referred to as Flash memory), phase change random access memory (PRAM), magnetoresistive random access memory (MRAM), etc., and may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®. Memory circuitry 2320 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[00214] The PMIC 2325 may include voltage regulators, surge protectors, power alarm detection circuitry, and one or more backup power sources such as a battery or capacitor. The power alarm detection circuitry may detect one or more of brown out (under-voltage) and surge (over-voltage) conditions. The power tee circuitry 2330 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 2300 using a single cable.

[00215] The network controller circuitry 2335 may provide connectivity to a network using a standard network interface protocol such as Ethernet, Ethernet over GRE Tunnels, Ethernet over Multiprotocol Label Switching (MPLS), or some other suitable protocol. Network connectivity may be provided to/from the infrastructure equipment 2300 via network interface connector 2340 using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 2335 may include one or more dedicated processors and/or FPGAs to communicate using one or more of the aforementioned protocols. In some implementations, the network controller circuitry 2335 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[00216] The positioning circuitry 2345 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a global navigation satellite system (GNSS). Examples of navigation satellite constellations (or GNSS) include United States’ Global Positioning System (GPS), Russia’s Global Navigation System (GLONASS), the European Union’s Galileo system, China’s BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., Navigation with Indian Constellation (NAVIC), Japan’s Quasi-Zenith Satellite System (QZSS), France’s Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), etc.), or the like. The positioning circuitry 2345 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as navigation satellite constellation nodes. In some embodiments, the positioning circuitry 2345 may include a Micro-Technology for Positioning, Navigation, and Timing (Micro-PNT) IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 2345 may also be part of, or interact with, the baseband circuitry 2310 and/or RFEMs 2315 to communicate with the nodes

and components of the positioning network. The positioning circuitry 2345 may also provide position data and/or time data to the application circuitry 2305, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 2011, etc.), or the like.

[00217] The components shown by Figure 23 may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I2C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[00218] Figure 24 illustrates an example of a platform 2400 (or “device 2400”) in accordance with various embodiments. In embodiments, the computer platform 2400 may be suitable for use as UEs 2001, 2002, 2101, application servers 2030, and/or any other element/device discussed herein. The platform 2400 may include any combinations of the components shown in the example. The components of platform 2400 may be implemented as integrated circuits (ICs), portions thereof, discrete electronic devices, or other modules, logic, hardware, software, firmware, or a combination thereof adapted in the computer platform 2400, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 24 is intended to show a high level view of components of the computer platform 2400. However, some of the components shown may be omitted, additional components may be present, and different arrangement of the components shown may occur in other implementations.

[00219] Application circuitry 2405 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I2C or universal programmable serial interface module, RTC, timer-counters including interval and watchdog timers, general purpose I/O, memory card controllers such as SD MMC or similar, USB interfaces, MIPI interfaces, and JTAG test access ports. The processors (or cores) of the application circuitry 2405 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 2400. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[00220] The processor(s) of application circuitry 2305 may include, for example, one or more processor cores, one or more application processors, one or more GPUs, one or more RISC

processors, one or more ARM processors, one or more CISC processors, one or more DSP, one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, a multithreaded processor, an ultra-low voltage processor, an embedded processor, some other known processing element, or any suitable combination thereof. In some embodiments, the application circuitry 2305 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[00221] As examples, the processor(s) of application circuitry 2405 may include an Intel® Architecture Core™ based processor, such as a Quark™, an Atom™, an i3, an i5, an i7, or an MCU-class processor, or another such processor available from Intel® Corporation, Santa Clara, CA. The processors of the application circuitry 2405 may also be one or more of Advanced Micro Devices (AMD) Ryzen® processor(s) or Accelerated Processing Units (APUs); A5-A9 processor(s) from Apple® Inc., Snapdragon™ processor(s) from Qualcomm® Technologies, Inc., Texas Instruments, Inc.® Open Multimedia Applications Platform (OMAP)™ processor(s); a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior M-class, Warrior I-class, and Warrior P-class processors; an ARM-based design licensed from ARM Holdings, Ltd., such as the ARM Cortex-A, Cortex-R, and Cortex-M family of processors; or the like. In some implementations, the application circuitry 2405 may be a part of a system on a chip (SoC) in which the application circuitry 2405 and other components are formed into a single integrated circuit, or a single package, such as the Edison™ or Galileo™ SoC boards from Intel® Corporation.

[00222] Additionally or alternatively, application circuitry 2405 may include circuitry such as, but not limited to, one or more a field-programmable devices (FPDs) such as FPGAs and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such embodiments, the circuitry of application circuitry 2405 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various embodiments discussed herein. In such embodiments, the circuitry of application circuitry 2405 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up tables (LUTs) and the like.

[00223] The baseband circuitry 2410 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The

various hardware electronic elements of baseband circuitry 2410 are discussed infra with regard to Figure 25.

[00224] The RFEMs 2415 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 25111 of Figure 25 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 2415, which incorporates both mmWave antennas and sub-mmWave.

[00225] The memory circuitry 2420 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 2420 may include one or more of volatile memory including random access memory (RAM), dynamic RAM (DRAM) and/or synchronous dynamic RAM (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM), magnetoresistive random access memory (MRAM), etc. The memory circuitry 2420 may be developed in accordance with a Joint Electron Devices Engineering Council (JEDEC) low power double data rate (LPDDR)-based design, such as LPDDR2, LPDDR3, LPDDR4, or the like. Memory circuitry 2420 may be implemented as one or more of solder down packaged integrated circuits, single die package (SDP), dual die package (DDP) or quad die package (Q17P), socketed memory modules, dual inline memory modules (DIMMs) including microDIMMs or MiniDIMMs, and/or soldered onto a motherboard via a ball grid array (BGA). In low power implementations, the memory circuitry 2420 may be on-die memory or registers associated with the application circuitry 2405. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 2420 may include one or more mass storage devices, which may include, inter alia, a solid state disk drive (SSDD), hard disk drive (HDD), a micro HDD, resistance change memories, phase change memories, holographic memories, or chemical memories, among others. For example, the computer platform 2400 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[00226] Removable memory circuitry 2423 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 2400. These portable data storage devices may be used for mass storage purposes, and may include, for example, flash memory cards (e.g., Secure Digital (SD) cards, microSD cards, xD picture cards, and the like), and USB flash drives, optical discs, external HDDs, and the like.

[00227] The platform 2400 may also include interface circuitry (not shown) that is used to connect external devices with the platform 2400. The external devices connected to the platform 2400 via the interface circuitry include sensor circuitry 2421 and electro-mechanical components (EMCs) 2422, as well as removable memory devices coupled to removable memory circuitry 2423.

[00228] The sensor circuitry 2421 include devices, modules, or subsystems whose purpose is to detect events or changes in its environment and send the information (sensor data) about the detected events to some other a device, module, subsystem, etc. Examples of such sensors include, inter alia, inertia measurement units (IMUs) comprising accelerometers, gyroscopes, and/or magnetometers; microelectromechanical systems (MEMS) or nanoelectromechanical systems (NEMS) comprising 3-axis accelerometers, 3-axis gyroscopes, and/or magnetometers; level sensors; flow sensors; temperature sensors (e.g., thermistors); pressure sensors; barometric pressure sensors; gravimeters; altimeters; image capture devices (e.g., cameras or lensless apertures); light detection and ranging (LiDAR) sensors; proximity sensors (e.g., infrared radiation detector and the like), depth sensors, ambient light sensors, ultrasonic transceivers; microphones or other like audio capture devices; etc.

[00229] EMCs 2422 include devices, modules, or subsystems whose purpose is to enable platform 2400 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 2422 may be configured to generate and send messages/signaling to other components of the platform 2400 to indicate a current state of the EMCs 2422. Examples of the EMCs 2422 include one or more power switches, relays including electromechanical relays (EMRs) and/or solid state relays (SSRs), actuators (e.g., valve actuators, etc.), an audible sound generator, a visual warning device, motors (e.g., DC motors, stepper motors, etc.), wheels, thrusters, propellers, claws, clamps, hooks, and/or other like electro-mechanical components. In embodiments, platform 2400 is configured to operate one or more EMCs 2422 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[00230] In some implementations, the interface circuitry may connect the platform 2400 with positioning circuitry 2445. The positioning circuitry 2445 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a GNSS. Examples of navigation satellite constellations (or GNSS) include United States' GPS, Russia's GLONASS, the European Union's Galileo system, China's BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., NAVIC), Japan's QZSS, France's DORIS, etc.), or the like. The positioning circuitry 2445 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as

navigation satellite constellation nodes. In some embodiments, the positioning circuitry 2445 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 2445 may also be part of, or interact with, the baseband circuitry 2310 and/or RFEMs 2415 to communicate with the nodes and components of the positioning network. The positioning circuitry 2445 may also provide position data and/or time data to the application circuitry 2405, which may use the data to synchronize operations with various infrastructure (e.g., radio base stations), for turn-by-turn navigation applications, or the like

[00231] In some implementations, the interface circuitry may connect the platform 2400 with Near-Field Communication (NFC) circuitry 2440. NFC circuitry 2440 is configured to provide contactless, short-range communications based on radio frequency identification (RFID) standards, wherein magnetic field induction is used to enable communication between NFC circuitry 2440 and NFC-enabled devices external to the platform 2400 (e.g., an “NFC touchpoint”). NFC circuitry 2440 comprises an NFC controller coupled with an antenna element and a processor coupled with the NFC controller. The NFC controller may be a chip/IC providing NFC functionalities to the NFC circuitry 2440 by executing NFC controller firmware and an NFC stack. The NFC stack may be executed by the processor to control the NFC controller, and the NFC controller firmware may be executed by the NFC controller to control the antenna element to emit short-range RF signals. The RF signals may power a passive NFC tag (e.g., a microchip embedded in a sticker or wristband) to transmit stored data to the NFC circuitry 2440, or initiate data transfer between the NFC circuitry 2440 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 2400.

[00232] The driver circuitry 2446 may include software and hardware elements that operate to control particular devices that are embedded in the platform 2400, attached to the platform 2400, or otherwise communicatively coupled with the platform 2400. The driver circuitry 2446 may include individual drivers allowing other components of the platform 2400 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 2400. For example, driver circuitry 2446 may include a display driver to control and allow access to a display device, a touchscreen driver to control and allow access to a touchscreen interface of the platform 2400, sensor drivers to obtain sensor readings of sensor circuitry 2421 and control and allow access to sensor circuitry 2421, EMC drivers to obtain actuator positions of the EMCs 2422 and/or control and allow access to the EMCs 2422, a camera driver to control and allow access to an embedded image capture device, audio drivers to control and allow access to one or more audio devices.

[00233] The power management integrated circuitry (PMIC) 2425 (also referred to as “power management circuitry 2425”) may manage power provided to various components of the platform 2400. In particular, with respect to the baseband circuitry 2410, the PMIC 2425 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 2425 may often be included when the platform 2400 is capable of being powered by a battery 2430, for example, when the device is included in a UE 2001, 2002, 2101.

[00234] In some embodiments, the PMIC 2425 may control, or otherwise be part of, various power saving mechanisms of the platform 2400. For example, if the platform 2400 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the platform 2400 may power down for brief intervals of time and thus save power. If there is no data traffic activity for an extended period of time, then the platform 2400 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The platform 2400 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The platform 2400 may not receive data in this state; in order to receive data, it must transition back to RRC_Connected state. An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[00235] A battery 2430 may power the platform 2400, although in some examples the platform 2400 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 2430 may be a lithium ion battery, a metal-air battery, such as a zinc-air battery, an aluminum-air battery, a lithium-air battery, and the like. In some implementations, such as in V2X applications, the battery 2430 may be a typical lead-acid automotive battery.

[00236] In some implementations, the battery 2430 may be a “smart battery,” which includes or is coupled with a Battery Management System (BMS) or battery monitoring integrated circuitry. The BMS may be included in the platform 2400 to track the state of charge (SoCh) of the battery 2430. The BMS may be used to monitor other parameters of the battery 2430 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 2430. The BMS may communicate the information of the battery 2430 to the application circuitry 2405 or other components of the platform 2400. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 2405 to directly monitor the voltage of the battery 2430 or the current flow from the battery 2430. The battery parameters may be used to determine

actions that the platform 2400 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[00237] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 2430. In some examples, the power block XS30 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 2400. In these examples, a wireless battery charging circuit may be included in the BMS. The specific charging circuits chosen may depend on the size of the battery 2430, and thus, the current required. The charging may be performed using the Airfuel standard promulgated by the Airfuel Alliance, the Qi wireless charging standard promulgated by the Wireless Power Consortium, or the Rezence charging standard promulgated by the Alliance for Wireless Power, among others.

[00238] User interface circuitry 2450 includes various input/output (I/O) devices present within, or connected to, the platform 2400, and includes one or more user interfaces designed to enable user interaction with the platform 2400 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 2400. The user interface circuitry 2450 includes input device circuitry and output device circuitry. Input device circuitry includes any physical or virtual means for accepting an input including, inter alia, one or more physical or virtual buttons (e.g., a reset button), a physical keyboard, keypad, mouse, touchpad, touchscreen, microphones, scanner, headset, and/or the like. The output device circuitry includes any physical or virtual means for showing information or otherwise conveying information, such as sensor readings, actuator position(s), or other like information. Output device circuitry may include any number and/or combinations of audio or visual display, including, inter alia, one or more simple visual outputs/indicators (e.g., binary status indicators (e.g., light emitting diodes (LEDs))) and multi-character visual outputs, or more complex outputs such as display devices or touchscreens (e.g., Liquid Chrystal Displays (LCD), LED displays, quantum dot displays, projectors, etc.), with the output of characters, graphics, multimedia objects, and the like being generated or produced from the operation of the platform 2400. The output device circuitry may also include speakers or other audio emitting devices, printer(s), and/or the like. In some embodiments, the sensor circuitry 2421 may be used as the input device circuitry (e.g., an image capture device, motion capture device, or the like) and one or more EMCs may be used as the output device circuitry (e.g., an actuator to provide haptic feedback or the like). In another example, NFC circuitry comprising an NFC controller coupled with an antenna element and a processing device may be included to read electronic tags and/or connect with another NFC-enabled device. Peripheral component interfaces may include, but are not limited to, a non-volatile memory port, a USB port, an audio jack, a power supply interface, etc.

[00239] Although not shown, the components of platform 2400 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIX, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I2C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[00240] Figure 25 illustrates example components of baseband circuitry 25110 and radio front end modules (RFEM) 25115 in accordance with various embodiments. The baseband circuitry 25110 corresponds to the baseband circuitry 2310 and 2410 of Figures 23 and 24, respectively. The RFEM 25115 corresponds to the RFEM 2315 and 2415 of Figures 23 and 24, respectively. As shown, the RFEMs 25115 may include Radio Frequency (RF) circuitry 25106, front-end module (FEM) circuitry 25108, antenna array 25111 coupled together at least as shown.

[00241] The baseband circuitry 25110 includes circuitry and/or control logic configured to carry out various radio/network protocol and radio control functions that enable communication with one or more radio networks via the RF circuitry 25106. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 25110 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 25110 may include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments. The baseband circuitry 25110 is configured to process baseband signals received from a receive signal path of the RF circuitry 25106 and to generate baseband signals for a transmit signal path of the RF circuitry 25106. The baseband circuitry 25110 is configured to interface with application circuitry 2305/2405 (see Figures 23 and 24) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 25106. The baseband circuitry 25110 may handle various radio control functions.

[00242] The aforementioned circuitry and/or control logic of the baseband circuitry 25110 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 25104A, a 4G/LTE baseband processor 25104B, a 5G/NR baseband processor 25104C, or some other baseband processor(s) 25104D for other existing generations, generations in development or to be developed in the future (e.g., sixth generation (6G), etc.). In other embodiments, some or all of the functionality of baseband processors 25104A-

D may be included in modules stored in the memory 25104G and executed via a Central Processing Unit (CPU) 25104E. In other embodiments, some or all of the functionality of baseband processors 25104A-D may be provided as hardware accelerators (e.g., FPGAs, ASICs, etc.) loaded with the appropriate bit streams or logic blocks stored in respective memory cells. In various embodiments, the memory 25104G may store program code of a real-time OS (RTOS), which when executed by the CPU 25104E (or other baseband processor), is to cause the CPU 25104E (or other baseband processor) to manage resources of the baseband circuitry 25110, schedule tasks, etc. Examples of the RTOS may include Operating System Embedded (OSE)[™] provided by Enea®, Nucleus RTOS[™] provided by Mentor Graphics®, Versatile Real-Time Executive (VRTX) provided by Mentor Graphics®, ThreadX[™] provided by Express Logic®, FreeRTOS, REX OS provided by Qualcomm®, OKL4 provided by Open Kernel (OK) Labs®, or any other suitable RTOS, such as those discussed herein. In addition, the baseband circuitry 25110 includes one or more audio digital signal processor(s) (DSP) 25104F. The audio DSP(s) 25104F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[00243] In some embodiments, each of the processors 25104A-25104E include respective memory interfaces to send/receive data to/from the memory 25104G. The baseband circuitry 25110 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as an interface to send/receive data to/from memory external to the baseband circuitry 25110; an application circuitry interface to send/receive data to/from the application circuitry 2305/2405 of FIGS. 23-25; an RF circuitry interface to send/receive data to/from RF circuitry 25106 of Figure 25; a wireless hardware connectivity interface to send/receive data to/from one or more wireless hardware elements (e.g., Near Field Communication (NFC) components, Bluetooth®/ Bluetooth® Low Energy components, Wi-Fi® components, and/or the like); and a power management interface to send/receive power or control signals to/from the PMIC 2425.

[00244] In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 25110 comprises one or more digital baseband systems, which are coupled with one another via an interconnect subsystem and to a CPU subsystem, an audio subsystem, and an interface subsystem. The digital baseband subsystems may also be coupled to a digital baseband interface and a mixed-signal baseband subsystem via another interconnect subsystem. Each of the interconnect subsystems may include a bus system, point-to-point connections, network-on-chip (NOC) structures, and/or some other suitable bus or interconnect technology, such as those discussed herein. The audio subsystem may include DSP circuitry, buffer memory, program memory, speech processing accelerator circuitry, data converter circuitry

such as analog-to-digital and digital-to-analog converter circuitry, analog circuitry including one or more of amplifiers and filters, and/or other like components. In an aspect of the present disclosure, baseband circuitry 25110 may include protocol processing circuitry with one or more instances of control circuitry (not shown) to provide control functions for the digital baseband circuitry and/or radio frequency circuitry (e.g., the radio front end modules 25115).

[00245] Although not shown by Figure 25, in some embodiments, the baseband circuitry 25110 includes individual processing device(s) to operate one or more wireless communication protocols (e.g., a “multi-protocol baseband processor” or “protocol processing circuitry”) and individual processing device(s) to implement PHY layer functions. In these embodiments, the PHY layer functions include the aforementioned radio control functions. In these embodiments, the protocol processing circuitry operates or implements various protocol layers/entities of one or more wireless communication protocols. In a first example, the protocol processing circuitry may operate LTE protocol entities and/or 5G/NR protocol entities when the baseband circuitry 25110 and/or RF circuitry 25106 are part of mmWave communication circuitry or some other suitable cellular communication circuitry. In the first example, the protocol processing circuitry would operate MAC, RLC, PDCP, SDAP, RRC, and NAS functions. In a second example, the protocol processing circuitry may operate one or more IEEE-based protocols when the baseband circuitry 25110 and/or RF circuitry 25106 are part of a Wi-Fi communication system. In the second example, the protocol processing circuitry would operate Wi-Fi MAC and logical link control (LLC) functions. The protocol processing circuitry may include one or more memory structures (e.g., 25104G) to store program code and data for operating the protocol functions, as well as one or more processing cores to execute the program code and perform various operations using the data. The baseband circuitry 25110 may also support radio communications for more than one wireless protocol.

[00246] The various hardware elements of the baseband circuitry 25110 discussed herein may be implemented, for example, as a solder-down substrate including one or more integrated circuits (ICs), a single packaged IC soldered to a main circuit board or a multi-chip module containing two or more ICs. In one example, the components of the baseband circuitry 25110 may be suitably combined in a single chip or chipset, or disposed on a same circuit board. In another example, some or all of the constituent components of the baseband circuitry 25110 and RF circuitry 25106 may be implemented together such as, for example, a system on a chip (SoC) or System-in-Package (SiP). In another example, some or all of the constituent components of the baseband circuitry 25110 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 25106 (or multiple instances of RF circuitry 25106). In yet another example, some or all of the constituent components of the baseband circuitry 25110 and the application circuitry

2305/2405 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

[00247] In some embodiments, the baseband circuitry 25110 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 25110 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 25110 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00248] RF circuitry 25106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 25106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 25106 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 25108 and provide baseband signals to the baseband circuitry 25110. RF circuitry 25106 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 25110 and provide RF output signals to the FEM circuitry 25108 for transmission.

[00249] In some embodiments, the receive signal path of the RF circuitry 25106 may include mixer circuitry 25106a, amplifier circuitry 25106b and filter circuitry 25106c. In some embodiments, the transmit signal path of the RF circuitry 25106 may include filter circuitry 25106c and mixer circuitry 25106a. RF circuitry 25106 may also include synthesizer circuitry 25106d for synthesizing a frequency for use by the mixer circuitry 25106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 25106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 25108 based on the synthesized frequency provided by synthesizer circuitry 25106d. The amplifier circuitry 25106b may be configured to amplify the down-converted signals and the filter circuitry 25106c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 25110 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 25106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00250] In some embodiments, the mixer circuitry 25106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 25106d to generate RF output signals for the FEM circuitry 25108. The

baseband signals may be provided by the baseband circuitry 25110 and may be filtered by filter circuitry 25106c.

[00251] In some embodiments, the mixer circuitry 25106a of the receive signal path and the mixer circuitry 25106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 25106a of the receive signal path and the mixer circuitry 25106a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 25106a of the receive signal path and the mixer circuitry 25106a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 25106a of the receive signal path and the mixer circuitry 25106a of the transmit signal path may be configured for super-heterodyne operation.

[00252] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 25106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 25110 may include a digital baseband interface to communicate with the RF circuitry 25106.

[00253] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[00254] In some embodiments, the synthesizer circuitry 25106d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 25106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00255] The synthesizer circuitry 25106d may be configured to synthesize an output frequency for use by the mixer circuitry 25106a of the RF circuitry 25106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 25106d may be a fractional N/N+1 synthesizer.

[00256] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 25110 or the application circuitry 2305/2405 depending on the desired

output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the application circuitry 2305/2405.

[00257] Synthesizer circuitry 25106d of the RF circuitry 25106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00258] In some embodiments, synthesizer circuitry 25106d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 25106 may include an IQ/polar converter.

[00259] FEM circuitry 25108 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 25111, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 25106 for further processing. FEM circuitry 25108 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 25106 for transmission by one or more of antenna elements of antenna array 25111. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 25106, solely in the FEM circuitry 25108, or in both the RF circuitry 25106 and the FEM circuitry 25108.

[00260] In some embodiments, the FEM circuitry 25108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 25108 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 25108 may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 25106). The transmit signal path of the FEM circuitry 25108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry

25106), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 25111.

[00261] The antenna array 25111 comprises one or more antenna elements, each of which is configured convert electrical signals into radio waves to travel through the air and to convert received radio waves into electrical signals. For example, digital baseband signals provided by the baseband circuitry 25110 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 25111 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arrangements as are known and/or discussed herein. The antenna array 25111 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 25111 may be formed in as a patch of metal foil (e.g., a patch antenna) in a variety of shapes, and may be coupled with the RF circuitry 25106 and/or FEM circuitry 25108 using metal transmission lines or the like.

[00262] Processors of the application circuitry 2305/2405 and processors of the baseband circuitry 25110 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 25110, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 2305/2405 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., TCP and UDP layers). As referred to herein, Layer 3 may comprise an RRC layer, described in further detail below. As referred to herein, Layer 2 may comprise a MAC layer, an RLC layer, and a PDCP layer, described in further detail below. As referred to herein, Layer 1 may comprise a PHY layer of a UE/RAN node, described in further detail below.

[00263] Figure 26 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Figure 26 includes an arrangement 2600 showing interconnections between various protocol layers/entities. The following description of Figure 26 is provided for various protocol layers/entities that operate in conjunction with the 5G/NR system standards and LTE system standards, but some or all of the aspects of Figure 26 may be applicable to other wireless communication network systems as well.

[00264] The protocol layers of arrangement 2600 may include one or more of PHY 2610, MAC 2620, RLC 2630, PDCP 2640, SDAP 2647, RRC 2655, and NAS layer 2657, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 2659, 2656, 2650, 2649, 2645, 2635, 2625, and 2615 in Figure 26) that may provide communication between two or more protocol layers.

[00265] The PHY 2610 may transmit and receive physical layer signals 2605 that may be received from or transmitted to one or more other communication devices. The physical layer signals 2605 may comprise one or more physical channels, such as those discussed herein. The PHY 2610 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC 2655. The PHY 2610 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and MIMO antenna processing. In embodiments, an instance of PHY 2610 may process requests from and provide indications to an instance of MAC 2620 via one or more PHY-SAP 2615. According to some embodiments, requests and indications communicated via PHY-SAP 2615 may comprise one or more transport channels.

[00266] Instance(s) of MAC 2620 may process requests from, and provide indications to, an instance of RLC 2630 via one or more MAC-SAPs 2625. These requests and indications communicated via the MAC-SAP 2625 may comprise one or more logical channels. The MAC 2620 may perform mapping between the logical channels and transport channels, multiplexing of MAC SDUs from one or more logical channels onto TBs to be delivered to PHY 2610 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 2610 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[00267] Instance(s) of RLC 2630 may process requests from and provide indications to an instance of PDCP 2640 via one or more radio link control service access points (RLC-SAP) 2635. These requests and indications communicated via RLC-SAP 2635 may comprise one or more RLC channels. The RLC 2630 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 2630 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC 2630 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[00268] Instance(s) of PDCP 2640 may process requests from and provide indications to instance(s) of RRC 2655 and/or instance(s) of SDAP 2647 via one or more packet data convergence protocol service access points (PDCP-SAP) 2645. These requests and indications

communicated via PDCP-SAP 2645 may comprise one or more radio bearers. The PDCP 2640 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[00269] Instance(s) of SDAP 2647 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 2649. These requests and indications communicated via SDAP-SAP 2649 may comprise one or more QoS flows. The SDAP 2647 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 2647 may be configured for an individual PDU session. In the UL direction, the NG-RAN 2010 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 2647 of a UE 2001 may monitor the QFIs of the DL packets for each DRB, and may apply the same mapping for packets flowing in the UL direction. For a DRB, the SDAP 2647 of the UE 2001 may map the UL packets belonging to the QoS flows(s) corresponding to the QoS flow ID(s) and PDU session observed in the DL packets for that DRB. To enable reflective mapping, the NG-RAN 2210 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 2655 configuring the SDAP 2647 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 2647. In embodiments, the SDAP 2647 may only be used in NR implementations and may not be used in LTE implementations.

[00270] The RRC 2655 may configure, via one or more management service access points (M-SAP), aspects of one or more protocol layers, which may include one or more instances of PHY 2610, MAC 2620, RLC 2630, PDCP 2640 and SDAP 2647. In embodiments, an instance of RRC 2655 may process requests from and provide indications to one or more NAS entities 2657 via one or more RRC-SAPs 2656. The main services and functions of the RRC 2655 may include broadcast of system information (e.g., included in MIBs or SIBs related to the NAS), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE 2001 and RAN 2010 (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter-RAT mobility, and measurement configuration for UE measurement reporting. The MIBs and SIBs may comprise one or more IEs, which may each comprise individual data fields or data structures.

[00271] The NAS 2657 may form the highest stratum of the control plane between the UE 2001 and the AMF 2221. The NAS 2657 may support the mobility of the UEs 2001 and the session management procedures to establish and maintain IP connectivity between the UE 2001 and a P-GW in LTE systems.

[00272] According to various embodiments, one or more protocol entities of arrangement 2600 may be implemented in UEs 2001, RAN nodes 2011, AMF 2221 in NR implementations or MME 2121 in LTE implementations, UPF 2202 in NR implementations or S-GW 2122 and P-GW 2123 in LTE implementations, or the like to be used for control plane or user plane communications protocol stack between the aforementioned devices. In such embodiments, one or more protocol entities that may be implemented in one or more of UE 2001, gNB 2011, AMF 2221, etc. may communicate with a respective peer protocol entity that may be implemented in or on another device using the services of respective lower layer protocol entities to perform such communication. In some embodiments, a gNB-CU of the gNB 2011 may host the RRC 2655, SDAP 2647, and PDCP 2640 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 2011 may each host the RLC 2630, MAC 2620, and PHY 2610 of the gNB 2011.

[00273] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 2657, RRC 2655, PDCP 2640, RLC 2630, MAC 2620, and PHY 2610. In this example, upper layers 2660 may be built on top of the NAS 2657, which includes an IP layer 2661, an SCTP 2662, and an application layer signaling protocol (AP) 2663.

[00274] In NR implementations, the AP 2663 may be an NG application protocol layer (NGAP or NG-AP) 2663 for the NG interface 2013 defined between the NG-RAN node 2011 and the AMF 2221, or the AP 2663 may be an Xn application protocol layer (XnAP or Xn-AP) 2663 for the Xn interface 2012 that is defined between two or more RAN nodes 2011.

[00275] The NG-AP 2663 may support the functions of the NG interface 2013 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 2011 and the AMF 2221. The NG-AP 2663 services may comprise two groups: UE-associated services (e.g., services related to a UE 2001, 2002) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 2011 and AMF 2221). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 2011 involved in a particular paging area; a UE context management function for allowing the AMF 2221 to establish, modify, and/or release a UE context in the AMF 2221 and the NG-RAN node 2011; a mobility function for UEs 2001 in ECM-CONNECTED mode for intra-system HOs to support mobility within NG-RAN and inter-system HOs to support mobility from/to EPS systems; a NAS Signaling Transport function for

transporting or rerouting NAS messages between UE 2001 and AMF 2221; a NAS node selection function for determining an association between the AMF 2221 and the UE 2001; NG interface management function(s) for setting up the NG interface and monitoring for errors over the NG interface; a warning message transmission function for providing means to transfer warning messages via NG interface or cancel ongoing broadcast of warning messages; a Configuration Transfer function for requesting and transferring of RAN configuration information (e.g., SON information, performance measurement (PM) data, etc.) between two RAN nodes 2011 via CN 2020; and/or other like functions.

[00276] The XnAP 2663 may support the functions of the Xn interface 2012 and may comprise XnAP basic mobility procedures and XnAP global procedures. The XnAP basic mobility procedures may comprise procedures used to handle UE mobility within the NG RAN 2011 (or E-UTRAN 2110), such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The XnAP global procedures may comprise procedures that are not related to a specific UE 2001, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[00277] In LTE implementations, the AP 2663 may be an S1 Application Protocol layer (S1-AP) 2663 for the S1 interface 2013 defined between an E-UTRAN node 2011 and an MME, or the AP 2663 may be an X2 application protocol layer (X2AP or X2-AP) 2663 for the X2 interface 2012 that is defined between two or more E-UTRAN nodes 2011.

[00278] The S1 Application Protocol layer (S1-AP) 2663 may support the functions of the S1 interface, and similar to the NG-AP discussed previously, the S1-AP may comprise S1-AP EPs. An S1-AP EP may be a unit of interaction between the E-UTRAN node 2011 and an MME 2121 within an LTE CN 2020. The S1-AP 2663 services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[00279] The X2AP 2663 may support the functions of the X2 interface 2012 and may comprise X2AP basic mobility procedures and X2AP global procedures. The X2AP basic mobility procedures may comprise procedures used to handle UE mobility within the E-UTRAN 2020, such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The X2AP global procedures may comprise procedures that are not

related to a specific UE 2001, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[00280] The SCTP layer (alternatively referred to as the SCTP/IP layer) 2662 may provide guaranteed delivery of application layer messages (e.g., NGAP or XnAP messages in NR implementations, or S1-AP or X2AP messages in LTE implementations). The SCTP 2662 may ensure reliable delivery of signaling messages between the RAN node 2011 and the AMF 2221/MME 2121 based, in part, on the IP protocol, supported by the IP 2661. The Internet Protocol layer (IP) 2661 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 2661 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 2011 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[00281] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 2647, PDCP 2640, RLC 2630, MAC 2620, and PHY 2610. The user plane protocol stack may be used for communication between the UE 2001, the RAN node 2011, and UPF 2202 in NR implementations or an S-GW 2122 and P-GW 2123 in LTE implementations. In this example, upper layers 2651 may be built on top of the SDAP 2647, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 2652, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 2653, and a User Plane PDU layer (UP PDU) 2663.

[00282] The transport network layer 2654 (also referred to as a “transport layer”) may be built on IP transport, and the GTP-U 2653 may be used on top of the UDP/IP layer 2652 (comprising a UDP layer and IP layer) to carry user plane PDUs (UP-PDUs). The IP layer (also referred to as the “Internet layer”) may be used to perform packet addressing and routing functionality. The IP layer may assign IP addresses to user data packets in any of IPv4, IPv6, or PPP formats, for example.

[00283] The GTP-U 2653 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP/IP 2652 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 2011 and the S-GW 2122 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 2610), an L2 layer (e.g., MAC 2620, RLC 2630, PDCP 2640, and/or SDAP 2647), the UDP/IP layer 2652, and the GTP-U 2653. The S-GW 2122 and the P-GW 2123 may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising an L1 layer, an L2 layer, the UDP/IP layer 2652, and the GTP-U 2653. As discussed previously, NAS protocols may

support the mobility of the UE 2001 and the session management procedures to establish and maintain IP connectivity between the UE 2001 and the P-GW 2123.

[00284] Moreover, although not shown by Figure 26, an application layer may be present above the AP 2663 and/or the transport network layer 2654. The application layer may be a layer in which a user of the UE 2001, RAN node 2011, or other network element interacts with software applications being executed, for example, by application circuitry 2305 or application circuitry 2405, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 2001 or RAN node 2011, such as the baseband circuitry 25110. In some implementations the IP layer and/or the application layer may provide the same or similar functionality as layers 5-7, or portions thereof, of the Open Systems Interconnection (OSI) model (e.g., OSI Layer 7 – the application layer, OSI Layer 6 – the presentation layer, and OSI Layer 5 – the session layer).

[00285] Figure 27 illustrates components of a core network in accordance with various embodiments. The components of the CN 2120 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In embodiments, the components of CN 2220 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 2120. In some embodiments, NFV is utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums (described in further detail below). A logical instantiation of the CN 2120 may be referred to as a network slice 2701, and individual logical instantiations of the CN 2120 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 2120 may be referred to as a network sub-slice 2702 (e.g., the network sub-slice 2702 is shown to include the P-GW 2123 and the PCRF 2126).

[00286] As used herein, the terms “instantiate,” “instantiation,” and the like may refer to the creation of an instance, and an “instance” may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. A network instance may refer to information identifying a domain, which may be used for traffic detection and routing in case of different IP domains or overlapping IP addresses. A network slice instance may refer to a set of network functions (NFs) instances and the resources (e.g., compute, storage, and networking resources) required to deploy the network slice.

[00287] With respect to 5G systems (see, e.g., Figure 22), a network slice always comprises a RAN part and a CN part. The support of network slicing relies on the principle that traffic for different slices is handled by different PDU sessions. The network can realize the different network

slices by scheduling and also by providing different L1/L2 configurations. The UE 2201 provides assistance information for network slice selection in an appropriate RRC message, if it has been provided by NAS. While the network can support large number of slices, the UE need not support more than 8 slices simultaneously.

[00288] A network slice may include the CN 2220 control plane and user plane NFs, NG-RANs 2210 in a serving PLMN, and a N3IWF functions in the serving PLMN. Individual network slices may have different S-NSSAI and/or may have different SSTs. NSSAI includes one or more S-NSSAIs, and each network slice is uniquely identified by an S-NSSAI. Network slices may differ for supported features and network functions optimizations, and/or multiple network slice instances may deliver the same service/features but for different groups of UEs 2201 (e.g., enterprise users). For example, individual network slices may deliver different committed service(s) and/or may be dedicated to a particular customer or enterprise. In this example, each network slice may have different S-NSSAIs with the same SST but with different slice differentiators. Additionally, a single UE may be served with one or more network slice instances simultaneously via a 5G AN and associated with eight different S-NSSAIs. Moreover, an AMF 2221 instance serving an individual UE 2201 may belong to each of the network slice instances serving that UE.

[00289] Network Slicing in the NG-RAN 2210 involves RAN slice awareness. RAN slice awareness includes differentiated handling of traffic for different network slices, which have been pre-configured. Slice awareness in the NG-RAN 2210 is introduced at the PDU session level by indicating the S-NSSAI corresponding to a PDU session in all signaling that includes PDU session resource information. How the NG-RAN 2210 supports the slice enabling in terms of NG-RAN functions (e.g., the set of network functions that comprise each slice) is implementation dependent. The NG-RAN 2210 selects the RAN part of the network slice using assistance information provided by the UE 2201 or the 5GC 2220, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 2210 also supports resource management and policy enforcement between slices as per SLAs. A single NG-RAN node may support multiple slices, and the NG-RAN 2210 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 2210 may also support QoS differentiation within a slice.

[00290] The NG-RAN 2210 may also use the UE assistance information for the selection of an AMF 2221 during an initial attach, if available. The NG-RAN 2210 uses the assistance information for routing the initial NAS to an AMF 2221. If the NG-RAN 2210 is unable to select an AMF 2221 using the assistance information, or the UE 2201 does not provide any such information, the NG-RAN 2210 sends the NAS signaling to a default AMF 2221, which may be among a pool of

AMFs 2221. For subsequent accesses, the UE 2201 provides a temp ID, which is assigned to the UE 2201 by the 5GC 2220, to enable the NG-RAN 2210 to route the NAS message to the appropriate AMF 2221 as long as the temp ID is valid. The NG-RAN 2210 is aware of, and can reach, the AMF 2221 that is associated with the temp ID. Otherwise, the method for initial attach applies.

[00291] The NG-RAN 2210 supports resource isolation between slices. NG-RAN 2210 resource isolation may be achieved by means of RRM policies and protection mechanisms that should avoid that shortage of shared resources if one slice breaks the service level agreement for another slice. In some implementations, it is possible to fully dedicate NG-RAN 2210 resources to a certain slice. How NG-RAN 2210 supports resource isolation is implementation dependent.

[00292] Some slices may be available only in part of the network. Awareness in the NG-RAN 2210 of the slices supported in the cells of its neighbors may be beneficial for inter-frequency mobility in connected mode. The slice availability may not change within the UE's registration area. The NG-RAN 2210 and the 5GC 2220 are responsible to handle a service request for a slice that may or may not be available in a given area. Admission or rejection of access to a slice may depend on factors such as support for the slice, availability of resources, support of the requested service by NG-RAN 2210.

[00293] The UE 2201 may be associated with multiple network slices simultaneously. In case the UE 2201 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 2201 tries to camp on the best cell. For inter-frequency cell reselection, dedicated priorities can be used to control the frequency on which the UE 2201 camps. The 5GC 2220 is to validate that the UE 2201 has the rights to access a network slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 2210 may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 2201 is requesting to access. During the initial context setup, the NG-RAN 2210 is informed of the slice for which resources are being requested.

[00294] NFV architectures and infrastructures may be used to virtualize one or more NFs, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[00295] Figure 28 is a block diagram illustrating components, according to some example embodiments, of a system 2800 to support NFV. The system 2800 is illustrated as including a VIM 2802, an NFVI 2804, an VNFM 2806, VNFs 2808, an EM 2810, an NFVO 2812, and a NM 2814.

[00296] The VIM 2802 manages the resources of the NFVI 2804. The NFVI 2804 can include physical or virtual resources and applications (including hypervisors) used to execute the system 2800. The VIM 2802 may manage the life cycle of virtual resources with the NFVI 2804 (e.g., creation, maintenance, and tear down of VMs associated with one or more physical resources), track VM instances, track performance, fault and security of VM instances and associated physical resources, and expose VM instances and associated physical resources to other management systems.

[00297] The VNFM 2806 may manage the VNFs 2808. The VNFs 2808 may be used to execute EPC components/functions. The VNFM 2806 may manage the life cycle of the VNFs 2808 and track performance, fault and security of the virtual aspects of VNFs 2808. The EM 2810 may track the performance, fault and security of the functional aspects of VNFs 2808. The tracking data from the VNFM 2806 and the EM 2810 may comprise, for example, PM data used by the VIM 2802 or the NFVI 2804. Both the VNFM 2806 and the EM 2810 can scale up/down the quantity of VNFs of the system 2800.

[00298] The NFVO 2812 may coordinate, authorize, release and engage resources of the NFVI 2804 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 2814 may provide a package of end-user functions with the responsibility for the management of a network, which may include network elements with VNFs, non-virtualized network functions, or both (management of the VNFs may occur via the EM 2810).

[00299] Figure 29 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 29 shows a diagrammatic representation of hardware resources 2900 including one or more processors (or processor cores) 2910, one or more memory/storage devices 2920, and one or more communication resources 2930, each of which may be communicatively coupled via a bus 2940. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 2902 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 2900.

[00300] The processors 2910 may include, for example, a processor 2912 and a processor 2914. The processor(s) 2910 may be, for example, a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.

[00301] The memory/storage devices 2920 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 2920 may include, but are not limited to, any type of volatile or nonvolatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

[00302] The communication resources 2930 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 2904 or one or more databases 2906 via a network 2908. For example, the communication resources 2930 may include wired communication components (e.g., for coupling via USB), cellular communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components.

[00303] Instructions 2950 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 2910 to perform any one or more of the methodologies discussed herein. The instructions 2950 may reside, completely or partially, within at least one of the processors 2910 (e.g., within the processor's cache memory), the memory/storage devices 2920, or any suitable combination thereof. Furthermore, any portion of the instructions 2950 may be transferred to the hardware resources 2900 from any combination of the peripheral devices 2904 or the databases 2906. Accordingly, the memory of processors 2910, the memory/storage devices 2920, the peripheral devices 2904, and the databases 2906 are examples of computer-readable and machine-readable media.

Further Embodiments

[00304] In some embodiments, a single communications services layer (CSL) may coordinate multiple radio computers. In some embodiments, a dedicated radio control framework (RCF) may be managing a single radio computer (e.g., one specific RCF for one specific radio computer) and/or a set of (e.g., more than one) radio computers. In some embodiments, for each RCF, a radio operating system (ROS), e.g., a specific radio operating system, may be managing a single radio computer (e.g., one specific RCF for one specific radio computer) and/or a set of (e.g., more than one) radio computers. In some embodiments, an identifier (ID) may be provided to each radio computer. In some embodiments, the ID may be a bit sequence with each radio computer having a distinct ID.

[00305] In some embodiments, a command, instruction, and/or data element from a CSL may be multiplexed to one or multiple radio computers. In some embodiments, the command, instruction, and/or data element from the CSL may be routed to a target radio computer through (or via) a

respective radio Computer ID. The command, instruction, and/or data element from the CSL may then be processed by one or multiple of the functions of the RCF (e.g., be a configuration manager, radio connection manager, multi-radio controller, resource manager, and/or flow controller of the RCF).

[00306] In some embodiments, a command, instruction, and/or data element from one or multiple radio computers may be de-multiplexed to a CSL. In some embodiments, the command, instruction, and/or data element from the one or multiple radio computers may be provided serially and/or in parallel to the CSL and processed by one or more of the CSL functions (e.g., administrator, mobility policy manager, networking stack, monitor).

[00307] In some embodiments, there may be as many instances of an RCF created as there are radio computers, e.g., one RCF corresponds to one radio computer. In some embodiments, an RCF may be related to a radio Computer in a fixed way. Alternatively, RCFs may be dynamically allocated to radio computers. In some embodiments, any set of radio computers may be created in a fixed way or dynamically.

[00308] In some embodiments, one or more radio computers may be assigned to a safety related application. In some embodiments, a single or multiple further radio computers may be assigned to a non-safety related application. In this way, the safety related application may be protected, e.g., in case of exceptions/malfunction of the RCF or radio operating system of the non-safety related application. In some embodiments, a safety related application may be a vehicular communications application. In some embodiments, the vehicular communications application may be, for example, provided by 3GPP 5G NR V2X, 3GPP LTE C-V2X (3GPP Long Term Evolution Cellular Vehicle-to-Everything Communication), ITS-G5 (Intelligent Transport Systems G5), dedicated short-range communications (DSRC), Wireless Access in Vehicular Environments (WAVE) and/or IEEE 802.11p systems.

[00309] In some embodiments, one or more radio computers may be assigned to a safety critical application. In some embodiments, a single or multiple further radio computers may be assigned to a non-safety critical application. In this way, the safety critical application is protected, e.g., in case of exceptions/malfunction of the RCF or radio operating system of the non-safety critical application.

[00310] In some embodiments, a command, instruction, and/or data element to or from a CSL may be tagged with a related source/target radio computer ID. In some embodiments, the radio computer ID may be to the related element (or container) that includes the command, instruction and/or data element.

[00311] In some embodiments, , for interactions between an administrator (e.g., in a CSL) and a configuration manager (e.g., in an RCF), a multiplexer (e.g., for the direction from CSL to RCF)

or de-multiplexer (for the direction from RCF to CSL) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to/from a CF1 reference point of a radio computer of the given ID.

[00312] In some embodiments, for interactions between a mobility policy manager (e.g., in a CSL) and a configuration manager (e.g., in an RCF), a multiplexer (e.g., for the direction from CSL to RCF) or de-multiplexer (for the direction from RCF to CSL) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CF2 reference point of the radio computer of the given ID.

[00313] In some embodiments, for interactions between a mobility policy manager (e.g., in a CSL) and a radio configuration manager (e.g., in an RCF), a multiplexer (e.g., for the direction from CSL to RCF) or de-multiplexer (for the direction from RCF to CSL) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CTRL1 reference point of the radio computer of the given ID.

[00314] In some embodiments, for interactions between a network (or networking) stack (e.g., in a CSL) and a flow controller (e.g., in an RCF), a multiplexer (e.g., for the direction from CSL to RCF) or de-multiplexer (for the direction from RCF to CSL) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CTRL4 reference point and/or to a DCTRL1 reference point of the radio computer of the given ID.

[00315] In some embodiments, for interactions between a monitor (e.g., in a CSL) and a unified radio application, a multiplexer (e.g., for the direction from CSL to RCF) or de-multiplexer (for the direction from RCF to CSL) may read and/or determine a radio computer ID of an associated command, instruction, and/or data element. In some embodiments, based on the radio computer ID, the administrator/configuration manager may direct the information to a CII reference point reference point of the radio computer of the given ID.

[00316] In some embodiments, a method of managing multiple radio computers may include:

- associating or causing to associate a first radio computer with a first application and a second radio computer with a second application, wherein the first and second applications perform different functions; and

- communicating or causing to communicate data between a communication services layer (CSL) and the first and second radio computers.

[00317] In such embodiments of the method, communicating or causing to communicate data between the CSL and the first and second radio computers may include:

communicating or causing to communicate data between the CSL and a generalized multiradio interface (gMURI); and

communicating or causing to communicate data between the gMURI and a radio control framework (RCF), wherein the RCF manages the first radio computer.

[00318] In some embodiments of the method, communicating or causing to communicate data between the CSL and the first and second radio computers further includes:

communicating or causing to communicate data between the CSL and a second gMURI; and

communicating or causing to communicate data between the second gMURI and a second radio control framework (RCF), wherein the second RCF manages the second radio computer.

[00319] In such embodiments of the method, the method may further include:

assigning or causing to assign each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

assigning or causing to assign each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00320] In some embodiments, 23 communicating or causing to communicate data between the CSL and the first and second radio computers may include:

communicating or causing to communicate data between the CSL and a gMURI;

communicating or causing to communicate data between the gMURI and a first radio control framework (RCF), wherein the first RCF manages the first radio computer; and

communicating or causing to communicate data between the gMURI and a second RCF, wherein the second RCF manages the second radio computer.

[00321] In such embodiments, the method may further include:

assigning or causing to assign each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

assigning or causing to assign each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00322] In such embodiments, the method may further include:

multiplexing or causing to multiplex the data prior to the gMURI communicating the data with the first and second RCFs.

[00323] In some embodiments an apparatus for use in managing multiple radio computers may include:

means for associating a first radio computer with a first application and a second radio computer with a second application, wherein the first and second applications perform different functions; and

means for communicating data between a communication services layer (CSL) and the first and second radio computers.

[00324] In some embodiments, the means for communicating data between the CSL and the first and second radio computers may include:

means for communicating data between the CSL and a generalized multiradio interface (MURI); and

means for communicating data between the gMURI and a radio control framework (RCF), wherein the RCF manages the first radio computer.

[00325] In such embodiments, the means for communicating data between the CSL and the first and second radio computers may further include:

means for communicating data between the CSL and a second generalized multiradio interface (gMURI); and

means for communicating data between the second gMURI and a second radio control framework (RCF), wherein the second RCF manages the second radio computer.

[00326] In such embodiments, the apparatus may further include:

means for assigning each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

means for assigning each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based

on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00327] In some embodiments, the means for communicating data between the CSL and the first and second radio computers may include:

means for communicating data between the CSL and a generalized multiradio interface (gMURI);

means for communicating data between the gMURI and a first radio control framework (RCF), wherein the first RCF manages the first radio computer; and

means for communicating data between the gMURI and a second RCF, wherein the second RCF manages the second radio computer.

[00328] In such embodiments, the apparatus may further include:

means for assigning each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

means for assigning each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00329] In such embodiments, the apparatus may further include:

means for multiplexing the data prior to the gMURI communicating the data with the first and second RCFs.

[00330] In some embodiments, an apparatus for managing multiple radio computers may be configured to:

associate a first radio computer with a first application and a second radio computer with a second application, wherein the first and second applications perform different functions; and

communicate data between a communication services layer (CSL) and the first and second radio computers.

[00331] In some embodiments, to communicate data between the CSL and the first and second radio computers, the apparatus is configured to:

communicate data between the CSL and a generalized multiradio interface (gMURI);
and

communicate data between the MURI and a radio control framework (RCF), wherein the RCF manages the first radio computer.

[00332] In such embodiment, to communicate data between the CSL and the first and second radio computers, the apparatus may be configured to:

communicate data between the CSL and a second generalized multiradio interface (gMURI); and

communicate data between the second gMURI and a second radio control framework (RCF), wherein the second RCF manages the second radio computer.

[00333] In such embodiments, the apparatus may be further configured to:

assign each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

assign each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00334] In some embodiments, to communicate data between the CSL and the first and second radio computers, the apparatus may be configured to:

communicate data between the CSL and a generalized multiradio interface (gMURI);

communicate data between the gMURI and a first radio control framework (RCF), wherein the first RCF manages the first radio computer; and

communicate data between the MURI and a second RCF, wherein the second RCF manages the second radio computer.

[00335] In some embodiments, the apparatus may be further configured to:

assign each of the first and second RCFs a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first RCF's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second RCF's unique ID; and/or

assign each of the first and second radio computers a unique identifier (ID), wherein a first set of data is communicated between the CSL and the first radio computer based on the first radio computer's unique ID and wherein a second set of data is communicated between the CSL and the second radio computer based on the second radio computer's unique ID.

[00336] In such embodiments, the apparatus may be further configured to:

multiplex the data prior to the gMURI communicating the data with the first and second RCFs.

[00337] It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

[00338] Embodiments of the present disclosure may be realized in any of various forms. For example, some embodiments may be realized as a computer-implemented method, a computer-readable memory medium, or a computer system. Other embodiments may be realized using one or more custom-designed hardware devices such as ASICs. Still other embodiments may be realized using one or more programmable hardware elements such as FPGAs.

[00339] In some embodiments, a non-transitory computer-readable memory medium may be configured so that it stores program instructions and/or data, where the program instructions, if executed by a computer system, cause the computer system to perform a method, e.g., any of the method embodiments described herein, or, any combination of the method embodiments described herein, or, any subset of any of the method embodiments described herein, or, any combination of such subsets.

[00340] In some embodiments, a device (e.g., a UE 106) may be configured to include a processor (or a set of processors) and a memory medium, where the memory medium stores program instructions, where the processor is configured to read and execute the program instructions from the memory medium, where the program instructions are executable to implement any of the various method embodiments described herein (or, any combination of the method embodiments described herein, or, any subset of any of the method embodiments described herein, or, any combination of such subsets). The device may be realized in any of various forms.

[00341] Although the embodiments above have been described in considerable detail, numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such variations and modifications.

CLAIMS

What is claimed is:

1. A user equipment device (UE), comprising:
 - at least one antenna;
 - at least two radios, wherein the at least two radio are configured to perform wireless communication using at least one radio access technology (RAT);
 - one or more processors coupled to the at least two radios, wherein the one or more processors and the at least two radios are configured to perform voice and/or data communications;
 - wherein the one or more processors are configured to cause the UE to:
 - associate a first application with a first radio of the at least two radios;
 - associate a second application with a second radio of the at least two radios, wherein the second application performs a different service than the first application; and
 - exchange data between a communication services layer (CSL) of the UE and the first and second radios.
2. The UE of claim 1,
 - wherein, to exchange the data between the CSL and the first and second radios, the one or more processors are configured to cause the UE to:
 - transfer the data from the CSL to a generalized multiradio interface (gMURI); and
 - transfer the data from the gMURI to the first and second radios.
3. The UE of claim 2,
 - wherein, to transfer the data from the gMURI to the first and second radios, the one or more processors are further configured to cause the UE to:
 - transfer the data from the gMURI to a first radio control function managing the first radio and a second radio control function managing the second radio.
4. The UE of claim 2,
 - wherein the gMURI supports administrative services, access control services, and data flow services between the CSL and the first and second radios.
5. The UE of claim 1,
 - wherein, to exchange the data between the CSL and the first and second radios, the one or more processors are configured to cause the UE to:

transfer the data from the CSL to a first generalized multiradio interface (gMURI) associated with the first radio and a second gMURI associated with the second radio; and
transfer the data from the first gMURI to the first radio based, at least in part, on an identifier included in the data.

6. The UE of claim 4,
wherein the identifier is associated with a first radio control function that manages the first radio.

7. The UE of claim 1,
wherein, to exchange the data between the CSL and the first and second radios, the one or more processors are configured to cause the UE to:
transfer the data from the CSL to a generalized multiradio interface (gMURI) with the first radio and the second radio, wherein the gMURI is one of a plurality of gMURIs included on the UE; and
transfer the data from the gMURI to the first radio based, at least in part, on an identifier included in the data.

8. The UE of claim 7,
wherein the one or more processors are further configured to cause the UE to:
multiplex the data transferred from the CSL to the gMURI via a multiplexing entity.

9. The UE of claim 7,
wherein the multiplexing entity is configured to support one or more reference points between the CSL and one or more radio control functions associated with the first and second radios.

10. An apparatus, comprising:
a memory; and
a processing element in communication with the memory, wherein the processing element is configured to:
associate a first application with a first radio computer and a second application with a second radio computer, wherein the second application performs a different function than the first application; and

exchange, via a generalized multiradio interface (gMURI), data between a communication services layer (CSL) and the first and second radio computers.

11. The apparatus of claim 10,

wherein the first application is a safety related application or a safety critical related application, and wherein the second application is a non-safety related application or a non-safety critical application.

12. The apparatus of claim 10,

wherein the first application is safety related application vehicular communications application provided by one of 3GPP 5G New Radio Vehicle-to-Everything Communication, 3GPP Long Term Evolution Cellular Vehicle-to-Everything Communication, Intelligent Transport Systems G5, dedicated short-range communications, Wireless Access in Vehicular Environments or IEEE 802.11p systems.

13. The apparatus of claim 10,

wherein the processing element is further configured to:

receive, via the gMURI, an attachment request from a radio control function associated with the first radio computer;

forward, via the gMURI, the attachment request to the CSL;

receive, via the gMURI, an attachment determination from the CSL; and

provide, via the gMURI, the attachment determination to the radio control function.

14. The apparatus of claim 13,

wherein, when the attachment request is successful, the attachment determination indicates an identifier associated to the radio control function by the CSL.

15. The apparatus of claim 14,

wherein the CSL includes an administrator function configured to assign the identifier to the radio control function.

16. A non-transitory computer readable memory medium storing program instructions executable by processing circuitry to cause a reconfigurable wireless device to:

associate a first application with a first radio computer and a second application with a second radio computer, wherein the first application performs a safety associated service, and wherein the second application performs a non-safety associated service; and

exchange, via a generalized multiradio interface (gMURI), data between a communication services layer (CSL) and the first and second radio computers.

17. The non-transitory computer readable memory medium of claim 16, wherein the first radio computer is supported by a first radio operating system, and wherein the second radio computer is supported by a second radio operating system.

18. The non-transitory computer readable memory medium of claim 16, wherein the first application affects at least one of health/life of a patient, functioning of a machine, or integrity of a machine and/or is time sensitive.

19. The non-transitory computer readable memory medium of claim 16, wherein, to exchange, via a generalized multiradio interface (gMURI), data between the CSL and the first and second radio computers, the program instructions are further executable to transfer the data from the gMURI to a first radio control function managing the first radio computer and a second radio control function managing the second radio computer.

20. The non-transitory computer readable memory medium of claim 16, wherein, to exchange, via a generalized multiradio interface (gMURI), data between the CSL and the first and second radio computers, the program instructions are further executable to:

- transfer the data from the CSL to a first gMURI associated with the first radio computer and a second gMURI associated with the second radio computer; and
- transfer the data from the first gMURI to the first radio computer based, at least in part, on an identifier included in the data.

1 / 30

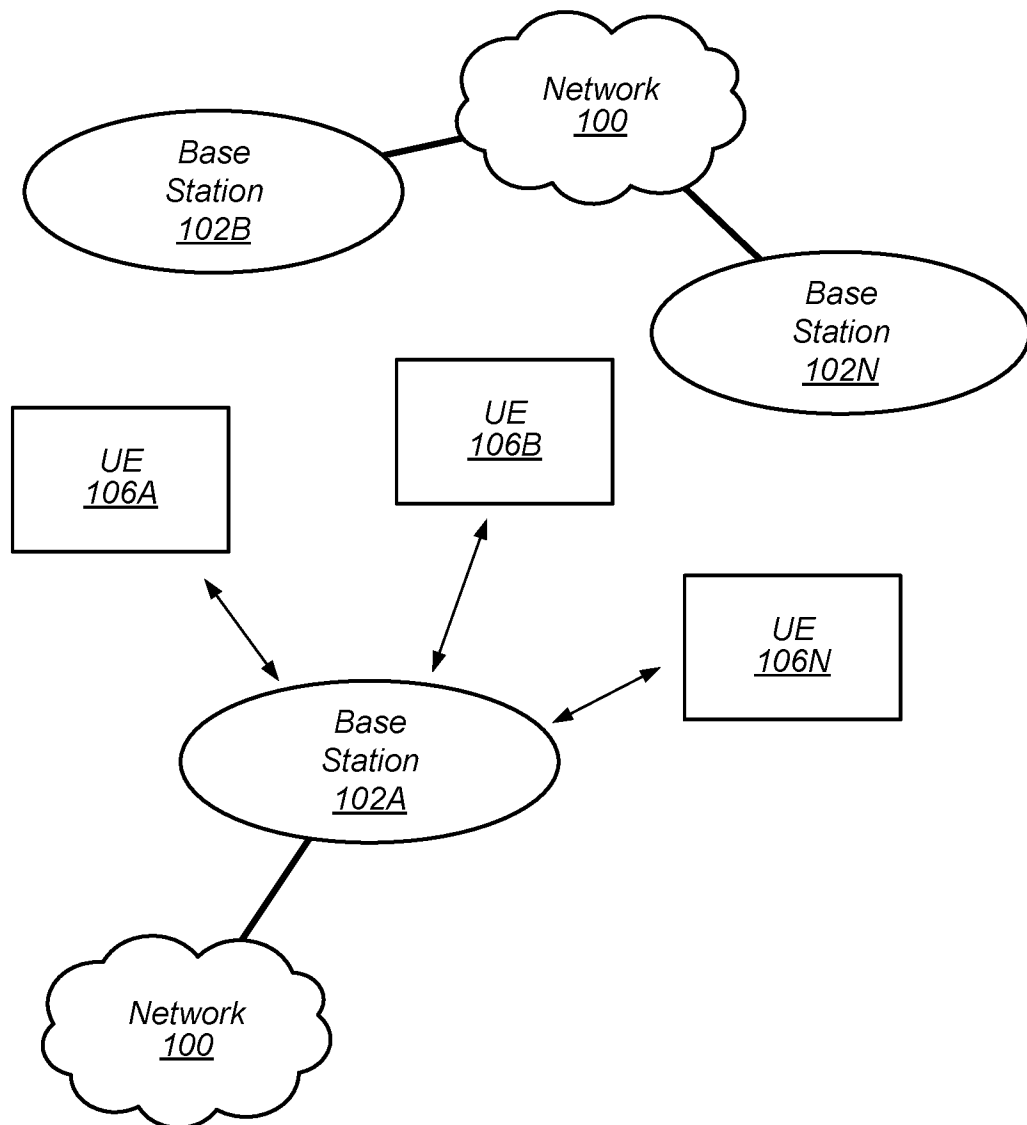


FIG. 1A

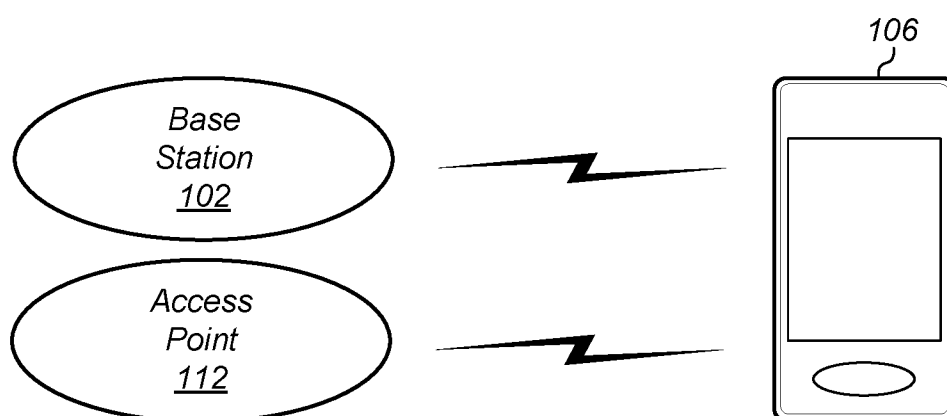


FIG. 1B

2 / 30

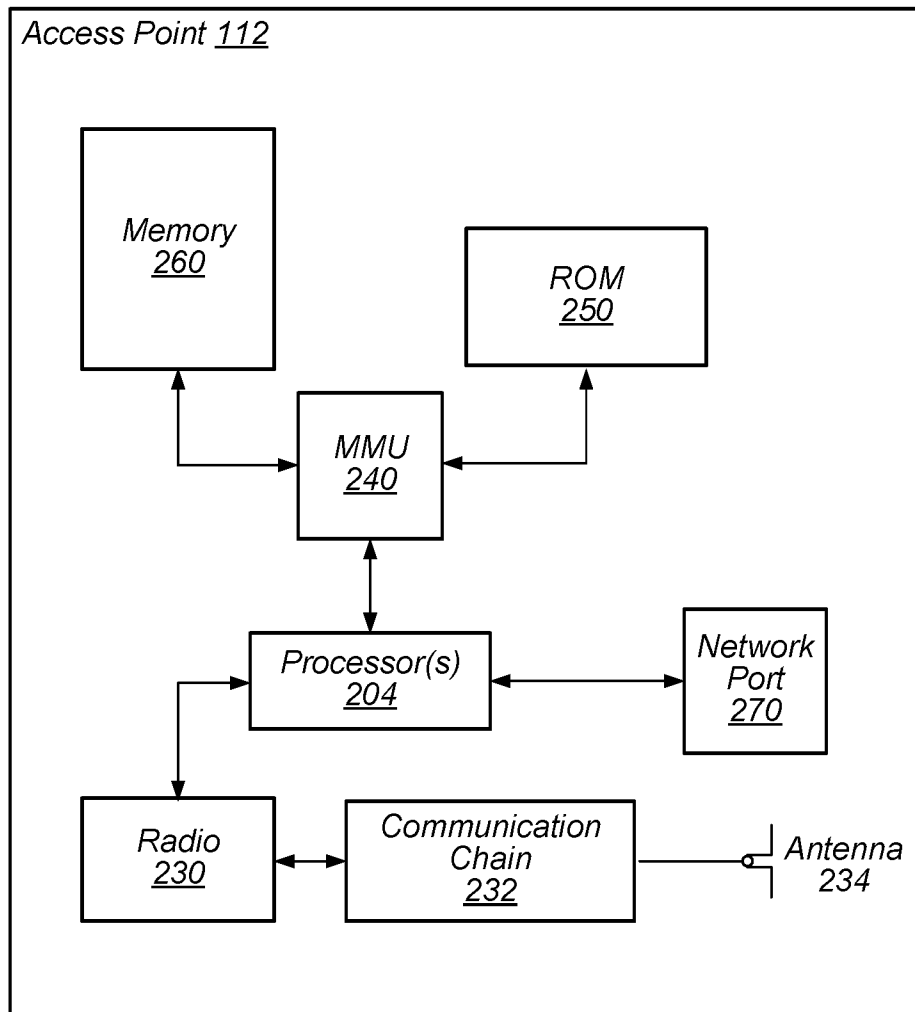


FIG. 2

3 / 30

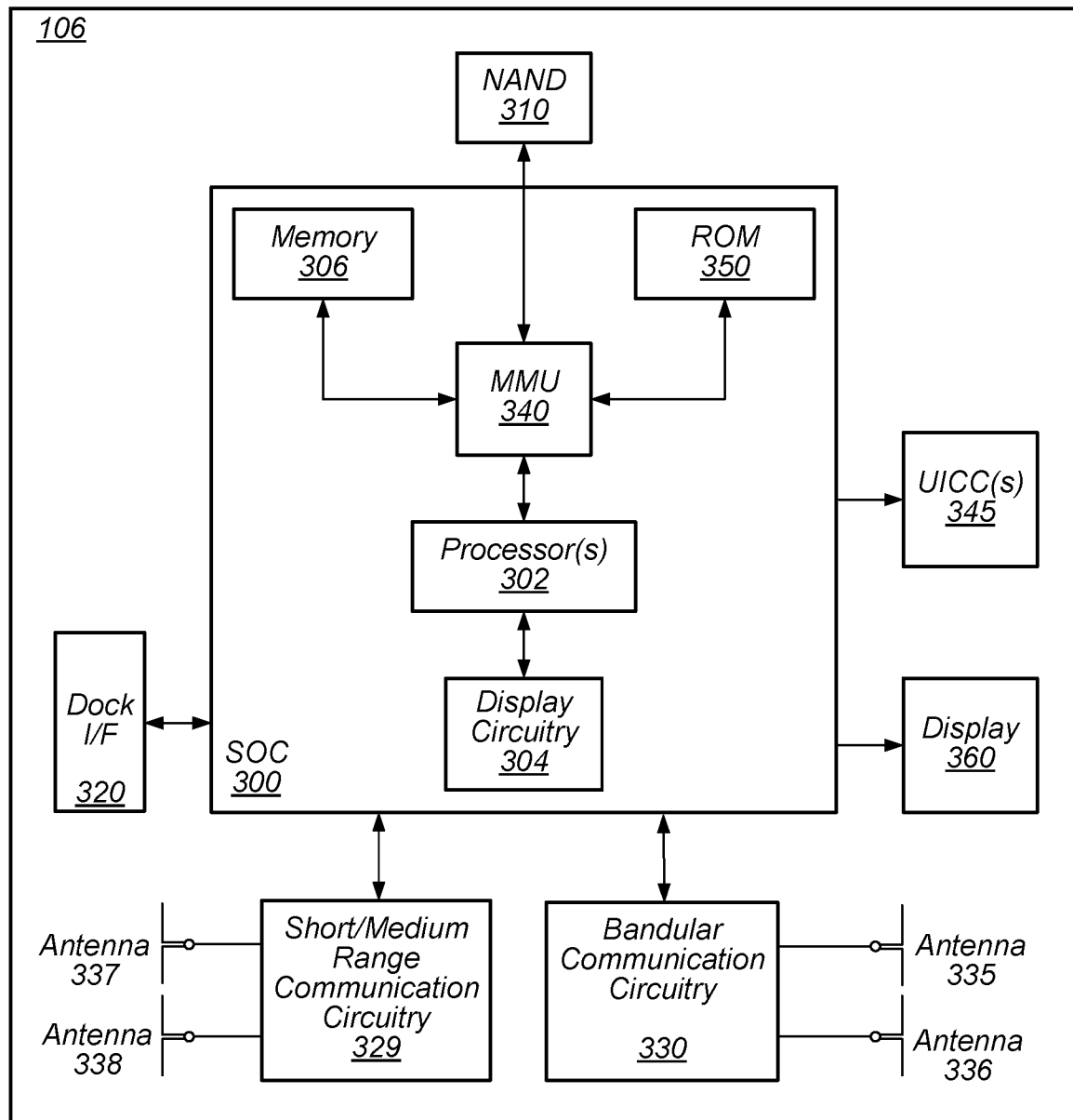


FIG. 3

4 / 30

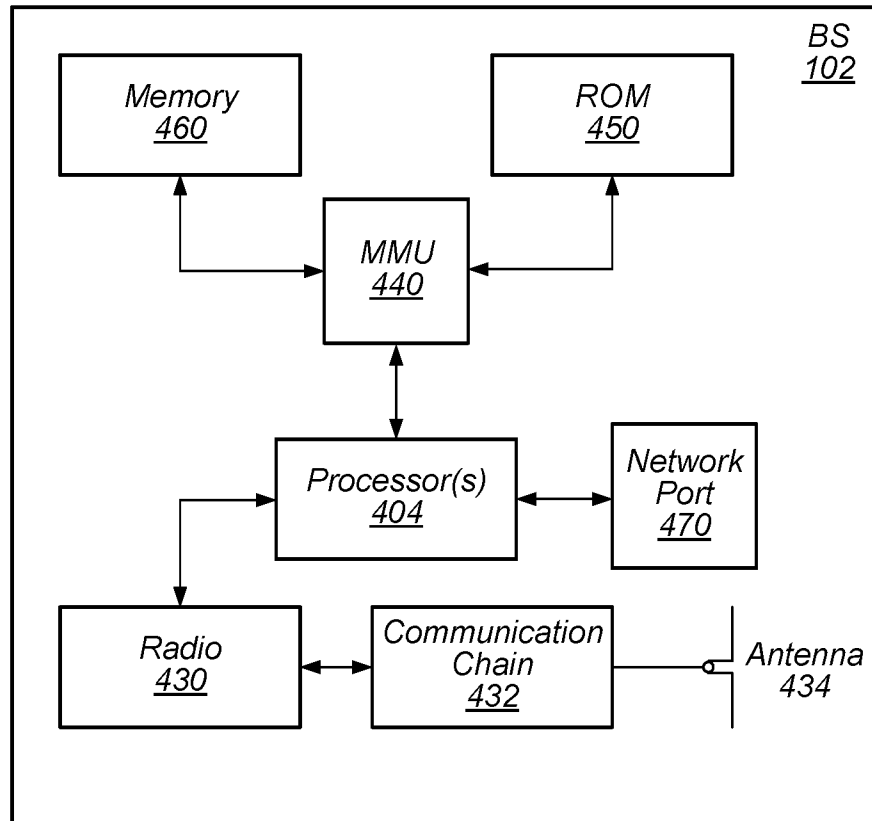


FIG. 4

5 / 30

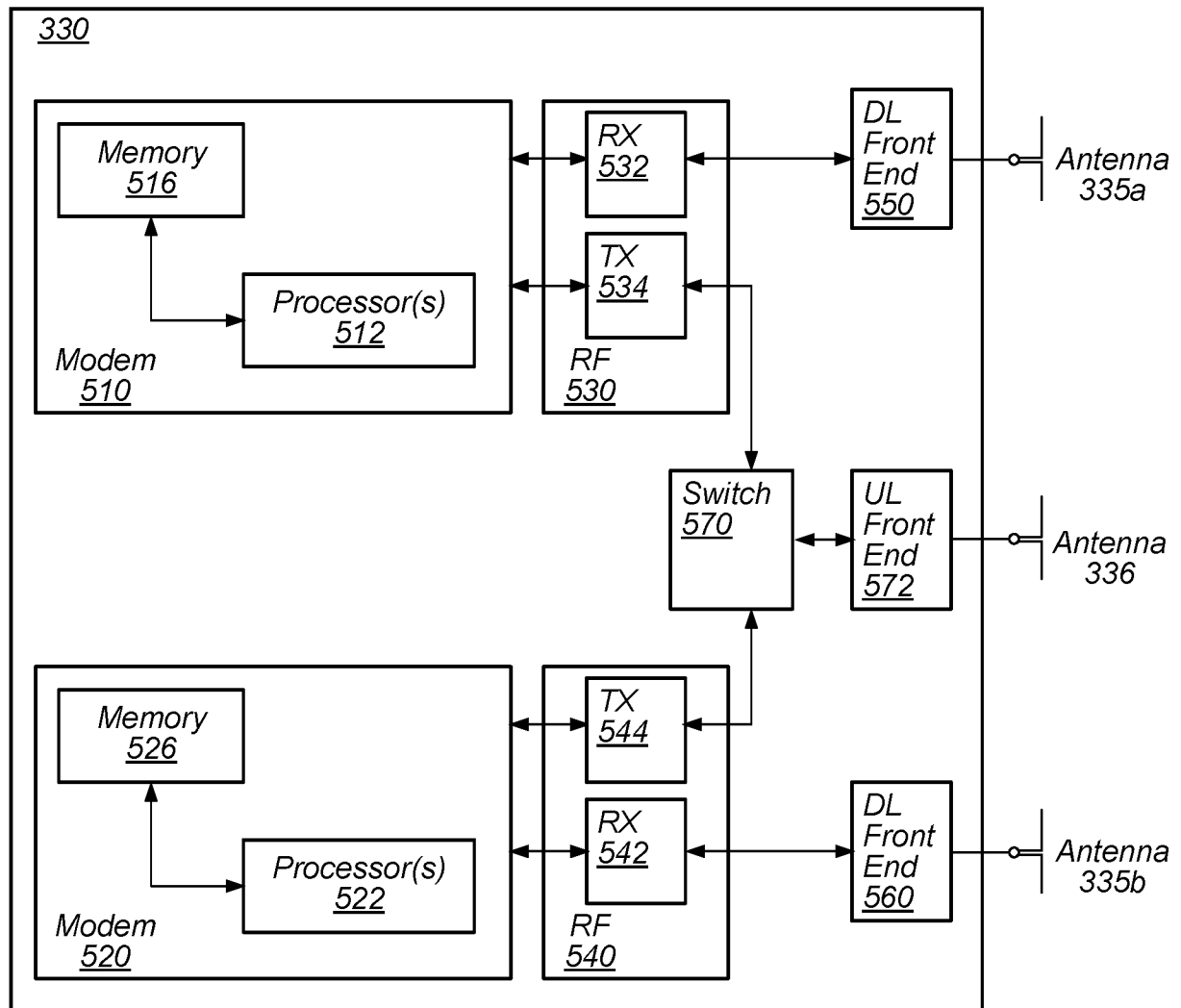


FIG. 5

6 / 30

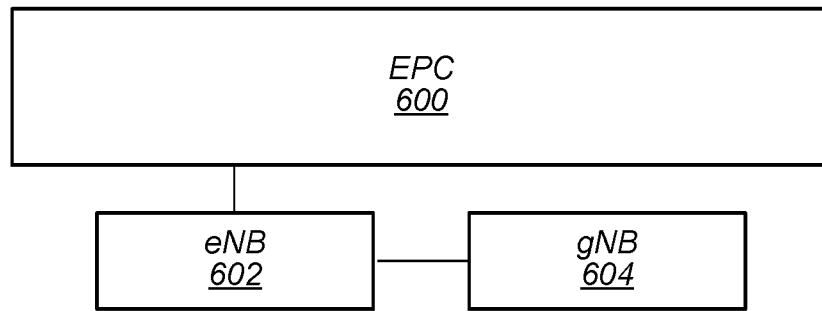


FIG. 6A

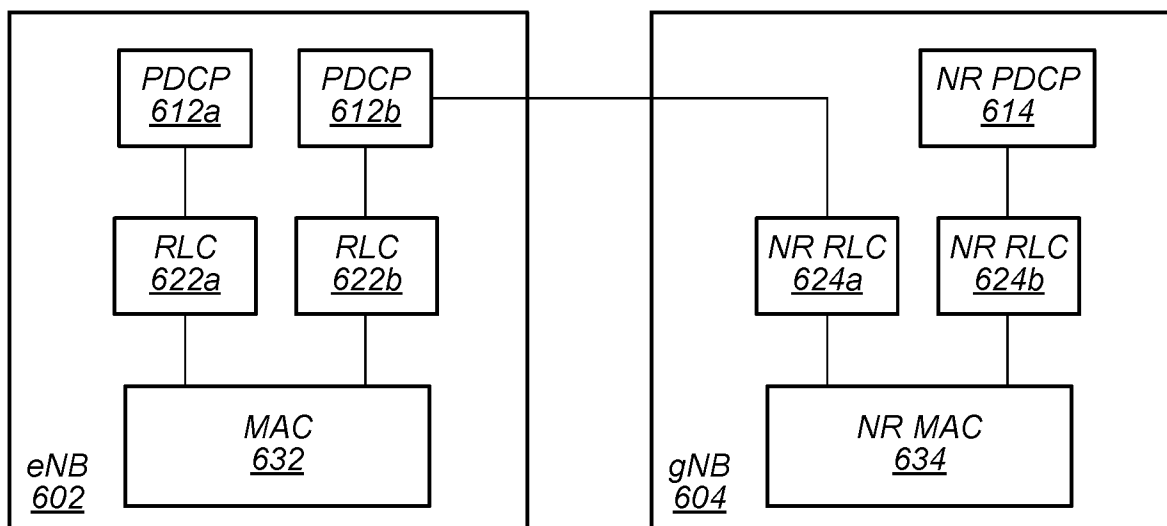


FIG. 6B

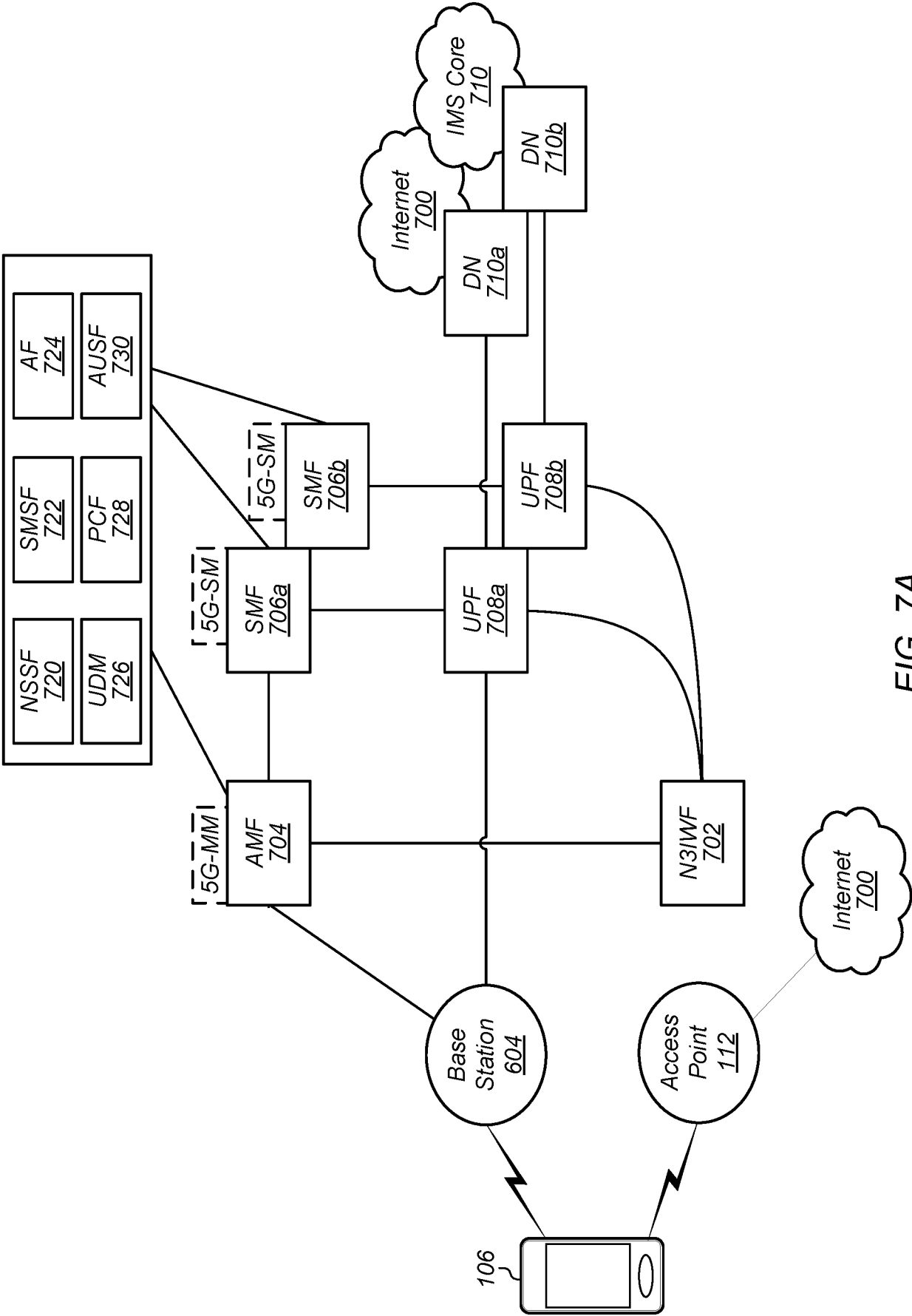


FIG. 7A

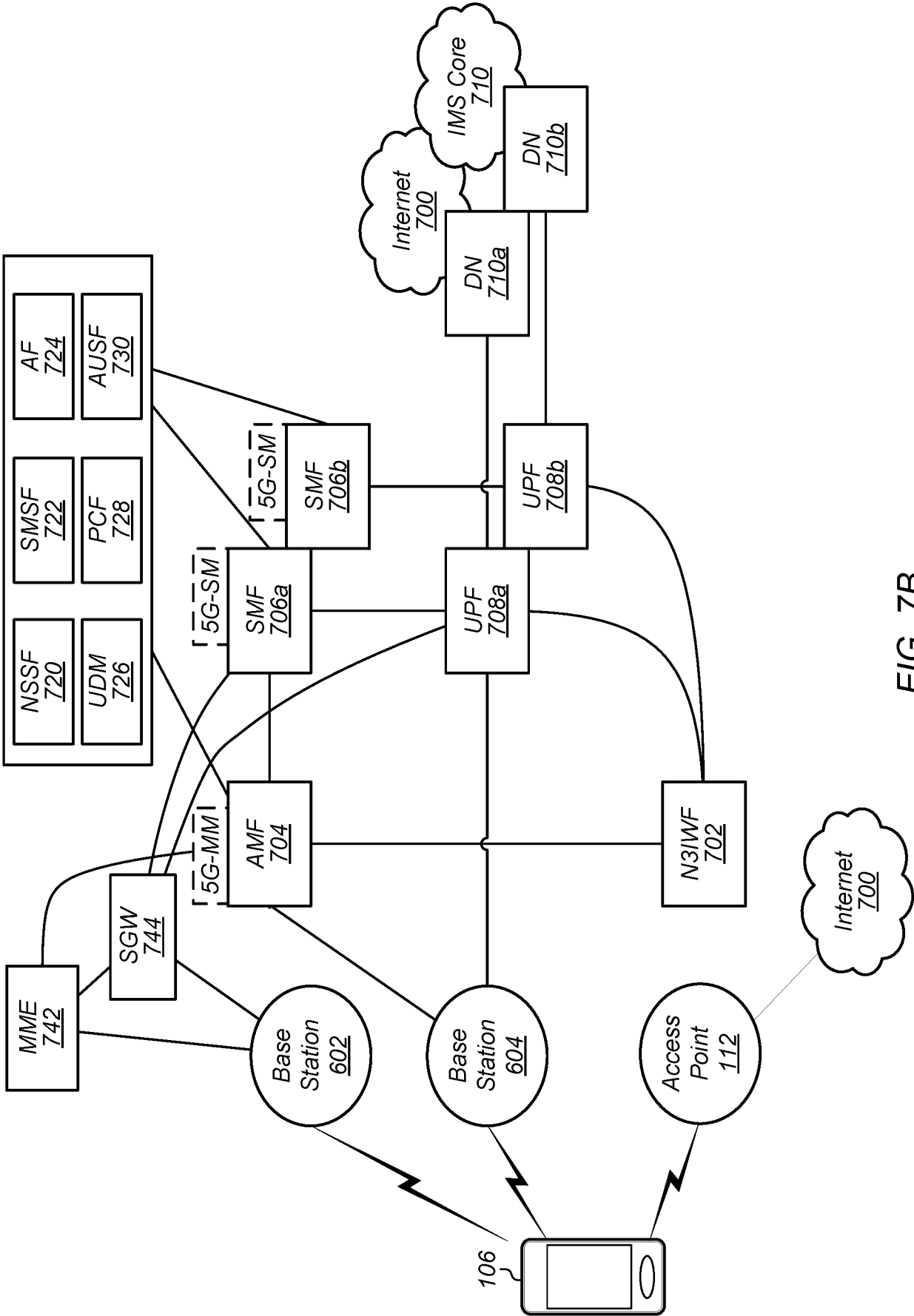


FIG. 7B

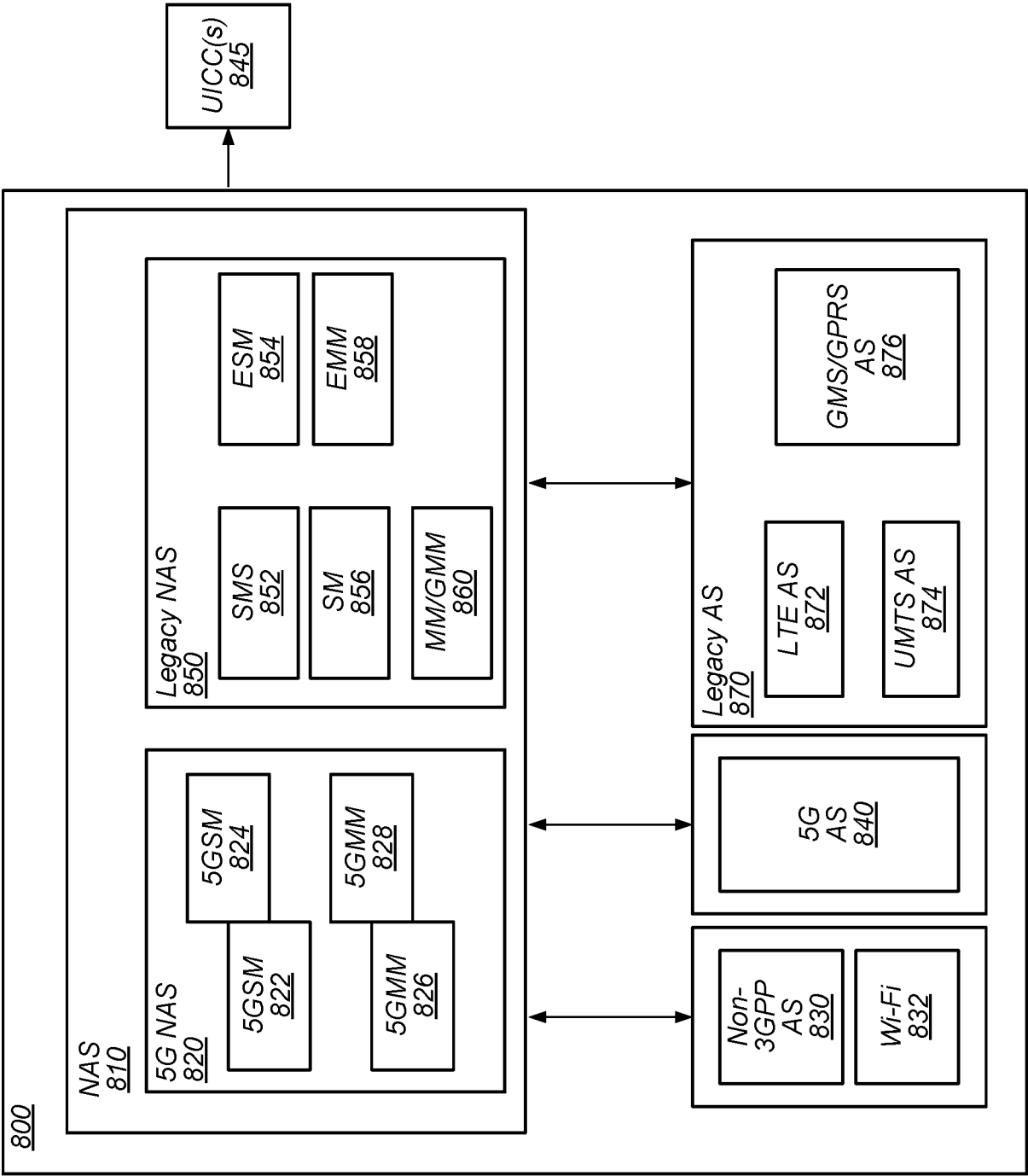


FIG. 8

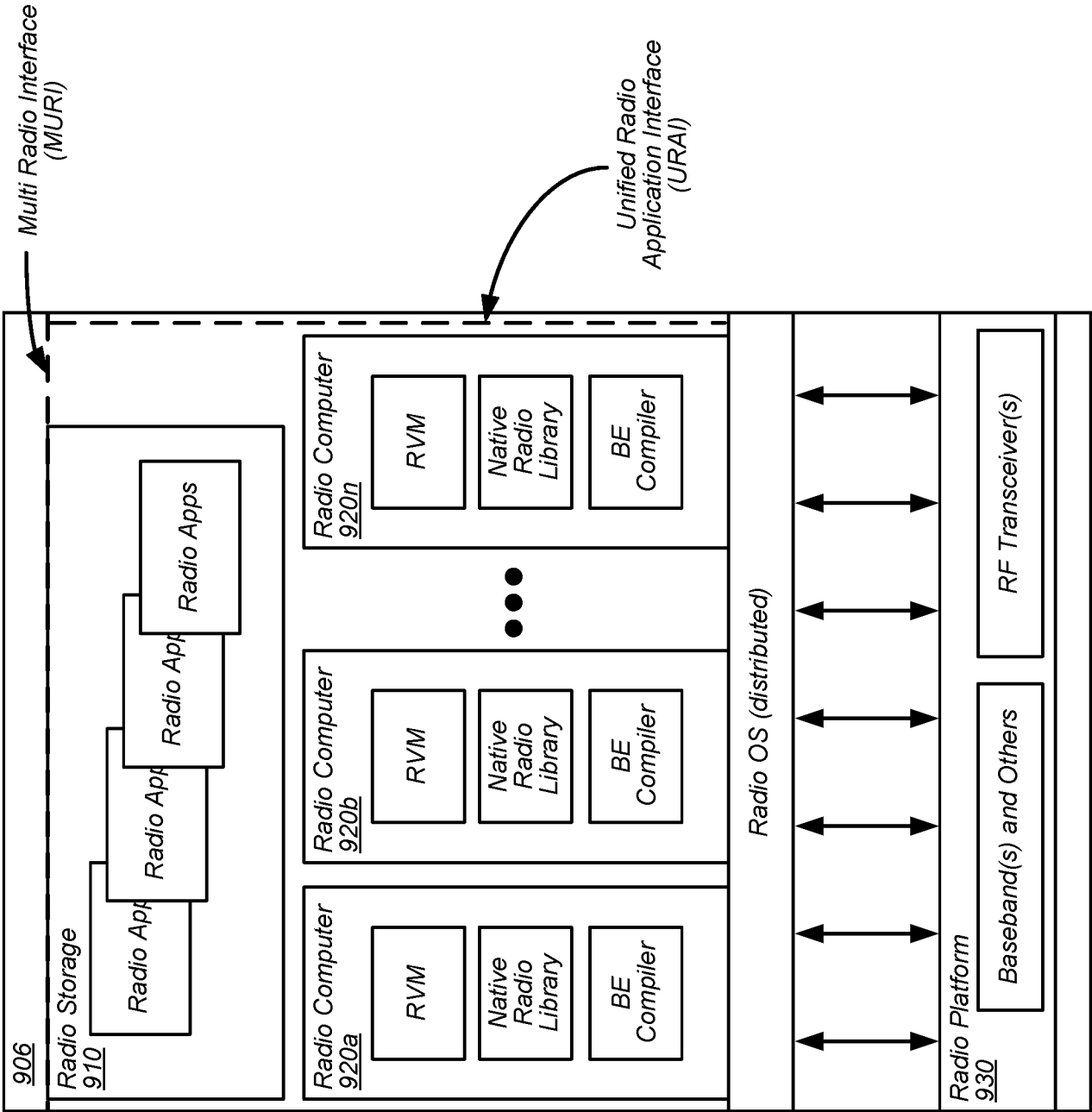


FIG. 9

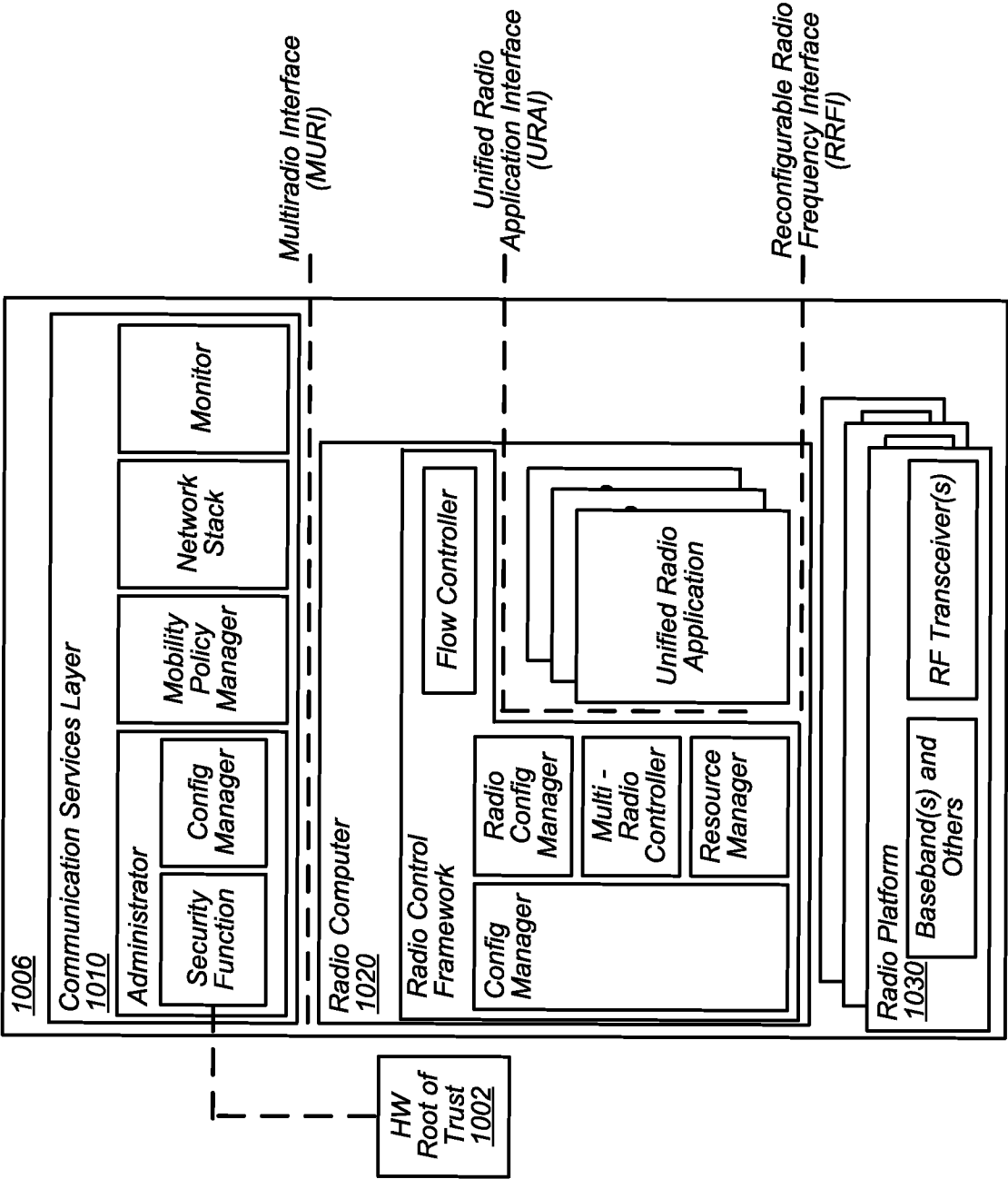


FIG. 10

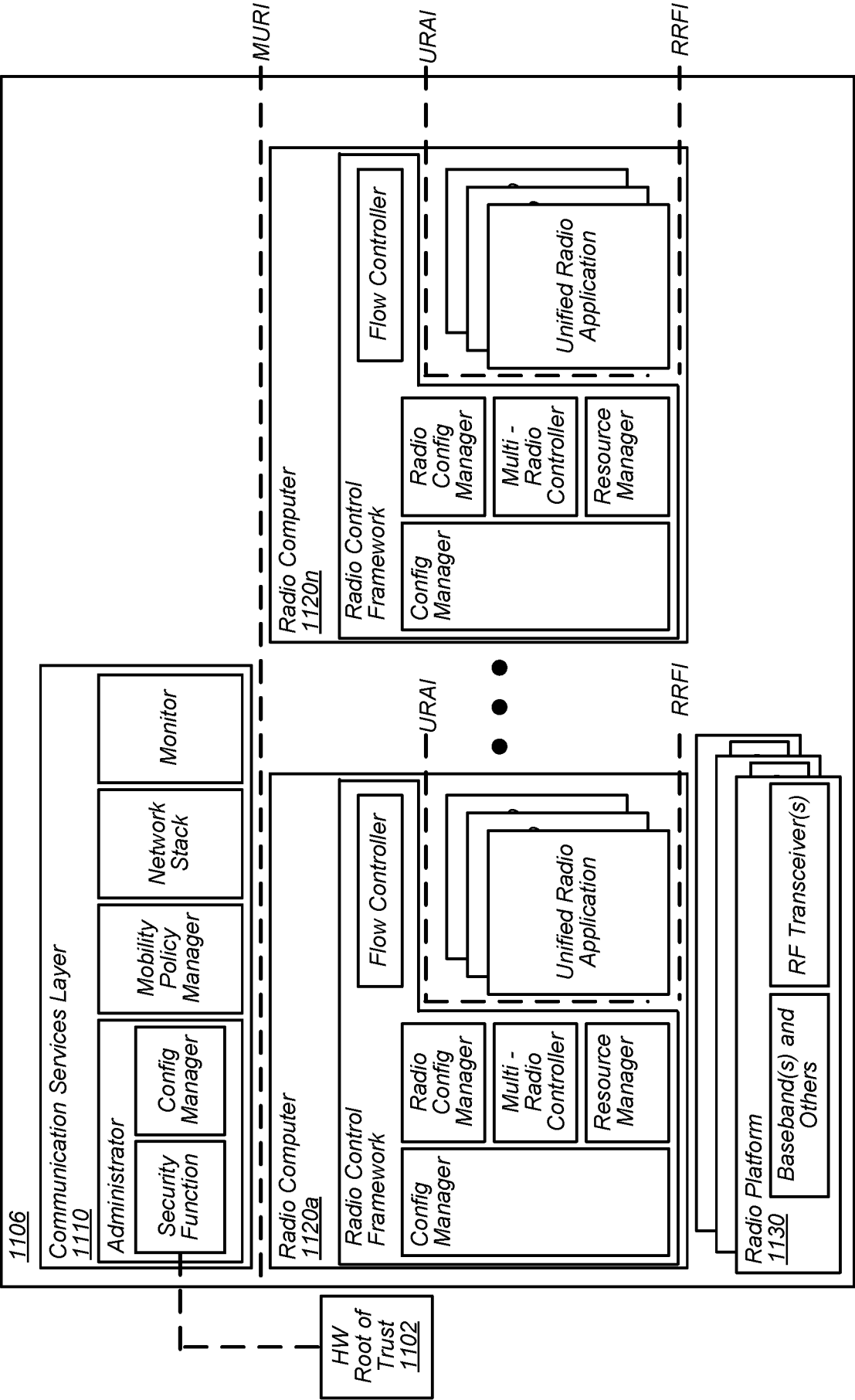


FIG. 11

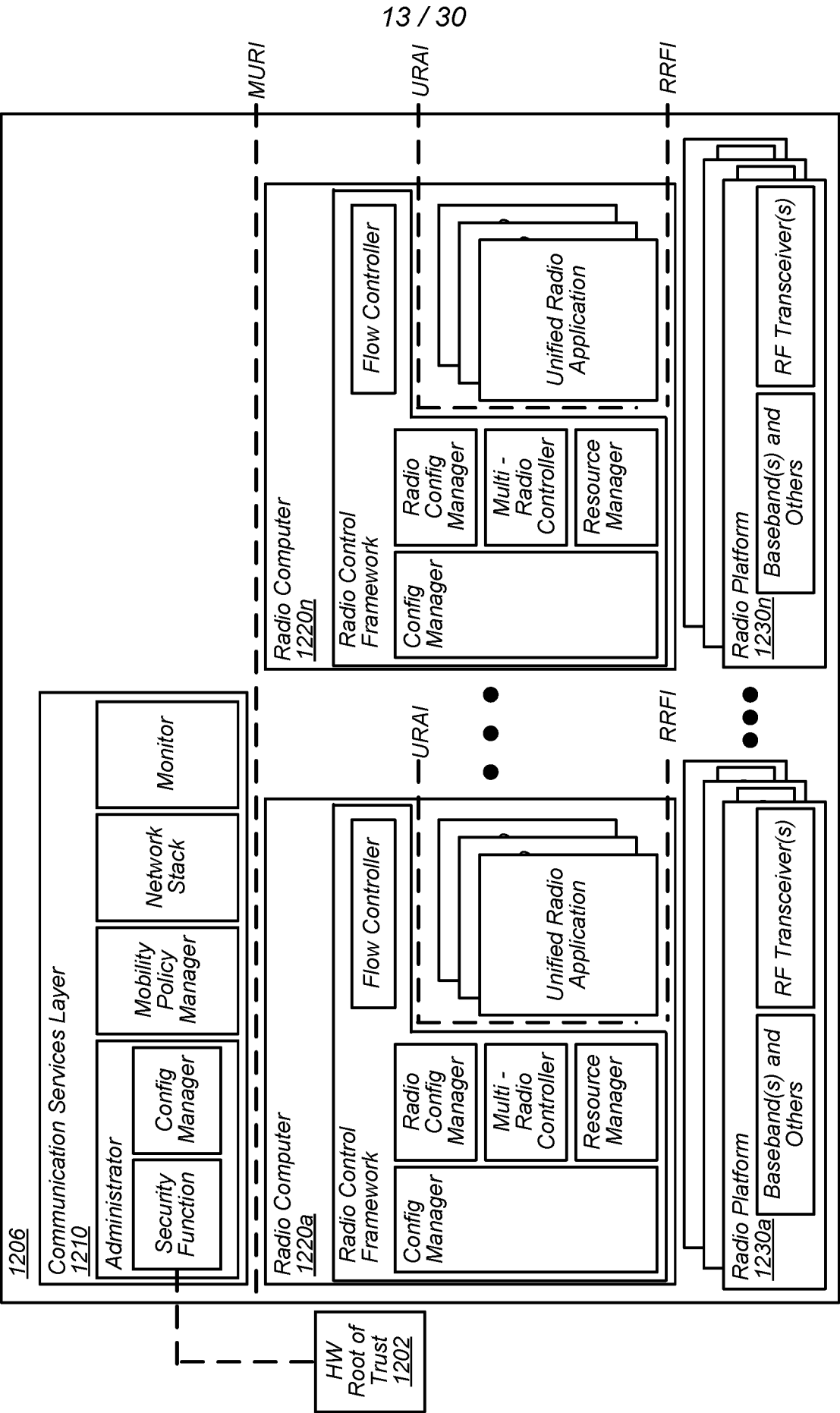


FIG. 12

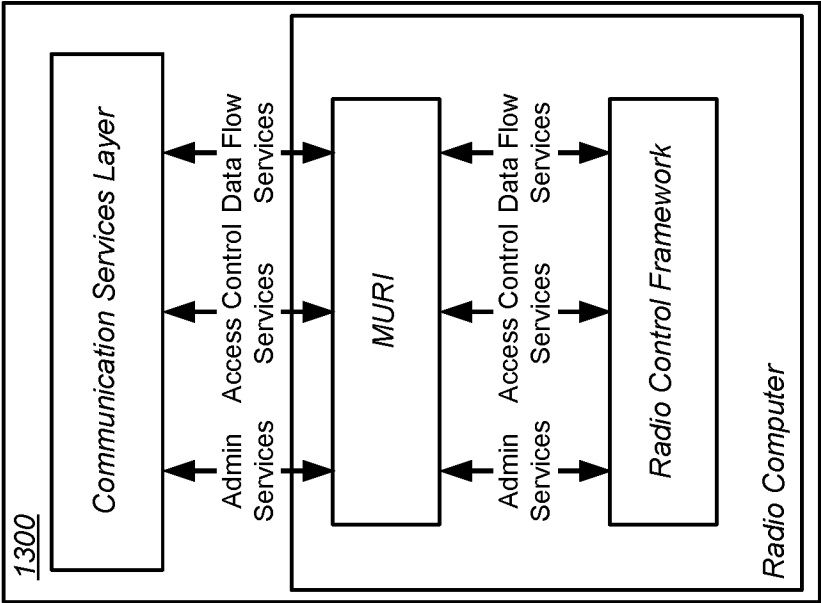


FIG. 13
(Prior Art)

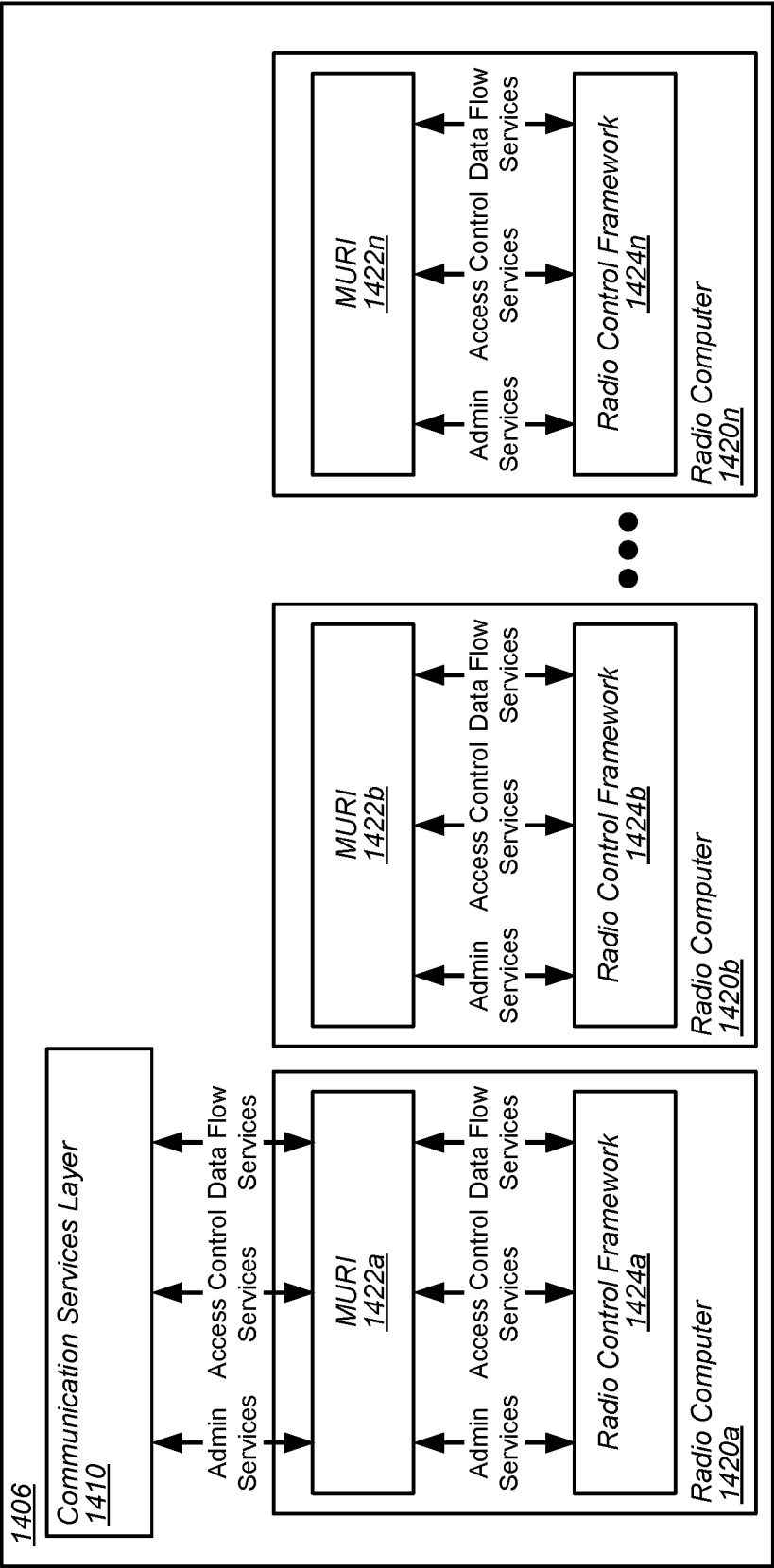


FIG. 14

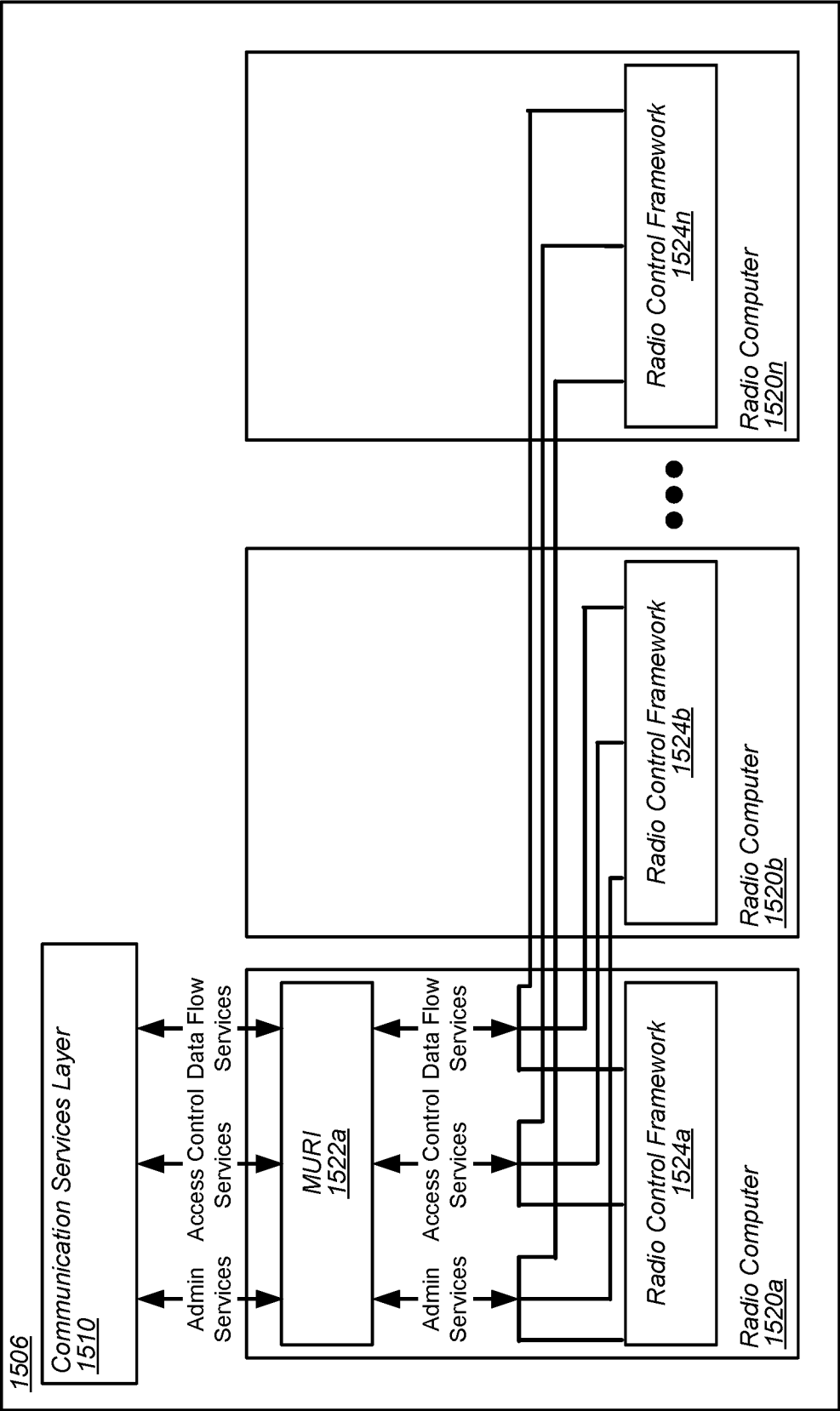


FIG. 15

17 / 30

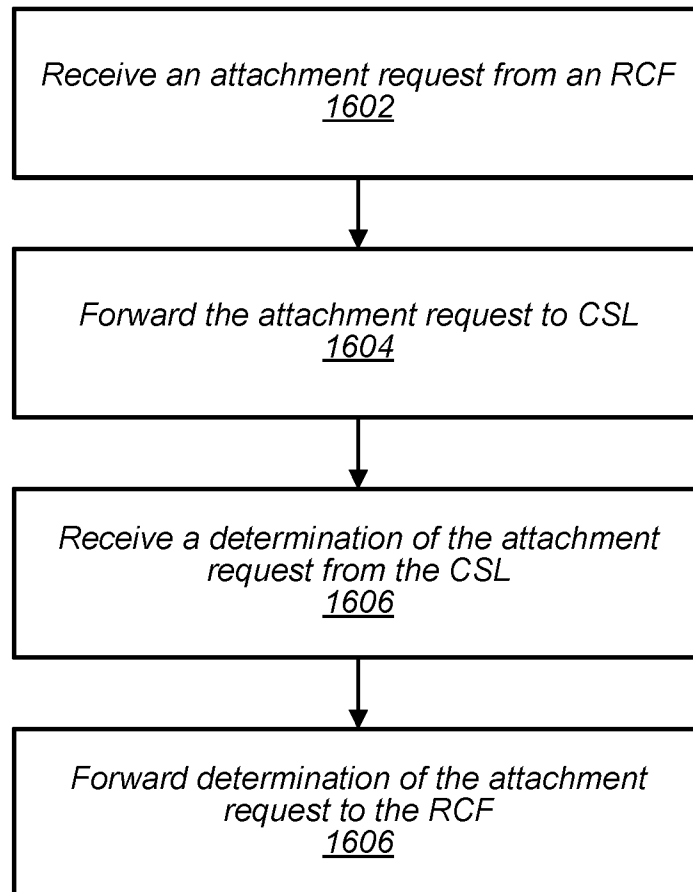


FIG. 16

18 / 30

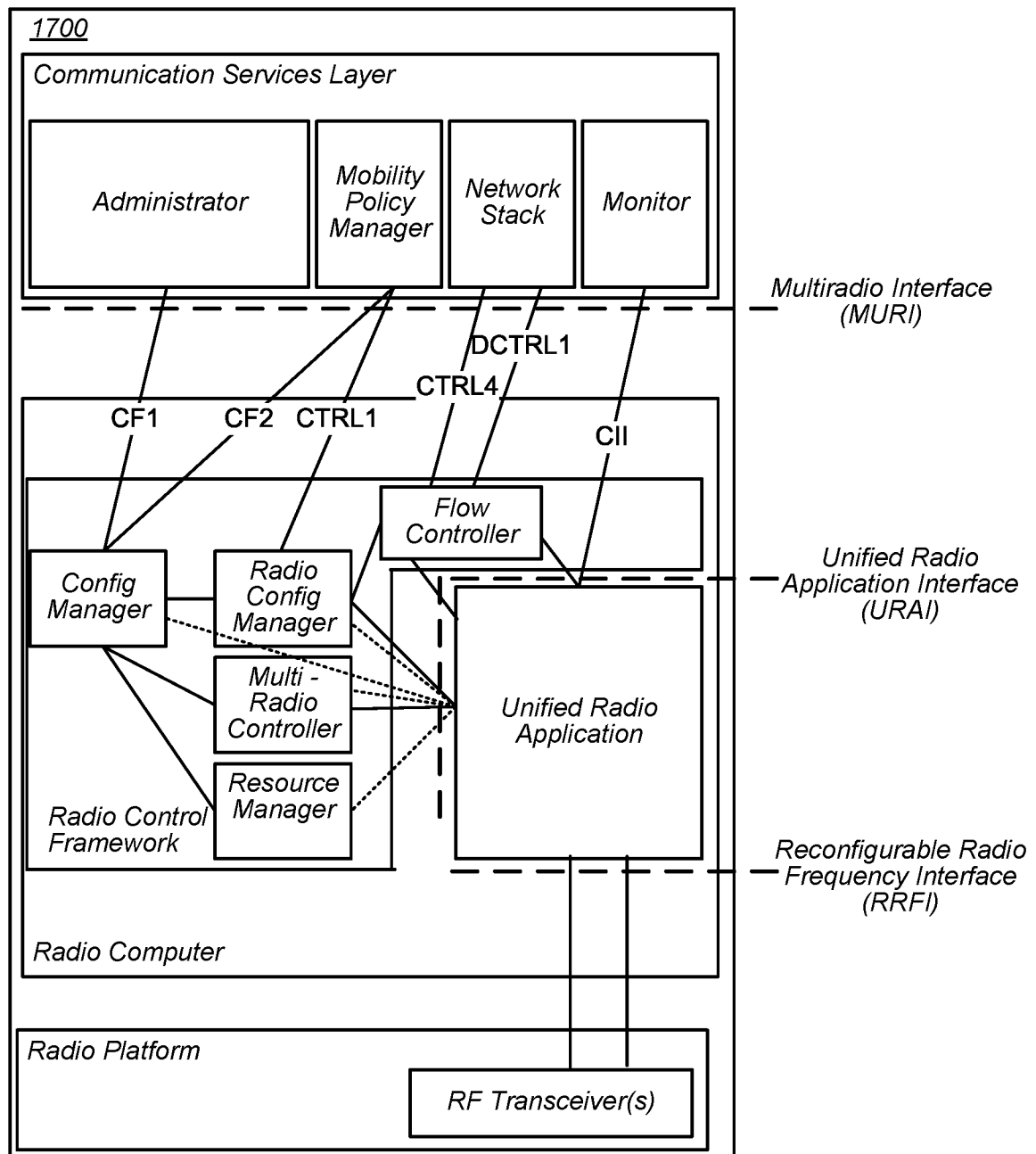
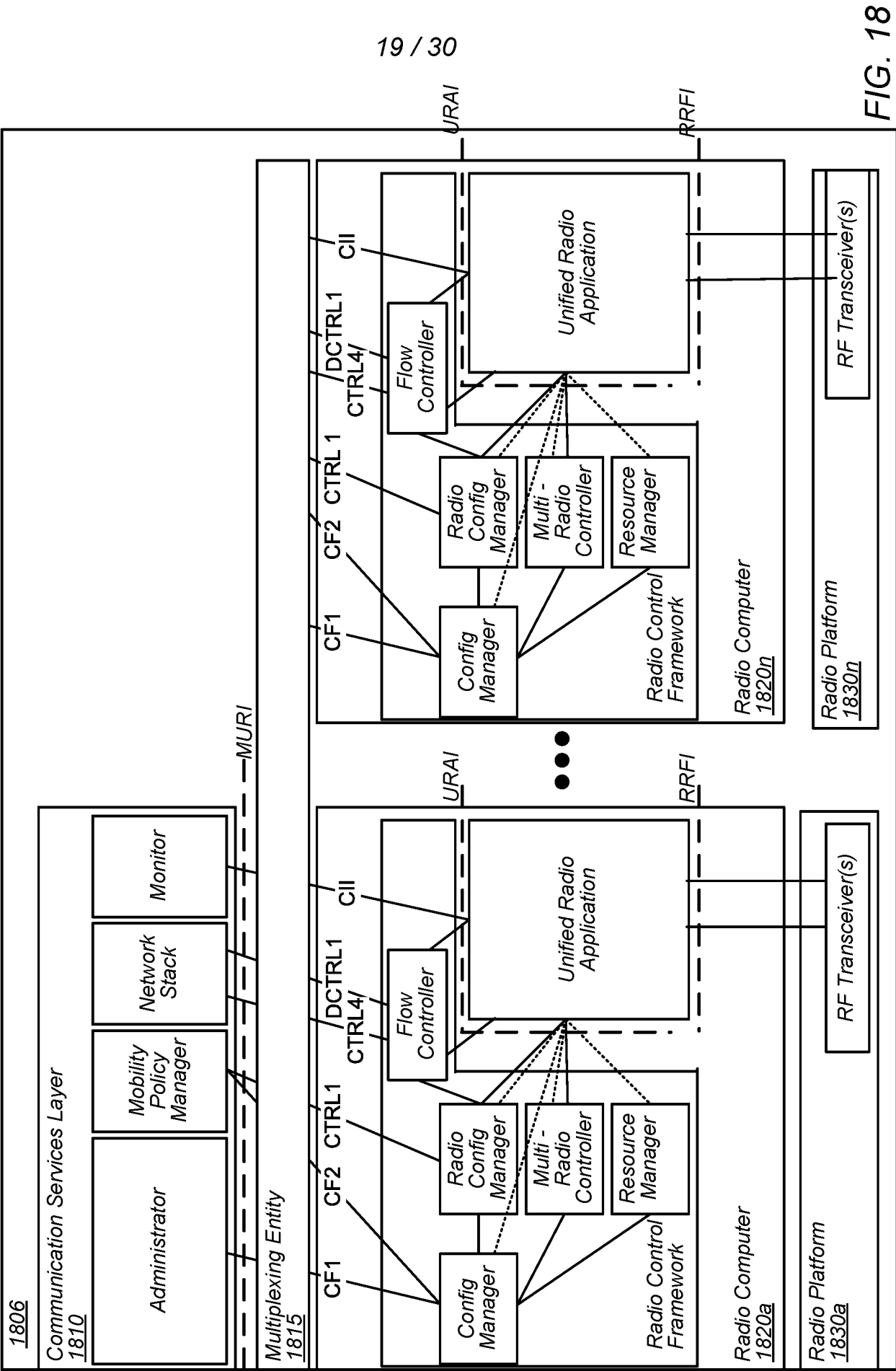


FIG. 17
(Prior Art)



20 / 30

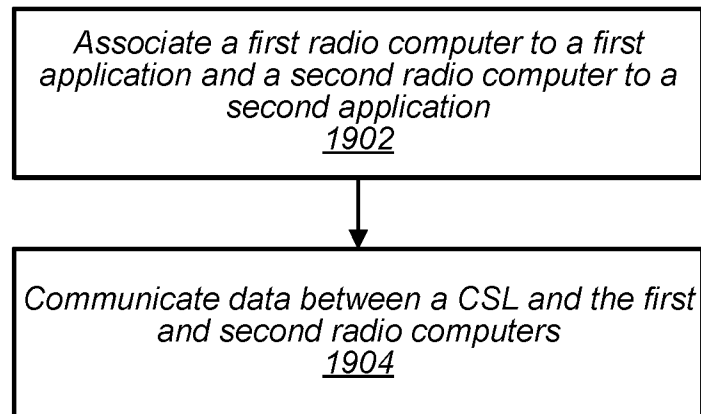


FIG. 19

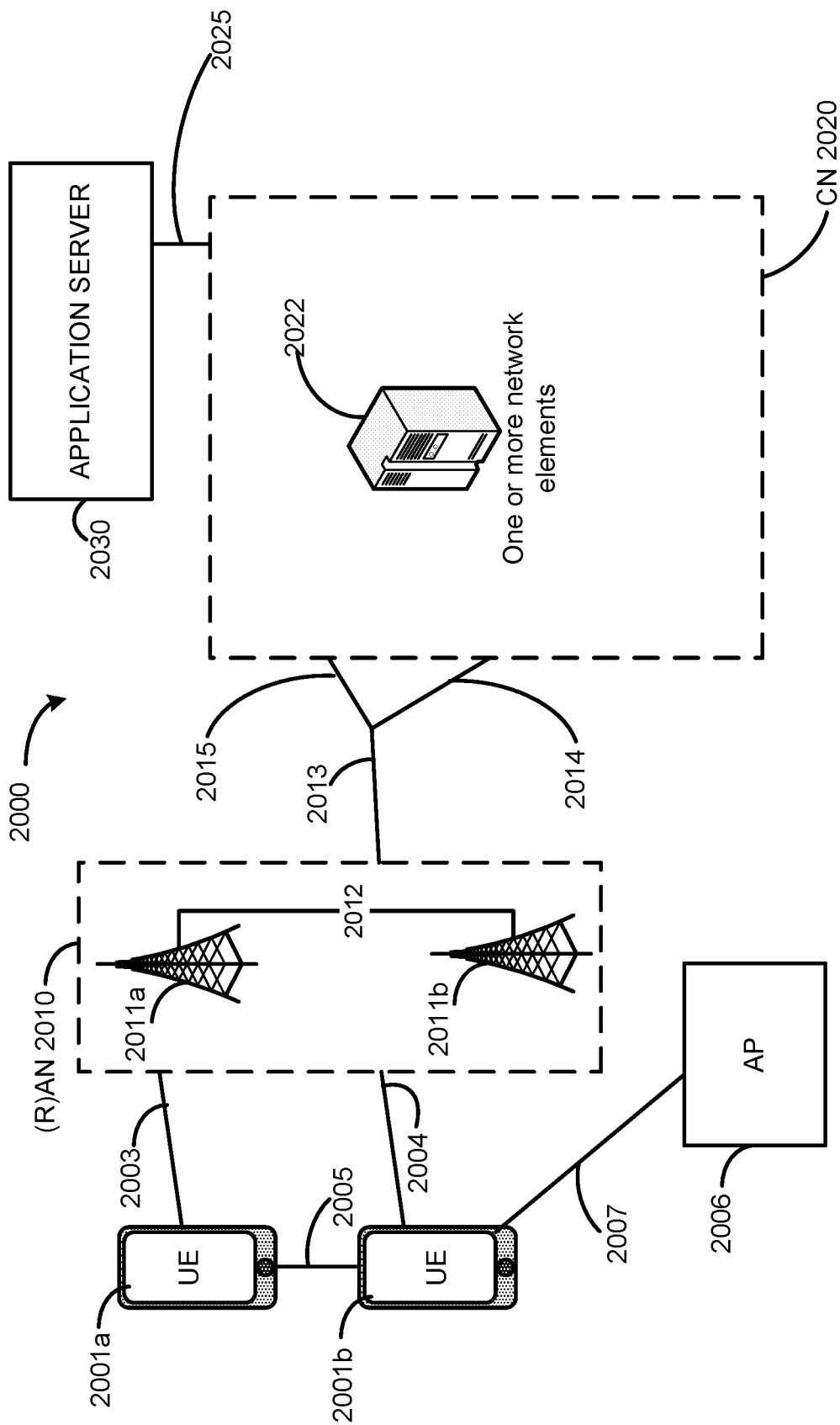


FIG. 20

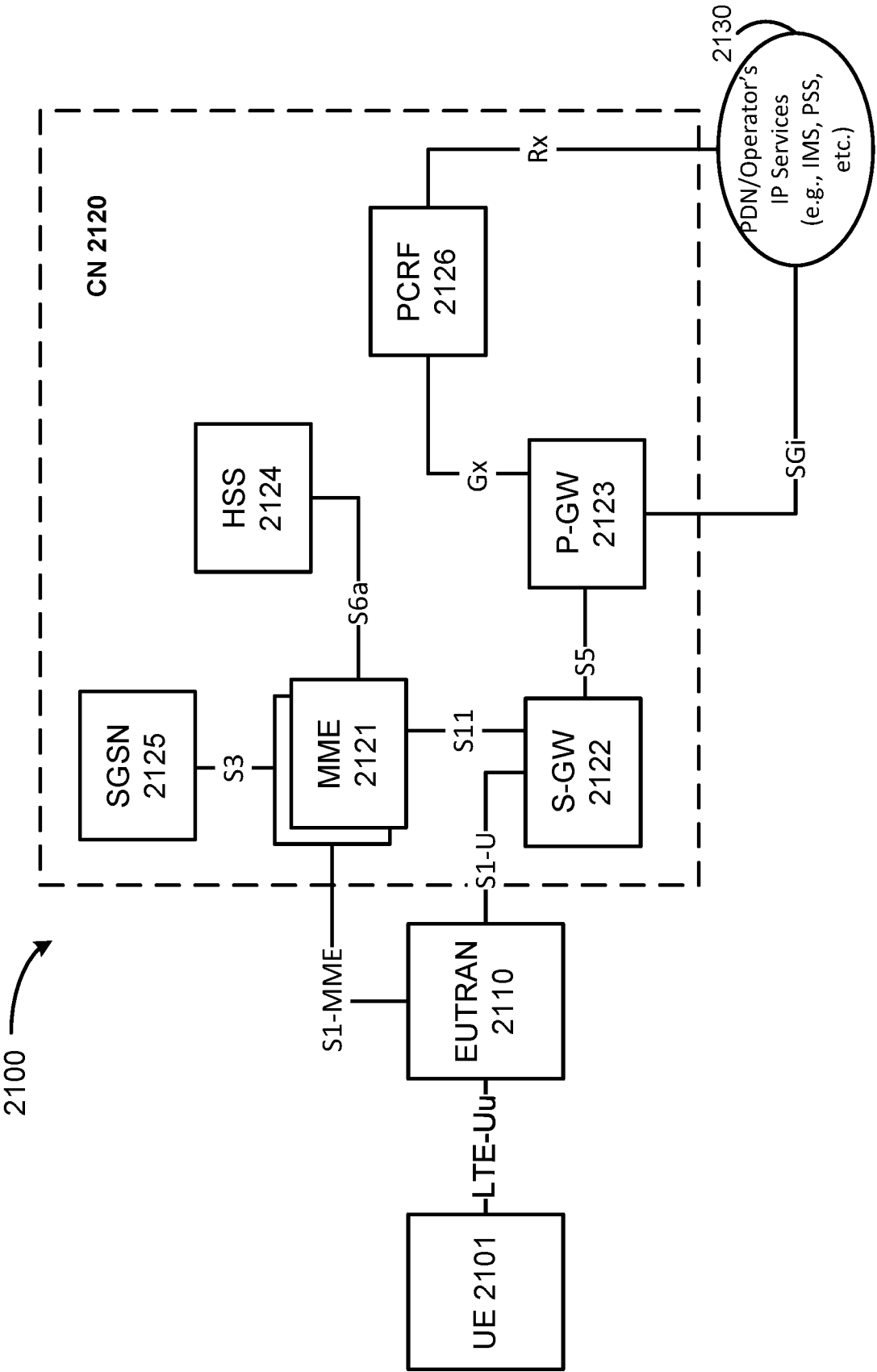


FIG. 21

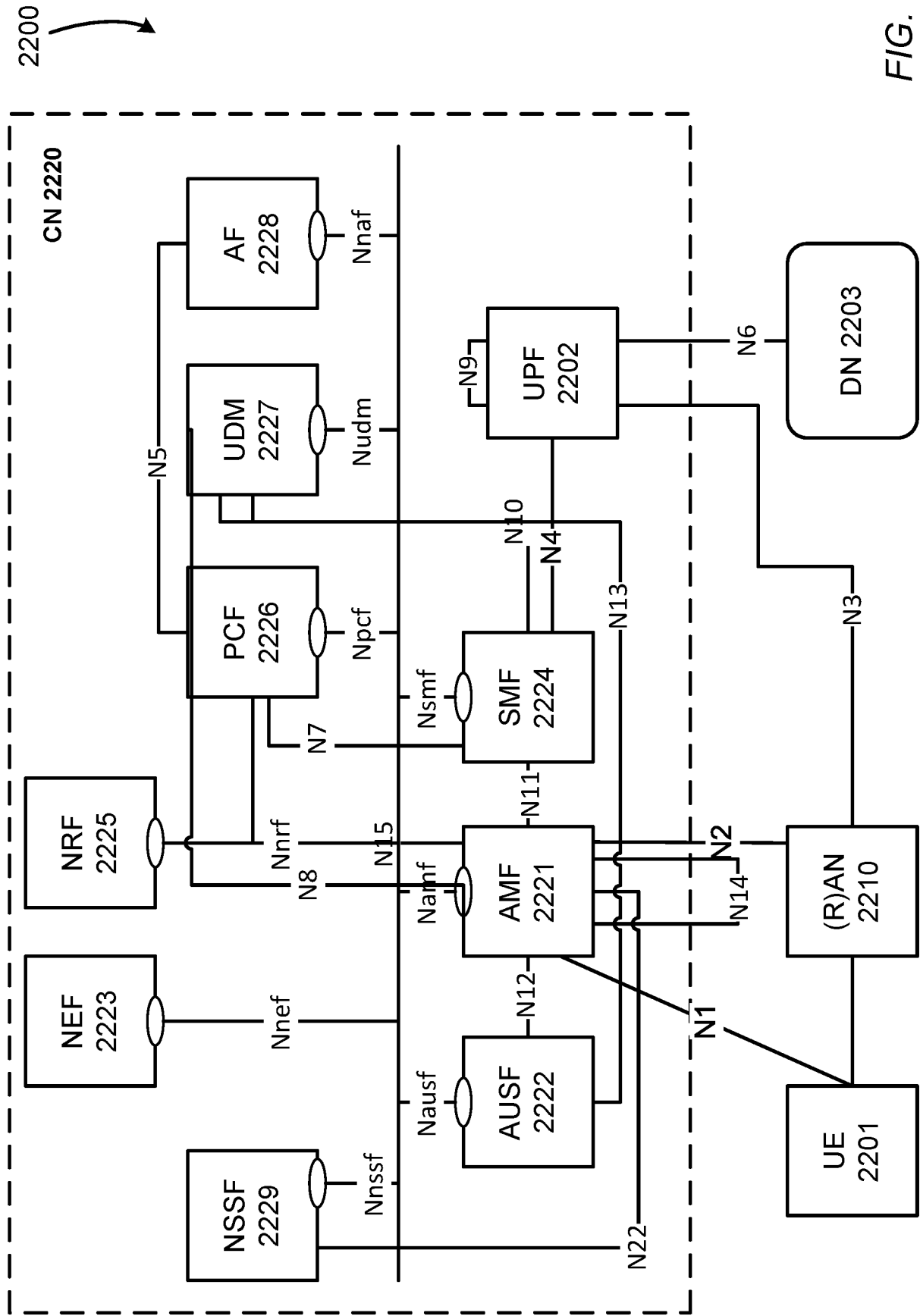


FIG. 22

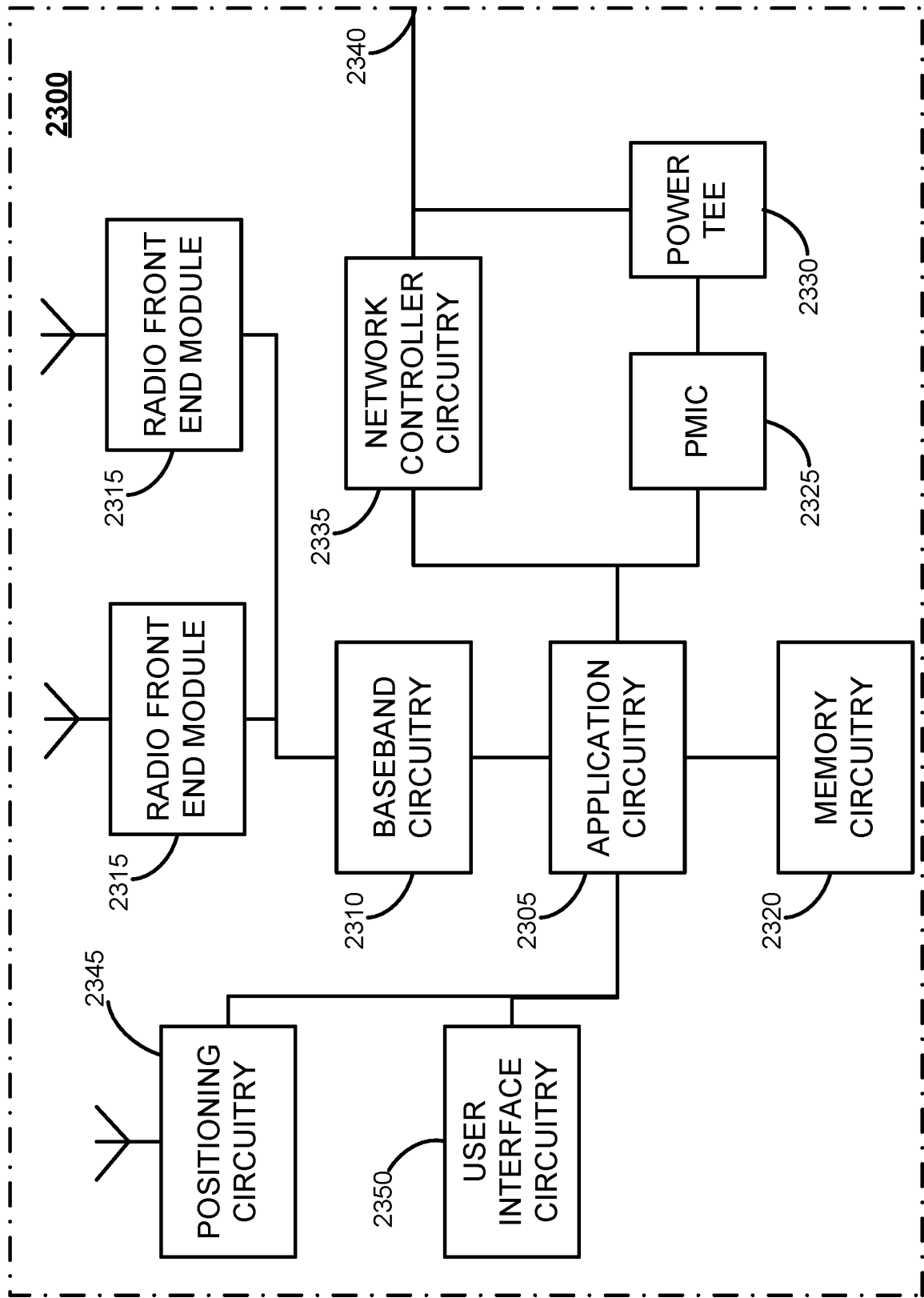


FIG. 23

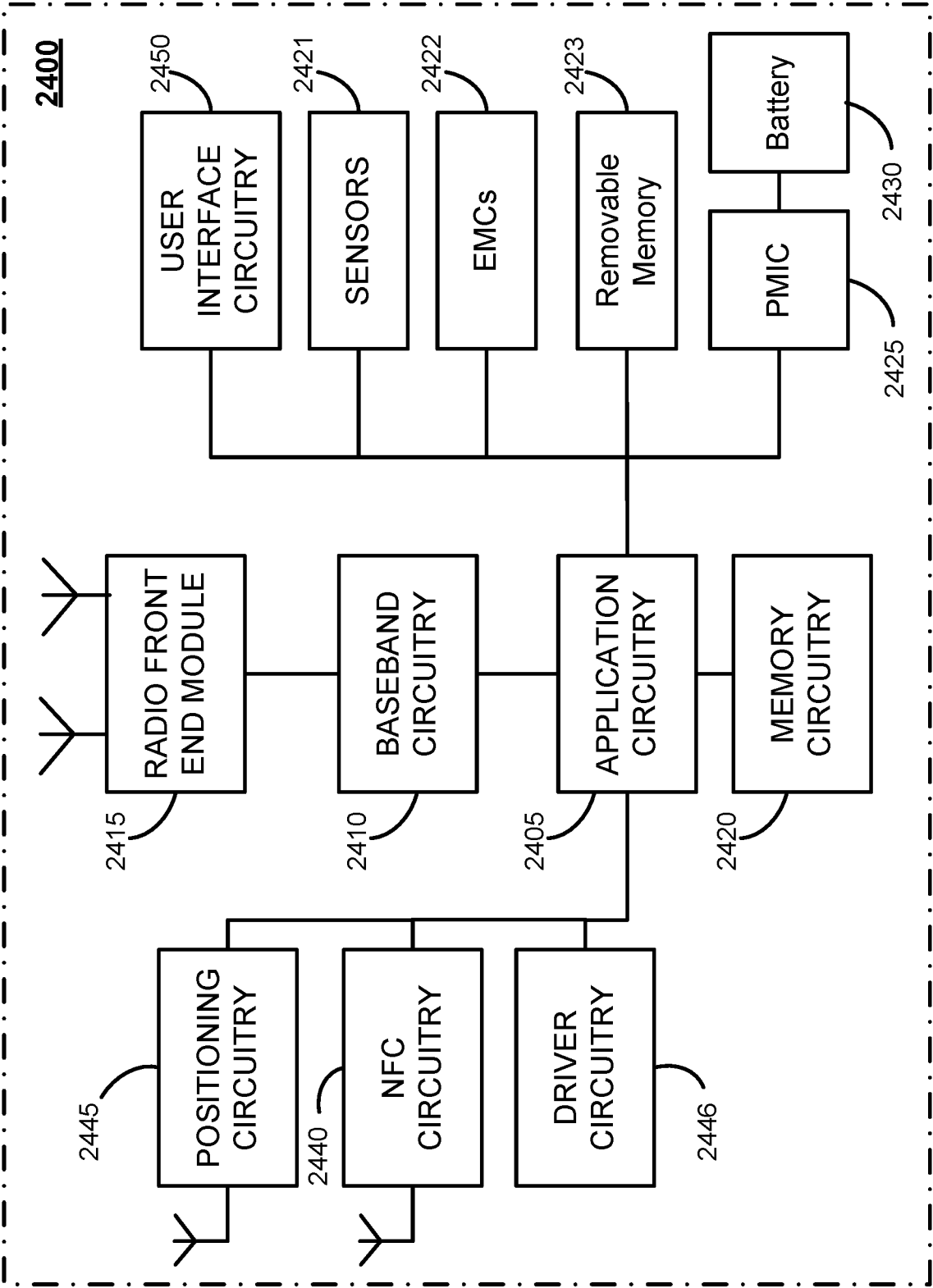


FIG. 24

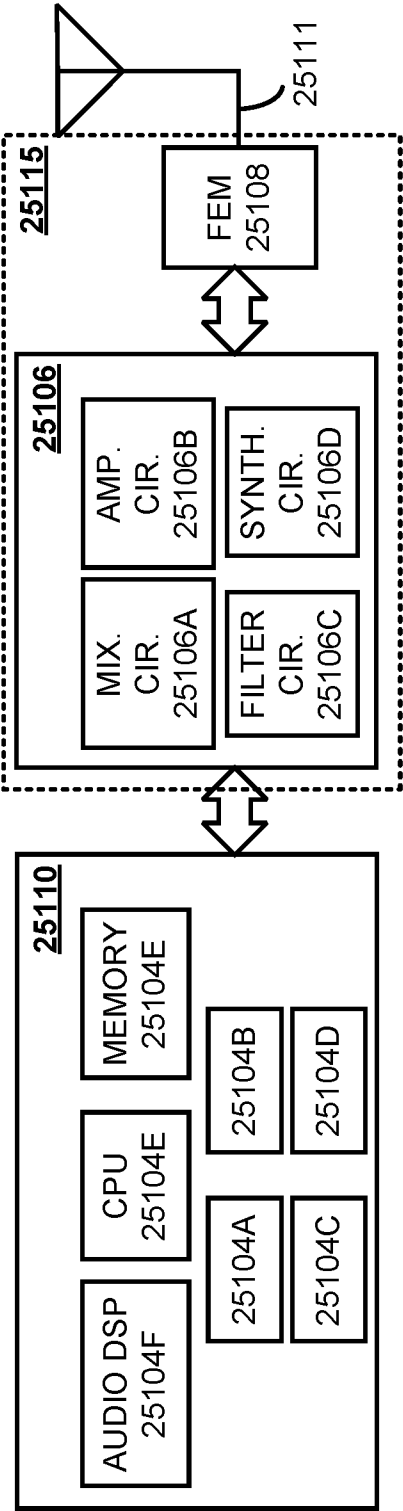


FIG. 25

27 / 30

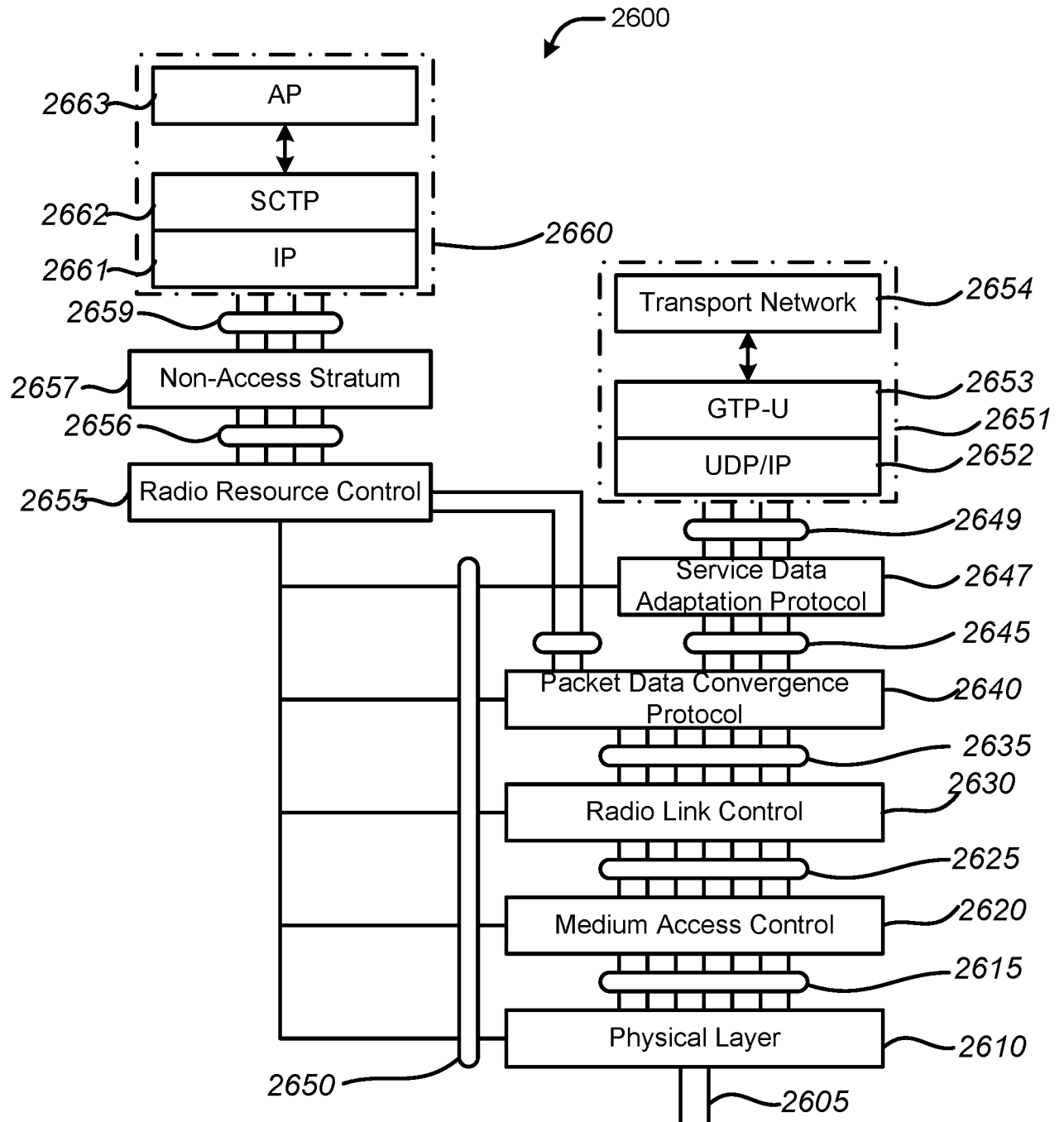


FIG. 26

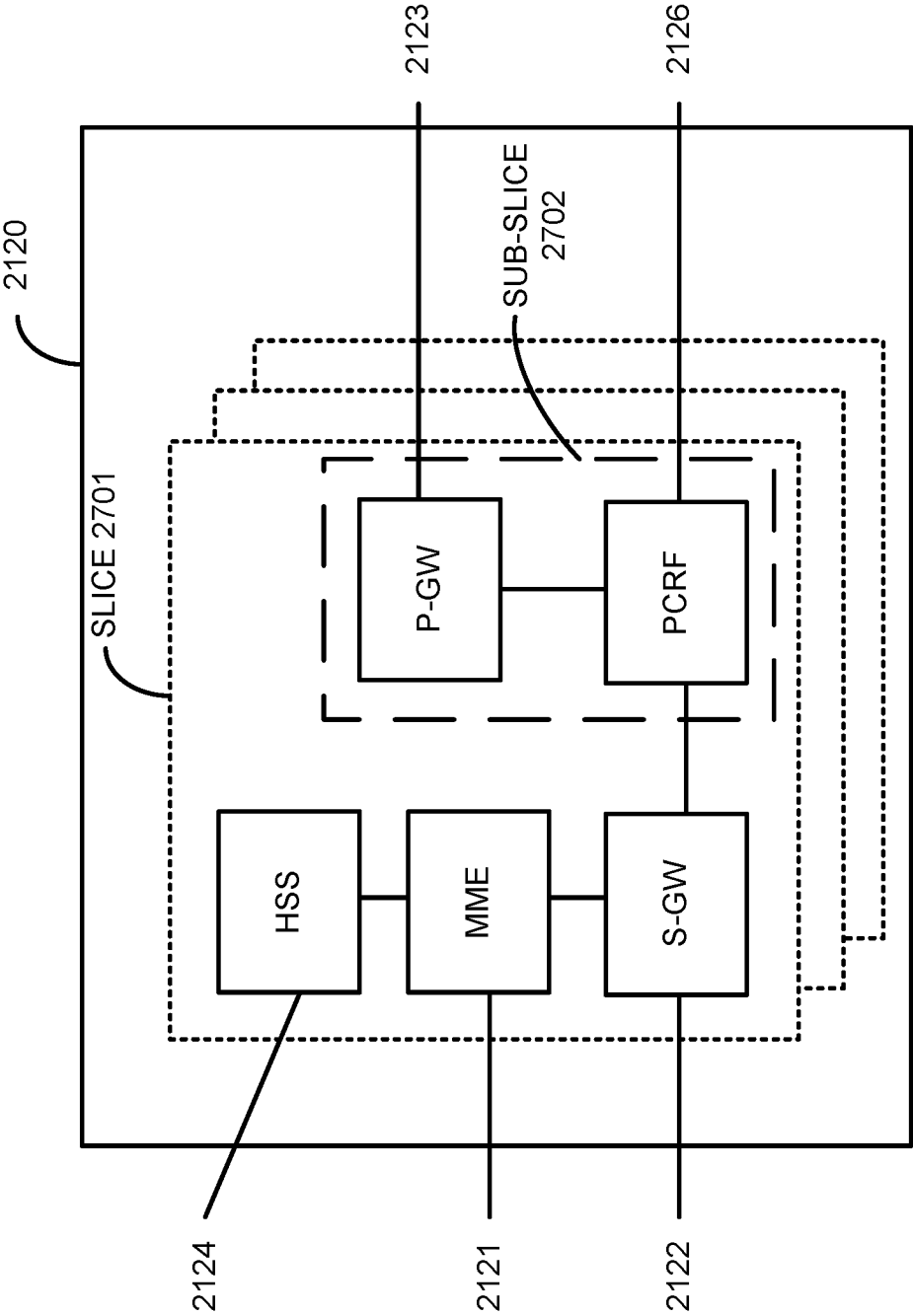


FIG. 27

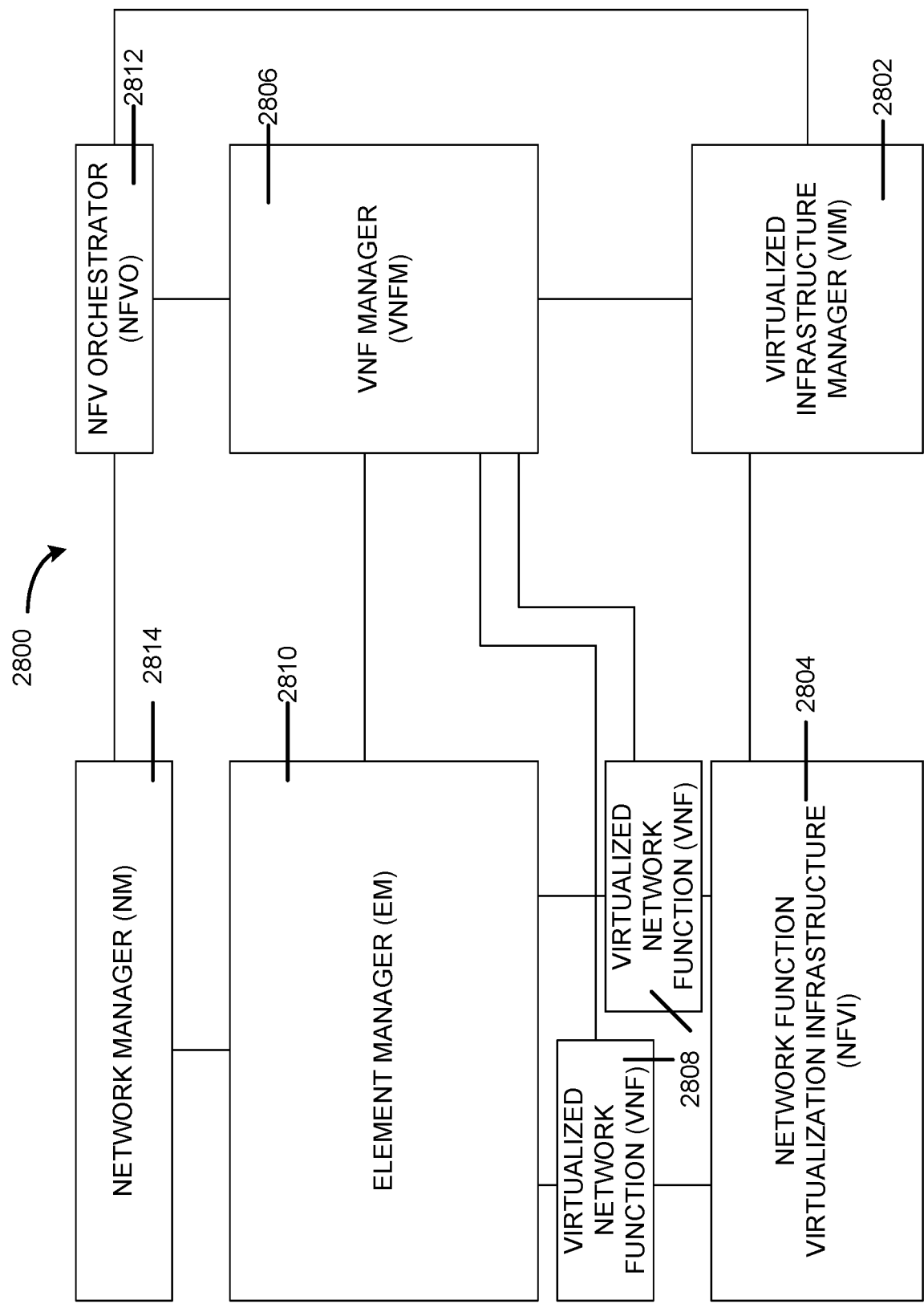


FIG. 28

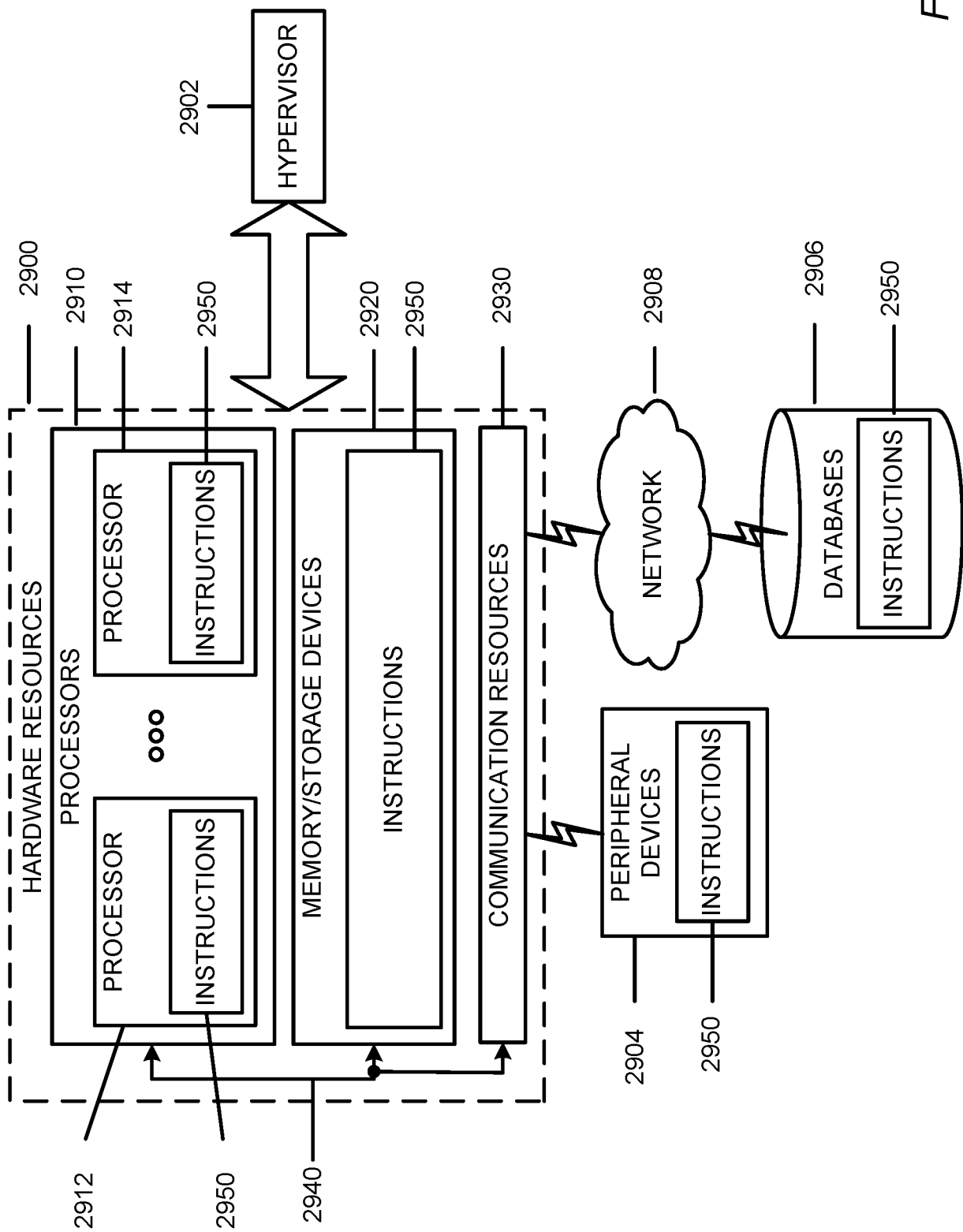


FIG. 29

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2019/066171

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W88/06

ADD. H04W72/02

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2006/053951 A1 (NOKIA CORP [FI]; HONKANEN MAURI [FI] ET AL.) 26 May 2006 (2006-05-26) page 7, line 1 - page 8, line 33 -----	1-20
X	EP 2 354 934 A1 (NOKIA CORP [FI]) 10 August 2011 (2011-08-10) paragraphs [0027], [0039], [0048] - [0054] -----	1,10,16



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

17 March 2020

Date of mailing of the international search report

06/04/2020

Name and mailing address of the ISA/

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Authorized officer

Weinmiller, Jost

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2019/066171

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WO 2006053951	A1	26-05-2006	BR PI0519043 A2 23-12-2008
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