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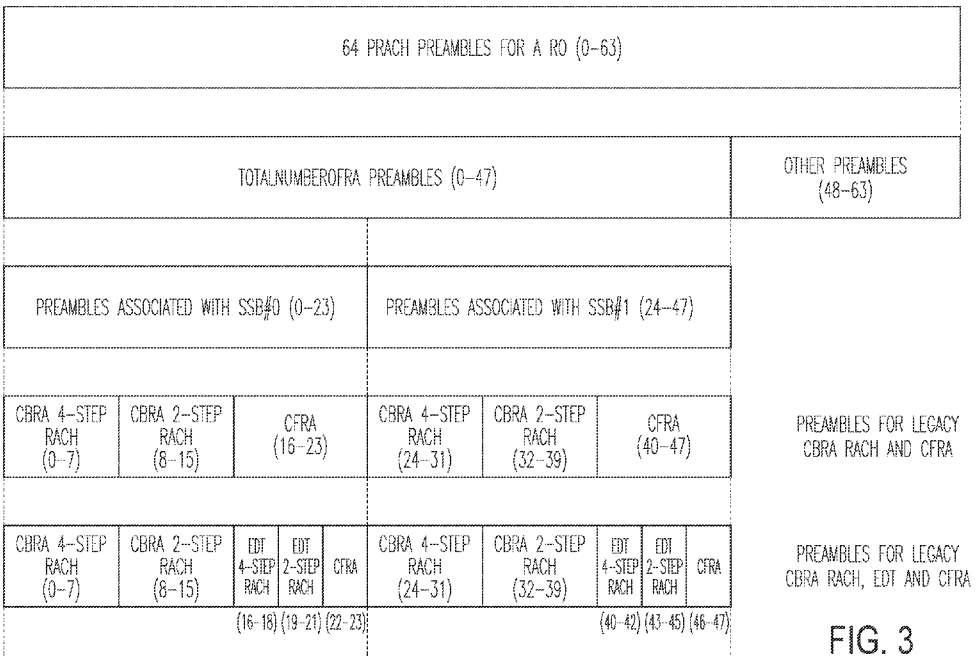

FIG. 3

(57) Abstract: A user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS) is to perform a random-access procedure with a generation Node B (gNB). The UE may be configured to encode a physical random-access channel (PRACH) preamble for uplink transmission and decode a random-access response (RAR) from the gNB. For a shared PRACH occasion (RO), the UE may perform the random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation.

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PHYSICAL RANDOM-ACCESS CHANNEL (PRACH) RESOURCE PARTITIONING FOR SMALL DATA TRANSMISSION (SDT)

PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 63/061,699 filed August 5, 2020 [reference number AD1564-Z] which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless communications. Some embodiments relate to wireless networks including 3GPP (Third Generation Partnership Project) and fifth-generation (5G) networks including 5G new radio (NR) (or 5G-NR) networks. Some embodiments pertain to physical random-access channel (PRACH) resource partitioning. Some embodiments pertain to small data transmission (SDT).

BACKGROUND

[0003] One issue with communicating data over a wireless network is that the transmission of data packets usually requires an established Radio Resource Control (RRC) connection between a given UE and gNB. When an RRC connection has been established, the UE is in RRC Connected mode. After an inactivity period, the RRC connection is released through an S1 -Release procedure and the UE may transition to RRC Idle mode. If an RRC Idle UE wants to communicate with the network, it has to perform a scheduling request (SR) to establish the RRC connection and request resources again. This approach may not be efficient for small data transmission (SDT). Thus, there are general needs for more efficient ways for communicating smaller amounts of data.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1A illustrates an architecture of a network, in accordance with some embodiments.

[0005] FIG. 1B and FIG. 1C illustrate a non-roaming 5G system architecture in accordance with some embodiments.

[0006] FIG. 2A illustrates a 4-Step RACH procedure in accordance with some embodiments.

[0007] FIG. 2B illustrates a 2-Step RACH procedure in accordance with some embodiments.

[0008] FIG. 3 illustrates PRACH resource partitioning for EDT and legacy RACH in accordance with some embodiments.

[0009] FIG. 4 illustrates PRACH resource partitioning for EDT and legacy RACH in accordance with some other embodiments.

[0010] FIG. 5 illustrates PRACH resource partitioning for EDT and legacy RACH in accordance with some other embodiments.

[0011] FIG. 6 illustrates PRACH resource partitioning for EDT and legacy RACH in accordance with some embodiments.

[0012] FIG. 7 is a function block diagram of a wireless communication device in accordance with some embodiments.

DETAILED DESCRIPTION

[0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0014] Some embodiments are directed to a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS). In these embodiments, to perform a random-access procedure with a generation Node B (gNB), the UE may be configured to encode a physical random-access channel (PRACH) preamble for uplink transmission and decode a random-access response (RAR) from the gNB. In these embodiments, for a shared PRACH occasion (RO), the UE may perform the random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation. These embodiments are described in more detail below.

[0015] FIG. 1A illustrates an architecture of a network in accordance with some embodiments. The network 140A is shown to include user equipment (UE) 101 and UE 102. The UEs 101 and 102 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks) but may also include any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, drones, or any other computing device including a wired and/or wireless communications interface. The UEs 101 and 102 can be collectively referred to herein as UE 101, and UE 101 can be used to perform one or more of the techniques disclosed herein.

[0016] Any of the radio links described herein (e.g., as used in the network 140A or any other illustrated network) may operate according to any exemplary radio communication technology and/or standard.

[0017] LTE and LTE-Advanced are standards for wireless communications of high-speed data for UE such as mobile telephones. In LTE-Advanced and various wireless systems, carrier aggregation is a technology according to which multiple carrier signals operating on different frequencies may be used to carry communications for a single UE, thus increasing the bandwidth available to a single device. In some embodiments, carrier aggregation may be used where one or more component carriers operate on unlicensed frequencies.

[0018] Embodiments described herein can be used in the context of any spectrum management scheme including, for example, dedicated licensed spectrum, unlicensed spectrum, (licensed) shared spectrum (such as Licensed Shared Access (LSA) in 2.3-2.4 GHz, 3.4-3.6 GHz, 3.6-3.8 GHz, and further frequencies and Spectrum Access System (SAS) in 3.55-3.7 GHz and further frequencies).

[0019] Embodiments described herein can also be applied to different Single Carrier or OFDM flavors (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.) and in particular 3GPP NR (New Radio) by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

[0020] In some embodiments, any of the UEs 101 and 102 can comprise an Internet-of-Things (IoT) UE or a Cellular IoT (CIoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. In some embodiments, any of the UEs 101 and 102 can include a narrowband (NB) IoT UE (e.g., such as an enhanced NB-IoT (eNB-IoT) UE and Further Enhanced (FeNB-IoT) UE). An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (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 includes 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.

[0021] In some embodiments, any of the UEs 101 and 102 can include enhanced MTC (eMTC) UEs or further enhanced MTC (FeMTC) UEs.

[0022] The UEs 101 and 102 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 110. The RAN 110 may be, for example, an Evolved Universal Mobile Telecommunications

System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs 101 and 102 utilize connections 103 and 104, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 103 and 104 are illustrated as an air interface to enable communicative coupling and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth-generation (5G) protocol, a New Radio (NR) protocol, and the like.

[0023] In an aspect, the UEs 101 and 102 may further directly exchange communication data via a ProSe interface 105. The ProSe interface 105 may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[0024] The UE 102 is shown to be configured to access an access point (AP) 106 via connection 107. The connection 107 can comprise a local wireless connection, such as, for example, a connection consistent with any IEEE 802.11 protocol, according to which the AP 106 can comprise a wireless fidelity (WiFi®) router. In this example, the AP 106 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[0025] The RAN 110 can include one or more access nodes that enable the connections 103 and 104. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), Next Generation NodeBs (gNBs), RAN nodes, and the like, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). In some embodiments, the communication nodes

111 and 112 can be transmission/reception points (TRPs). In instances when the communication nodes 111 and 112 are NodeBs (e.g., eNBs or gNBs), one or more TRPs can function within the communication cell of the NodeBs. The RAN 110 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 111, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 112.

[0026] Any of the RAN nodes 111 and 112 can terminate the air interface protocol and can be the first point of contact for the UEs 101 and 102. In some embodiments, any of the RAN nodes 111 and 112 can fulfill various logical functions for the RAN 110 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. In an example, any of the nodes 111 and/or 112 can be a new generation Node-B (gNB), an evolved node-B (eNB), or another type of RAN node.

[0027] The RAN 110 is shown to be communicatively coupled to a core network (CN) 120 via an S1 interface 113. In embodiments, the CN 120 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN (e.g., as illustrated in reference to FIGS. 1B-1C). In this aspect, the S1 interface 113 is split into two parts: the S1-U interface 114, which carries traffic data between the RAN nodes 111 and 112 and the serving gateway (S-GW) 122, and the S1-mobility management entity (MME) interface 115, which is a signaling interface between the RAN nodes 111 and 112 and MMEs 121.

[0028] In this aspect, the CN 120 comprises the MMEs 121, the S-GW 122, the Packet Data Network (PDN) Gateway (P-GW) 123, and a home subscriber server (HSS) 124. The MMEs 121 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 121 may manage mobility embodiments in access such as gateway selection and tracking area list management. The HSS 124 may comprise a database for network users, including subscription-related

information to support the network entities' handling of communication sessions. The CN 120 may comprise one or several HSSs 124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 124 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[0029] The S-GW 122 may terminate the S1 interface 113 towards the RAN 110, and routes data packets between the RAN 110 and the CN 120. In addition, the S-GW 122 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities of the S-GW 122 may include a lawful intercept, charging, and some policy enforcement.

[0030] The P-GW 123 may terminate an SGi interface toward a PDN. The P-GW 123 may route data packets between the EPC network 120 and external networks such as a network including the application server 184 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 125. The P-GW 123 can also communicate data to other external networks 131A, which can include the Internet, IP multimedia subsystem (IPS) network, and other networks. Generally, the application server 184 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this aspect, the P-GW 123 is shown to be communicatively coupled to an application server 184 via an IP interface 125. The application server 184 can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101 and 102 via the CN 120.

[0031] The P-GW 123 may further be a node for policy enforcement and charging data collection. Policy and Charging Rules Function (PCRF) 126 is the policy and charging control element of the CN 120. In a non-roaming scenario, in some embodiments, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with a

local breakout of traffic, there may be two PCRFs associated with a UE'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 126 may be communicatively coupled to the application server 184 via the P-GW 123.

[0032] In some embodiments, the communication network 140A can be an IoT network or a 5G network, including 5G new radio network using communications in the licensed (5G NR) and the unlicensed (5G NR-U) spectrum. One of the current enablers of IoT is the narrowband-IoT (NB-IoT).

[0033] An NG system architecture can include the RAN 110 and a 5G network core (5GC) 120. The NG-RAN 110 can include a plurality of nodes, such as gNBs and NG-eNBs. The core network 120 (e.g., a 5G core network or 5GC) can include an access and mobility function (AMF) and/or a user plane function (UPF). The AMF and the UPF can be communicatively coupled to the gNBs and the NG-eNBs via NG interfaces. More specifically, in some embodiments, the gNBs and the NG-eNBs can be connected to the AMF by NG-C interfaces, and to the UPF by NG-U interfaces. The gNBs and the NG-eNBs can be coupled to each other via Xn interfaces.

[0034] In some embodiments, the NG system architecture can use reference points between various nodes as provided by 3GPP Technical Specification (TS) 23.501 (e.g., V15.4.0, 2018-12). In some embodiments, each of the gNBs and the NG-eNBs can be implemented as a base station, a mobile edge server, a small cell, a home eNB, and so forth. In some embodiments, a gNB can be a master node (MN) and NG-eNB can be a secondary node (SN) in a 5G architecture.

[0035] FIG. 1B illustrates a non-roaming 5G system architecture in accordance with some embodiments. Referring to FIG. 1B, there is illustrated a 5G system architecture 140B in a reference point representation. More specifically, UE 102 can be in communication with RAN 110 as well as one or more other 5G core (5GC) network entities. The 5G system architecture 140B includes a plurality of network functions (NFs), such as access and mobility management function (AMF) 132, session management function (SMF) 136,

policy control function (PCF) 148, application function (AF) 150, user plane function (UPF) 134, network slice selection function (NSSF) 142, authentication server function (AUSF) 144, and unified data management (UDM)/home subscriber server (HSS) 146. The UPF 134 can provide a connection to a data network (DN) 152, which can include, for example, operator services, Internet access, or third-party services. The AMF 132 can be used to manage access control and mobility and can also include network slice selection functionality. The SMF 136 can be configured to set up and manage various sessions according to network policy. The UPF 134 can be deployed in one or more configurations according to the desired service type. The PCF 148 can be configured to provide a policy framework using network slicing, mobility management, and roaming (similar to PCRF in a 4G communication system). The UDM can be configured to store subscriber profiles and data (similar to an HSS in a 4G communication system).

[0036] In some embodiments, the 5G system architecture 140B includes an IP multimedia subsystem (IMS) 168B as well as a plurality of IP multimedia core network subsystem entities, such as call session control functions (CSCFs). More specifically, the IMS 168B includes a CSCF, which can act as a proxy CSCF (P-CSCF) 162BE, a serving CSCF (S-CSCF) 164B, an emergency CSCF (E-CSCF) (not illustrated in FIG. 1B), or interrogating CSCF (I-CSCF) 166B. The P-CSCF 162B can be configured to be the first contact point for the UE 102 within the IM subsystem (IMS) 168B. The S-CSCF 164B can be configured to handle the session states in the network, and the E-CSCF can be configured to handle certain embodiments of emergency sessions such as routing an emergency request to the correct emergency center or PSAP. The I-CSCF 166B can be configured to function as the contact point within an operator's network for all IMS connections destined to a subscriber of that network operator, or a roaming subscriber currently located within that network operator's service area. In some embodiments, the I-CSCF 166B can be connected to another IP multimedia network 170E, e.g. an IMS operated by a different network operator.

[0037] In some embodiments, the UDM/HSS 146 can be coupled to an application server 160E, which can include a telephony application server (TAS)

or another application server (AS). The AS 160B can be coupled to the IMS 168B via the S-CSCF 164B or the I-CSCF 166B.

[0038] A reference point representation shows that interaction can exist between corresponding NF services. For example, FIG. 1B illustrates the following reference points: N1 (between the UE 102 and the AMF 132), N2 (between the RAN 110 and the AMF 132), N3 (between the RAN 110 and the UPF 134), N4 (between the SMF 136 and the UPF 134), N5 (between the PCF 148 and the AF 150, not shown), N6 (between the UPF 134 and the DN 152), N7 (between the SMF 136 and the PCF 148, not shown), N8 (between the UDM 146 and the AMF 132, not shown), N9 (between two UPFs 134, not shown), N10 (between the UDM 146 and the SMF 136, not shown), N11 (between the AMF 132 and the SMF 136, not shown), N12 (between the AUSF 144 and the AMF 132, not shown), N13 (between the AUSF 144 and the UDM 146, not shown), N14 (between two AMFs 132, not shown), N15 (between the PCF 148 and the AMF 132 in case of a non-roaming scenario, or between the PCF 148 and a visited network and AMF 132 in case of a roaming scenario, not shown), N16 (between two SMFs, not shown), and N22 (between AMF 132 and NSSF 142, not shown). Other reference point representations not shown in FIG. 1B can also be used.

[0039] FIG. 1C illustrates a 5G system architecture 140C and a service-based representation. In addition to the network entities illustrated in FIG. 1B, system architecture 140C can also include a network exposure function (NEF) 154 and a network repository function (NRF) 156. In some embodiments, 5G system architectures can be service-based and interaction between network functions can be represented by corresponding point-to-point reference points Ni or as service-based interfaces.

[0040] In some embodiments, as illustrated in FIG. 1C, service-based representations can be used to represent network functions within the control plane that enable other authorized network functions to access their services. In this regard, 5G system architecture 140C can include the following service-based interfaces: Namf 158H (a service-based interface exhibited by the AMF 132), Nsmf 158I (a service-based interface exhibited by the SMF 136), Nnef 158B (a

service-based interface exhibited by the NEF 154), Npcf 158D (a service-based interface exhibited by the PCF 148), a Nudm 158E (a service-based interface exhibited by the UDM 146), Naf 158F (a service-based interface exhibited by the AF 150), Nnrf 158C (a service-based interface exhibited by the NRF 156), Nnssf 158A (a service-based interface exhibited by the NSSF 142), Nausf 158G (a service-based interface exhibited by the AUSF 144). Other service-based interfaces (e.g., Nudr, N5g-eir, and Nudsf) not shown in FIG. 1C can also be used.

[0041] In some embodiments, any of the UEs or base stations described in connection with FIGS. 1A-1C can be configured to perform the functionalities described herein.

[0042] Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform. The next generation wireless communication system, 5G, or new radio (NR) will provide access to information and sharing of data anywhere, anytime by various users and applications. NR is expected to be a unified network/system that targets to meet vastly different and sometimes conflicting performance dimensions and services. Such diverse multi-dimensional requirements are driven by different services and applications. In general, NR will evolve based on 3GPP LTE-Advanced with additional potential new Radio Access Technologies (RATs) to enrich people's lives with better, simple, and seamless wireless connectivity solutions. NR will enable everything connected by wireless and deliver fast, rich content and services.

[0043] Some embodiments are directed to a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS). In these embodiments, to perform a random-access procedure with a generation Node B (gNB), the UE may be configured to encode a physical random-access channel (PRACH) preamble for uplink transmission and decode a random-access response (RAR) from the gNB. In these embodiments, for a shared PRACH occasion (RO), the UE may perform the random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation.

[0044] In some embodiments, for an SDT when a shared PRACH occasion is configured, the UE may select a PRACH preamble from a PRACH resource allocated for SDT and transmit the selected PRACH preamble for SDT within the shared PRACH occasion. In these embodiments, for a non-SDT operation when a shared PRACH occasion is configured, the UE may select a PRACH preamble from a PRACH resource allocated for non-SDT operation and transmit the selected PRACH preamble for non-SDT operation within the shared PRACH occasion.

[0045] In these embodiments, the UE may transmit a PRACH comprising the selected PRACH preamble. In these embodiments, a STD may comprise a data transmission without an established RRC connection.

[0046] In some embodiments, the UE may be configured to decode signalling (e.g., an system information block (SIB) from the gNB indicating whether the shared PRACH occasion is configured for the SDT and the non-SDT operation, or whether separate PRACH occasions are configured for the SDT and the non-SDT operation.

[0047] In some embodiments, the UE may be configured to decode signalling from the gNB, the signalling allocating PRACH preambles associated with synchronization signal block (SSBs) (e.g., preambles 0-23 associated with SSB#0 and preambles 24-47 associated with SSB#1 for the shared PRACH occasion).

[0048] In these embodiments, for a shared PRACH occasion, some of the PRACH preambles may be allocated for at least one of a legacy contention based random access (CBRA) 4-step random-access procedure and a legacy CBRA 2-step random-access procedure, some of the PRACH preambles may be allocated for contention free random access (CFRA), some of the PRACH preambles may be allocated for an SDT 4-step random-access procedure and some of the preambles may be allocated for an SDT 2-step random-access procedure. These embodiments are described in more detail below.

[0049] In some embodiments, one of the SDT 4-step random-access procedure and the SDT 2-step random-access procedure is used for the SDT transmission, and one of the legacy CBRA 2-step random-access procedure, the

legacy CBRA 4-step random-access procedure, and the CFRA are used for the non-SDT operation.

[0050] In some embodiments, for the shared PRACH occasion for each SSB, a set of the allocated preambles may be allocated for the legacy CBRA 4-step random-access procedure (e.g., preambles 0-7 associated with SSB#0 and preambles 24-31 associated with SSB#1), a set of the allocated preambles may be allocated for the legacy CBRA 2-step random-access procedure (e.g., preambles 8-15 associated with SSB#0 and preambles 32-39 associated with SSB#1), and a set of the allocated preambles may be allocated for the CFRA (e.g., preambles 16-23 associated with SSB#0 and preambles 40-47 associated with SSB#1).

[0051] In these embodiments, for the shared RO, some of the preambles that may be allocated for the CFRA may be allocated for the SDT 4-step random-access procedure (e.g., preambles 16 - 18 associated with SSB#0 and preambles 40-42 associated with SSB#1) and some of the preambles for the CFRA may be allocated for an SDT 2-step random-access procedure (e.g., preambles 19-21 associated with SSB#0 and preambles 43-45 associated with SSB#1). These embodiments are illustrated in FIG. 3. In these embodiments illustrated in FIG. 3, preambles for the SDT 4-step random-access procedure are allocated before preambles for the SDT 2-step random-access procedure.

[0052] In some embodiments, for the shared PRACH occasion for each SSB, a set of the allocated preambles may be allocated for the legacy CBRA 4-step random-access procedure (e.g., preambles 0-15 associated with SSB#0 and preambles 24-39 associated with SSB#1) and a set of the allocated preambles may be allocated for the CFRA (e.g., preambles 16-23 associated with SSB#0 and preambles 40-47 associated with SSB#1). In these embodiments, for the shared PRACH occasion, some of the preambles allocated for the CFRA may be allocated for an SDT 4-step random-access procedure (e.g., preambles 16-20 associated with SSB#0 and preambles 40-44 associated with SSB#1). In these embodiments, no preambles may be allocated to the SDT 2-step random-access procedure. These embodiments are illustrated in FIG. 4.

[0053] In some embodiments, for the shared PRACH occasion for each SSB, a set of the allocated preambles may be allocated for the legacy CBRA 4-step random-access procedure (e.g., preambles 0-9 associated with SSB#0 and preambles 24-33 associated with SSB#1), a set of the allocated preambles may be allocated for the legacy CBRA 2-step random-access procedure (e.g., preambles 10-19 associated with SSB#0 and preambles 34-43 associated with SSB#1), and a set of the allocated preambles may be allocated for the CFRA (e.g., preambles 20-23 associated with SSB#0 and preambles 44-47 associated with SSB#1. In these embodiments, for the shared PRACH occasion, some of the preambles allocated for the CBRA 4-step random-access procedure may be allocated for an SDT 4-step random-access procedure (e.g., preambles 8-9 associated with SSB#0 and preambles 32-33 associated with SSB#1) and some of the preambles for the CBRA 2-step random-access procedure may be allocated for an SDT 2-step random-access procedure (e.g., preambles 18-19 associated with SSB#0 and preambles 42-43 associated with SSB#1). These embodiments are illustrated in FIG. 5

[0054] In some embodiments, for the shared PRACH occasion, preambles that may be allocated for other purposes may be allocated to an SDT 4-step random-access procedure (e.g., preambles 40-43 associated with SSB#0 and preambles 48-51 associated with SSB#1) and to an SDT 2-step random-access procedure (e.g., preambles 44-47 associated with SSB#0 and preambles 52-55 associated with SSB#1). These embodiments are illustrated in FIG. 6. In these embodiments illustrated in FIG. 6, preambles for the SDT 4-step random-access procedure are allocated before preambles for the SDT 2-step random-access procedure. In these embodiments, the preambles allocated for other purposes are preambles that are not allocated for the legacy CBRA 4-step random-access procedure (e.g., preambles 0-9), preambles that are not allocated for the legacy CBRA 2-step random-access procedure, and preambles that are not allocated for the CFRA, although the scope of the embodiments is not limited in this respect.

[0055] In these embodiments, the signalling from the gNB allocates preambles associated with the SSBs (i.e., preambles 0-19 associated with SSB#0

and preambles 20-39 associated with SSB#1) for the shared PRACH occasion. In these embodiments, for each SSB a set of the allocated preambles may be allocated for the legacy CBRA 4-step random-access procedure (e.g., preambles 0-7 associated with SSB#0 and preambles 20-27 associated with SSB#1), a set of the allocated preambles may be allocated for the legacy CBRA 2-step random-access procedure (e.g., preambles 8-15 associated with SSB#0 and preambles 28-35 associated with SSB#1), and a set of the allocated preambles may be allocated for CFRA (e.g., preambles 16-19 associated with SSB#0 and preambles36-39 associated with SSB#1).

[0056] In some embodiments, when the separate PRACH occasions are configured, the UE may be configured to perform a 4-step random-access procedure for an SDT and perform a 2-step random-access procedure for a non-SDT operation, and the SDT comprises a transmission of data from the UE without establishment of an radio-resource control (RRC) connection with the gNB.

[0057] Some embodiments are directed to a non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS. To perform a random-access procedure with a generation Node B (gNB), the processing circuitry is to configure the UE to encode a physical random-access channel (PRACH) preamble for uplink transmission and decode a random-access response (RAR) from the gNB. In these embodiments, for a shared PRACH occasion, the processing circuitry is to configure the UE to perform the random-access procedure using different PRACH preambles to differentiate a small (or early) data transmission (SDT) from a non-SDT operation.

[0058] Some embodiments are directed to a generation node B (gNB) configured for operation in a fifth-generation new radio (5G NR) system (5GS). In these embodiments, the gNB may encode signalling for transmission to a user equipment (UE) to allocate physical random-access channel (PRACH) resources to configure to UE to perform a random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-

SDT operation for a shared PRACH occasion. In these embodiments, for an SDT when a shared PRACH occasion is configured, the gNB may decode a PRACH preamble for the SDT received within the shared PRACH occasion. For a non-SDT operation when the shared PRACH occasion is configured, the gNB may decode a PRACH preamble for the non-SDT operation within the shared PRACH occasion.

[0059] In these embodiments, the gNB may encode a system information block (SIB) for transmission to the UE indicating whether the shared PRACH occasion is configured for both the SDT and the non-SDT operation, or whether separate PRACH occasions are configured for the SDT and the non-SDT operation.

[0060] In these embodiments, the gNB may encode the signalling allocating PRACH preambles associated with synchronization signal block (SSBs) for the shared PRACH occasion. In some embodiments, the SDT may be a transmission of data from the UE without establishment of an radio-resource control (RRC) connection with the UE.

[0061] In Rel-15 NR, 4-step random access (RACH) procedure was defined. As illustrated in FIG. 2A, in the first step, UE transmits physical random-access channel (PRACH) in the uplink by selecting one preamble signature. Subsequently, in the second step, gNB feedbacks the random-access response (RAR) which carries timing advanced (TA) command information and uplink grant for the uplink transmission. Further, in the third step, UE transmits Msg3 physical uplink shared channel (PUSCH) which may carry contention resolution ID. In the fourth step, gNB sends the contention resolution message in physical downlink shared channel (PDSCH).

[0062] In Rel-16 NR, 2-step RACH procedure was further defined, with the motivation to allow fast access and low latency uplink transmission. As illustrated in FIG. 2B, in the first step, UE transmits a PRACH preamble and associated MsgA PUSCH on a configured time and frequency resource, where MsgA PUSCH may carry at least equivalent contents of Msg3 in 4-step RACH. In the second step, after successful detection of PRACH preamble and decoding

of MsgA PUSCH, gNB transmits MsgB which may carry equivalent contents of Msg2 and Msg4 in 4-step RACH.

[0063] To optimize the support of infrequency small data transmission, early data transmission (EDT) may be employed during random access procedure, which can help reduce data transmission delay and save the UE power consumption. In order to support EDT during random access procedure for 4-step RACH, dedicated PRACH resource may need to be reserved for EDT operation, so as to allow gNB to identify whether data transmission can be enabled for Msg3 transmission. In this case, certain mechanisms may need to be defined for the PRACH resource partitioning between the support of EDT operation and legacy RACH procedure. This disclosure describes PRACH resource partitioning for the support of small data transmission.

[0064] As mentioned above, to support EDT during random access procedure for 4-step RACH, dedicated PRACH resource may need to be reserved for EDT operation, so as to allow gNB to identify whether data transmission can be enabled for Msg3 transmission. In this case, certain mechanisms may need to be defined for the PRACH resource partitioning between the support of EDT operation and legacy RACH procedure.

[0065] Embodiment of PRACH resource partitioning for the support of EDT are provided as follows:

[0066] In one embodiment of the disclosure, separate PRACH occasions can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively. In this case, separate parameters for synchronization signal block (SSB) to RACH occasion (RO) association can be configured for EDT with 4-step RACH and/or 2-step RACH. If not configured, the configuration from legacy 4-step RACH and/or 2-step RACH can be reused.

[0067] In one example, when separate PRACH occasion is configured for EDT with 4-step RACH, the following text can be added in Section 8.1 in 3GPP TS 38.213 "NR: Physical layer procedures for control", V16.2.0, which is incorporated herein by reference in its entirety. Note that in the following description, Type-3 random access procedure indicates the EDT with 4-step RACH.

[0068] For Type-3 random access procedure with separate configuration of PRACH occasions with Type-1 and Type-2 random access procedure, a UE is provided a number N of SS/PBCH block indexes associated with one PRACH occasion and a number R of contention based preambles per SS/PBCH block index per valid PRACH occasion by *ssb-perRACH-OccasionAndCB-PreamblesPerSSB-edt* when provided; otherwise, by *ssb-perRACH-OccasionAndCB-PreamblesPerSSB*.

[0069] In another embodiment of the disclosure, shared PRACH occasions, but different PRACH preambles can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively.

[0070] More specifically, 64 preambles are defined for a PRACH occasion (RO). Further, total number of preambles for contention based random access (CBRA) and contention free random access (CFRA) is configured by *totalNumberOfRA-Preambles*, which is further divided into N sets. Each set of PRACH preambles is associated with one synchronization signal block (SSB). Within each set of PRACH preambles associated with same SSB, 4-step CBRA RACH preambles are first mapped, and followed by CBRA 2-step RACH preambles. The remaining preambles are allocated for CFRA.

[0071] When EDT is configured using 4-step RACH and/or 2-step RACH, PRACH preambles for EDT may be allocated as a part of consecutive preambles for CFRA. In particular, within the set of preambles associated with a same SSB, PRACH preamble for EDT for 4-step RACH is allocated after CBRA 2-step RACH, while PRACH preamble for EDT for 2-step RACH is allocated after EDT for 4-step RACH. Further, in case when EDT for 4-step RACH is not configured or not supported, PRACH preamble for EDT for 2-step RACH is allocated after CBRA 2-step RACH.

[0072] FIG. 3 illustrates one example of PRACH resource partitioning for EDT with 4-step and/or 2-step RACH and legacy RACH procedure. In the example, 2 SSBs are associated with one RO. In addition, preambles with index 0-23 are associated with SSB#0 and preambles with index 24-47 are associated with SSB#1. Further, within the preamble associated with a same SSB, PRACH preamble for EDT for 4-step RACH is allocated after CBRA 2-step RACH,

while PRACH preamble for EDT for 2-step RACH is allocated after EDT for 4-step RACH.

[0073] Note that in another option, if only EDT for 4-step RACH is supported while EDT for 2-step RACH is not supported, the same principle may be applied, e.g., EDT with 4-step RACH is mapped after CBRA for 2-step RACH in preambles associated with one SSB.

[0074] In one example, when shared PRACH occasion is configured for EDT with 4-step RACH and legacy 2-step and 4-step RACH, the following text can be added in Section 8.1 in TS38.213. Note that in the following description, Type-3 random access procedure indicates the EDT with 4-step RACH.

[0075] For Type-3 random access procedure with common configuration of PRACH occasions with Type-1 and Type-2 random access procedure, if $N < 1$, one SS/PBCH block index is mapped to $1/N$ consecutive valid PRACH occasions and M contention based preambles with consecutive indexes associated with the SS/PBCH block index per valid PRACH occasion start from preamble index $R + Q$. If $N \geq 1$, M contention based preambles with consecutive indexes associated with SS/PBCH block index n, $0 \leq n \leq N - 1$, per valid PRACH occasion start from preamble index $n \cdot N_{\text{preamble}}^{\text{total}}/N + R + Q$, where $N_{\text{preamble}}^{\text{total}}$ is provided by *totalNumberOfRA-Preambles* for Type-1 random access procedure.

[0076] In another embodiment of the disclosure, if EDT with 4-step RACH is supported, and if separate PRACH occasions for CBRA 2-step RACH are configured from legacy 4-step RACH and EDT with 4-step RACH, the EDT with 4-step RACH is mapped after CBRA 4-step RACH within preambles associated with one SSB. Note that this can apply for the case when separate RO is configured for EDT with 2-step RACH or for the case when EDT with 2-step RACH is not supported.

[0077] FIG. 4 illustrates one example of PRACH resource partitioning for EDT with 4-step RACH and legacy CBRA RACH procedure. In the example, In the example, 2 SSBs are associated with one RO. In addition, preambles with index 0-23 are associated with SSB#0 and preambles with index 24-47 are associated with SSB#1. Further, within the preamble associated with a

same SSB, PRACH preamble for EDT for 4-step RACH is allocated after CBRA 4-step RACH.

[0078] In one example, when shared PRACH occasion is configured for EDT with 4-step RACH and legacy 4-step RACH, the following text can be added in Section 8.1 in TS38.213. Note that in the following description, Type-3 random access procedure indicates the EDT with 4-step RACH.

[0079] For Type-3 random access procedure with common configuration of PRACH occasions with Type-1 random access procedure, if $N < 1$, one SS/PBCH block index is mapped to $1/N$ consecutive valid PRACH occasions and M contention based preambles with consecutive indexes associated with the SS/PBCH block index per valid PRACH occasion start from preamble index R. If $N \geq 1$, M contention based preambles with consecutive indexes associated with SS/PBCH block index n, $0 \leq n \leq N-1$, per valid PRACH occasion start from preamble index $n \cdot N_{\text{preamble}}^{\text{total}}/N + R$, where $N_{\text{preamble}}^{\text{total}}$ is provided by *totalNumberOfRA-Preambles* for Type-1 random access procedure.

[0080] In another embodiment of the disclosure, when shared PRACH occasions, but different PRACH preambles can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively. In this option, EDT for 4-step and/or 2-step RACH is allocated within the preambles for legacy CBRA 4-step and/or CBRA 2-step RACH, respectively.

[0081] Note that when separate RO is configured for EDT with 2-step RACH or for the case when EDT with 2-step RACH is not supported, only EDT for 4-step RACH, legacy CBRA 4-step RACH and CFRA can be allocated within a set of preambles associated with an SSB.

[0082] FIG. 5 illustrates one example of PRACH resource partitioning for EDT and legacy RACH. In the example, 2 SSBs are associated with one RO. In addition, preambles with index 0-23 are associated with SSB#0 and preambles with index 24-47 are associated with SSB#1 for legacy 4-step RACH and 2-step RACH. Further, within each set of preambles associated with an SSB, preambles for EDT for 4-step and 2-step RACH are allocated within preambles for CBRA 4-step RACH and 2-step RACH, respectively.

[0083] Note that for this option, when preamble group A and group B is configured for CBRA 4-step and 2-step RACH, EDT for 4-step RACH and/or 2-step RACH may be allocated within preamble group A and/or group B for CBRA 4-step RACH and/or 2-step RACH, respectively.

[0084] In another embodiment of the disclosure, when shared PRACH occasions, but different PRACH preambles can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively. In this option, EDT for 4-step and/or 2-step RACH is allocated within the preambles for other purpose, e.g., from *totalNumberOfRA-Preambles* to 63 within a RO.

[0085] Further, the preambles for other purpose are partitioned into multiple sets, where each set is associated with an SSB. The number of sets is determined by *ssb-perRACH-OccasionAndCB-PreamblesPerSSB* or *ssb-perRACH-OccasionAndCB-PreamblesPerSSB-msgA*. Within each set of preambles, EDT for 2-step RACH is allocated after EDT for 4-step RACH. If EDT for 2-step RACH is not configured or not supported, only EDT for 4-step RACH is allocated within each set.

[0086] FIG. 6 illustrates one example of PRACH resource partitioning for EDT and legacy RACH. In the example, 2 SSBs are associated with one RO. In addition, preambles with index 0-19 are associated with SSB#0 and preambles with index 20-39 are associated with SSB#1 for legacy 4-step RACH and 2-step RACH. Further, preambles for EDT for 4-step and 2-step RACH are allocated within preambles for other purposes, e.g., from index 40-63. Similarly, two sets of preambles are allocated within the preambles for other purposes, where each set is associated with an SSB. Within each set, EDT for 2-step RACH is allocated after EDT for 4-step RACH.

[0087] In another embodiment of the disclosure, when preamble group A and group B is configured for EDT with 4-step and 2-step RACH, additional PRACH resource partitioning may be applied based on the aforementioned options. In particular, preamble for EDT with 4-step RACH is further divided into preamble group A and group B, where preamble group A is allocated before

preamble group B for EDT with 4-step RACH. The same mechanism can be applied for EDT with 2-step RACH.

[0088] FIG. 7 illustrates a functional block diagram of a wireless communication device in accordance with some embodiments. The communication device 700 may also be suitable for use as a handheld device (e.g., a UE), a base station (e.g., a gNB), a mobile device, a cellular telephone, a smartphone, a tablet, a netbook, a wireless terminal, a laptop computer, a wearable computer device, a femtocell, a high data rate (HDR) subscriber station, an access point, an access terminal, or other personal communication system (PCS) device.

[0089] The communication device 700 may include communications circuitry 702 and a transceiver 710 for transmitting and receiving signals to and from other communication stations using one or more antennas 701. The communications circuitry 702 may include circuitry that can operate the physical layer (PHY) communications and/or medium access control (MAC) communications for controlling access to the wireless medium, and/or any other communications layers for transmitting and receiving signals. The communication device 700 may also include processing circuitry 706 and memory 708 arranged to perform the operations described herein. In some embodiments, the communications circuitry 702 and the processing circuitry 706 may be configured to perform operations detailed in the above figures, diagrams, and flows.

[0090] In accordance with some embodiments, the communications circuitry 702 may be arranged to contend for a wireless medium and configure frames or packets for communicating over the wireless medium. The communications circuitry 702 may be arranged to transmit and receive signals. The communications circuitry 702 may also include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 706 of the communication device 700 may include one or more processors. In other embodiments, two or more antennas 701 may be coupled to the communications circuitry 702 arranged for sending and receiving signals. The memory 708 may store information for configuring the processing circuitry 706 to perform

operations for configuring and transmitting message frames and performing the various operations described herein. The memory 708 may include any type of memory, including non-transitory memory, for storing information in a form readable by a machine (e.g., a computer). For example, the memory 708 may include a computer-readable storage device, read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices and other storage devices and media.

[0091] In some embodiments, the communication device 700 may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), a wearable computer device, or another device that may receive and/or transmit information wirelessly.

[0092] In some embodiments, the communication device 700 may include one or more antennas 701. The antennas 701 may include one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas, or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated for spatial diversity and the different channel characteristics that may result between each of the antennas and the antennas of a transmitting station.

[0093] In some embodiments, the communication device 700 may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0094] Although the communication device 700 is illustrated as having several separate functional elements, two or more of the functional elements may

be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may include one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of the communication device 700 may refer to one or more processes operating on one or more processing elements.

[0095] **EXAMPLES**

[0096] Example 1 may include a method of wireless communication for a fifth generation (5G) or new radio (NR) system, the method comprising:

[0097] Configuring, by gNodeB, separate physical random-access channel (PRACH) preambles for early data transmission (EDT) using 2-step random access (RACH) procedure and/or 4-step RACH procedure.

[0098] Example 2 may include the method of example 1 or some other example herein, wherein separate PRACH occasions can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively;

[0099] Example 3 may include the method of example 1 or some other example herein, wherein shared PRACH occasions, but different PRACH preambles can be configured for EDT with 4-step and/or 2-step RACH from legacy 4-step and/or 2-step RACH, respectively.

[00100] Example 4 may include the method of example 3 or some other example herein, wherein when EDT is configured using 4-step RACH and/or 2-step RACH, PRACH preambles for EDT may be allocated as a part of consecutive preambles for contention free random access (CFRA)

[00101] Example 5 may include the method of example 3 or some other example herein, wherein within the set of preambles associated with a same synchronization signal block (SSB), PRACH preamble for EDT for 4-step RACH is allocated after contention based random access (CBRA) 2-step RACH, while PRACH preamble for EDT for 2-step RACH is allocated after EDT for 4-step RACH.

[00102] Example 6 may include the method of example 3 or some other example herein, wherein if EDT with 4-step RACH is supported, and if separate PRACH occasions for CBRA 2-step RACH are configured from legacy 4-step RACH and EDT with 4-step RACH, the EDT with 4-step RACH is mapped after CBRA 4-step RACH within preambles associated with one SSB

[00103] Example 7 may include the method of example 3 or some other example herein, wherein EDT for 4-step and/or 2-step RACH is allocated within the preambles for legacy CBRA 4-step and/or CBRA 2-step RACH, respectively.

[00104] Example 8 may include the method of example 7 or some other example herein, wherein when preamble group A and group B is configured for CBRA 4-step and 2-step RACH, EDT for 4-step RACH and/or 2-step RACH may be allocated within preamble group A and/or group B for CBRA 4-step RACH and/or 2-step RACH, respectively.

[00105] Example 9 may include the method of example 3 or some other example herein, wherein EDT for 4-step and/or 2-step RACH is allocated within the preambles for other purpose, e.g., from totalNumberOfRA-Preambles to 63 within a RO.

[00106] Example 10 may include the method of example 9 or some other example herein, wherein preambles for other purpose are partitioned into multiple sets, where each set is associated with an SSB.

[00107] Example 11 may include the method of example 9 or some other example herein, wherein within each set of preambles, EDT for 2-step RACH is allocated after EDT for 4-step RACH; wherein if EDT for 2-step RACH is not configured or not supported, only EDT for 4-step RACH is allocated within each set.

[00108] Example 12 may include the method of example 1 or some other example herein, wherein when preamble group A and group B is configured for EDT with 4-step and 2-step RACH, additional PRACH resource partitioning may be applied based on the aforementioned options.

[00109] Example 13 may include the method of example 12 or some other example herein, wherein preamble for EDT with 4-step RACH is further divided

into preamble group A and group B, where preamble group A is allocated before preamble group B for EDT with 4-step RACH.

[00110] Example 14 may include a method comprising:

[00111] receiving configuration information for a physical random-access channel (PRACH) preamble for early data transmission (EDT); and

[00112] encoding, the PRACH preamble for transmission to a gNB as part of a random-access channel (RACH) procedure.

[00113] Example 15 may include the method of example 14 or some other example herein, wherein the RACH procedure is a 2-step RACH procedure and/or a 4-step RACH procedure.

[00114] Example 16 may include the method of example 14-15 or some other example herein, wherein the PRACH preamble for EDT is different than a PRACH preamble for normal (e.g., non-EDT) communication.

[00115] Example 17 may include the method of example 14-16 or some other example herein, wherein the PRACH preamble for EDT is allocated as a part of consecutive preambles for contention free random access (CFRA)

[00116] Example 18 may include the method of example 14-16 or some other example herein, wherein within a set of PRACH preambles associated with a same synchronization signal block (SSB), the PRACH preamble for EDT for 4-step RACH is allocated after contention based random access (CBRA) 2-step RACH, while the PRACH preamble for EDT for 2-step RACH is allocated after EDT for 4-step RACH.

[00117] Example 19 may include the method of example 14-16 or some other example herein, wherein if EDT with 4-step RACH is supported, and if separate PRACH occasions for CBRA 2-step RACH are configured from legacy 4-step RACH and EDT with 4-step RACH, the EDT with 4-step RACH is mapped after CBRA 4-step RACH within preambles associated with one SSB

[00118] Example 20 may include the method of example 14-16 or some other example herein, wherein EDT for 4-step and/or 2-step RACH is allocated within the preambles for legacy CBRA 4-step and/or CBRA 2-step RACH, respectively.

[00119] Example 21 may include the method of example 20 or some other example herein, wherein when preamble group A and group B is configured for

CBRA 4-step and 2-step RACH, EDT for 4-step RACH and/or 2-step RACH is allocated within preamble group A and/or group B for CBRA 4-step RACH and/or 2-step RACH, respectively.

[00120] Example 22 may include the method of example 14-16 or some other example herein, wherein EDT for 4-step and/or 2-step RACH is allocated within one or more RACH preambles that are used for another purpose, e.g., from totalNumberOfRA-Preambles to 63 within a RACH occasion (RO).

[00121] Example 23 may include the method of example 22 or some other example herein, wherein the one or more RACH preambles for another purpose are partitioned into multiple sets, where each set is associated with an SSB.

[00122] Example 24 may include the method of example 22 or some other example herein, wherein within each set of preambles, EDT for 2-step RACH is allocated after EDT for 4-step RACH; wherein if EDT for 2-step RACH is not configured or not supported, only EDT for 4-step RACH is allocated within each set.

[00123] Example 25 may include the method of example 14-16 or some other example herein, wherein when the configuration information includes a preamble group A and preamble group B for EDT with 4-step and 2-step RACH, respectively, and wherein additional PRACH resource partitioning is applied.

[00124] Example 26 may include the method of example 25 or some other example herein, wherein the preamble group A for EDT with 4-step RACH is further divided into preamble group C and preamble group D, wherein preamble group C is allocated before preamble group D for EDT with 4-step RACH.

[00125] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS), the apparatus comprising: processing circuitry; and memory,

wherein to perform a random-access procedure with a generation Node B (gNB), the processing circuitry is to configure the UE to:

encode a physical random-access channel (PRACH) preamble for uplink transmission; and

decode a random-access response (RAR) from the gNB,

wherein for a shared PRACH occasion, the processing circuitry is to configure the UE to perform the random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation, and

wherein the memory is configured to store the PRACH preamble.

2. The apparatus of claim 1, wherein for the SDT when the shared PRACH occasion is configured, the processing circuitry is further configured to:

select a PRACH preamble from a PRACH resource allocated for SDT; and

configure the UE to transmit the selected PRACH preamble for SDT within the shared PRACH occasion, and

wherein for the non-SDT operation when the shared PRACH occasion is configured, the processing circuitry is further configured to:

select a PRACH preamble from a PRACH resource allocated for non-SDT operation; and

configure the UE to transmit the selected PRACH preamble for non-SDT operation within the shared PRACH occasion.

3. The apparatus of claim 2, wherein the processing circuitry is configured to decode signalling from the gNB indicating whether the shared

PRACH occasion is configured for the SDT and the non-SDT operation, or whether separate PRACH occasions are configured for the SDT and the non-SDT operation.

4. The apparatus of claim 3, wherein the processing circuitry is configured to decode signalling from the gNB, the signalling allocating PRACH preambles associated with synchronization signal block (SSBs) for the shared PRACH occasion,

wherein the shared PRACH occasion, some of the PRACH preambles are allocated for at least one of a legacy contention based random access (CBRA) 4-step random-access procedure and a legacy CBRA 2-step random-access procedure, some of the PRACH preambles are allocated for contention free random access (CFRA), some of the PRACH preambles are allocated for an SDT 4-step random-access procedure and some of the preambles are allocated for an SDT 2-step random-access procedure.

5. The apparatus of claim 4, wherein one of the SDT 4-step random-access procedure and the SDT 2-step random-access procedure is used for the SDT transmission, and

wherein one of the legacy CBRA 2-step random-access procedure, the legacy CBRA 4-step random-access procedure, and the CFRA are used for the non-SDT operation.

6. The apparatus of claim 5, wherein for the shared PRACH occasion for each SSB, a set of the allocated preambles are allocated for the legacy CBRA 4-step random-access procedure, a set of the allocated preambles is allocated for the legacy CBRA 2-step random-access procedure, and a set of the allocated preambles are allocated for the CFRA, and

wherein for the shared RO, some of the preambles that are allocated for the CFRA are allocated for the SDT 4-step random-access procedure and some of the preambles for the CFRA are allocated for an SDT 2-step random-access procedure.

7. The apparatus of claim 5, wherein for the shared PRACH occasion for each SSB, a set of the allocated preambles are allocated for the legacy CBRA 4-step random-access procedure and a set of the allocated preambles are allocated for the CFRA, and

wherein for the shared PRACH occasion, some of the preambles allocated for the CFRA are allocated for an SDT 4-step random-access procedure.

8. The apparatus of claim 5, wherein for the shared PRACH occasion for each SSB, a set of the allocated preambles are allocated for the legacy CBRA 4-step random-access procedure, a set of the allocated preambles is allocated for the legacy CBRA 2-step random-access procedure, and a set of the allocated preambles are allocated for the CFRA, and

wherein for the shared PRACH occasion, some of the preambles allocated for the CBRA 4-step random-access procedure are allocated for an SDT 4-step random-access procedure and some of the preambles for the CBRA 2-step random-access procedure are allocated for an SDT 2-step random-access procedure.

9. The apparatus of claim 5, wherein for the shared PRACH occasion, preambles that are allocated for other purposes are allocated to an SDT 4-step random-access procedure and to an SDT 2-step random-access procedure.

10. The apparatus of claim 2, wherein when the separate PRACH occasions are configured, the processing circuitry is to configure the UE to perform a 4-step random-access procedure for an SDT and perform a 2-step random-access procedure for a non-SDT operation, and

wherein the SDT comprises a transmission of data from the UE without establishment of an radio-resource control (RRC) connection with the gNB.

11. A non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a user equipment (UE) configured for operation in a fifth-generation new radio (5G NR) system (5GS),

wherein to perform a random-access procedure with a generation Node B (gNB), the processing circuitry is to configure the UE to:

encode a physical random-access channel (PRACH) preamble for uplink transmission; and

decode a random-access response (RAR) from the gNB,

wherein for a shared PRACH occasion, the processing circuitry is to configure the UE to perform the random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation.

12. The non-transitory computer-readable storage of claim 11, wherein for the SDT when the shared PRACH occasion is configured, the processing circuitry is further configured to:

select a PRACH preamble from a PRACH resource allocated for SDT; and

configure the UE to transmit the selected PRACH preamble for SDT within the shared PRACH occasion, and

wherein for the non-SDT operation when the shared PRACH occasion is configured, the processing circuitry is further configured to:

select a PRACH preamble from a PRACH resource allocated for non-SDT operation; and

configure the UE to transmit the selected PRACH preamble for non-SDT operation within the shared PRACH occasion.

13. The a non-transitory computer-readable storage of claim 12, wherein the processing circuitry is configured to decode signalling from the gNB indicating whether the shared PRACH occasion is configured for the SDT and the non-SDT operation, or whether separate PRACH occasions are configured for the SDT and the non-SDT operation.

14. The non-transitory computer-readable storage of claim 13, wherein the processing circuitry is configured to decode signalling from the gNB, the

signalling allocating PRACH preambles associated with synchronization signal block (SSBs) for the shared PRACH occasion,

wherein the shared PRACH occasion, some of the PRACH preambles are allocated for at least one of a legacy contention based random access (CBRA) 4-step random-access procedure and a legacy CBRA 2-step random-access procedure, some of the PRACH preambles are allocated for contention free random access (CFRA), some of the PRACH preambles are allocated for an SDT 4-step random-access procedure and some of the preambles are allocated for an SDT 2-step random-access procedure.

15. The non-transitory computer-readable storage of claim 14, wherein one of the SDT 4-step random-access procedure and the SDT 2-step random-access procedure is used for the SDT transmission, and

wherein one of the legacy CBRA 2-step random-access procedure, the legacy CBRA 4-step random-access procedure, and the CFRA are used for the non-SDT operation.

16. An apparatus of a generation node B (gNB) configured for operation in a fifth-generation new radio (5G NR) system (5GS), the apparatus comprising: processing circuitry; and memory,

wherein the processing circuitry is configured to:

encode signalling for transmission to a user equipment (UE) to allocate physical random-access channel (PRACH) resources to configure to UE to perform a random-access procedure using different PRACH preambles to differentiate a small data transmission (SDT) from a non-SDT operation for a shared PRACH occasion.

17. The apparatus of claim 16, wherein for an SDT when a shared PRACH occasion is configured, the processing circuitry is further configured to decode a PRACH preamble for the SDT received within the shared PRACH occasion, and

wherein for a non-SDT operation when the shared PRACH occasion is configured, the processing circuitry is further configured to decode a PRACH preamble for the non-SDT operation within the shared PRACH occasion.

18. The apparatus of claim 17, wherein the processing circuitry is configured to encode a system information block (SIB) for transmission to the UE indicating whether the shared PRACH occasion is configured for both the SDT and the non-SDT operation, or whether separate PRACH occasions are configured for the SDT and the non-SDT operation.

19. The apparatus of claim 18, wherein the processing circuitry is configured to encode the signalling allocating PRACH preambles associated with synchronization signal block (SSBs) for the shared PRACH occasion,

wherein the shared PRACH occasion, some of the PRACH preambles are allocated for at least one of a legacy contention based random access (CBRA) 4-step random-access procedure and a legacy CBRA 2-step random-access procedure, some of the PRACH preambles are allocated for contention free random access (CFRA), some of the PRACH preambles are allocated for an SDT 4-step random-access procedure and some of the preambles are allocated for an SDT 2-step random-access procedure.

20. The apparatus of claim 19, wherein the SDT comprises a transmission of data from the UE without establishment of an radio-resource control (RRC) connection with the UE.

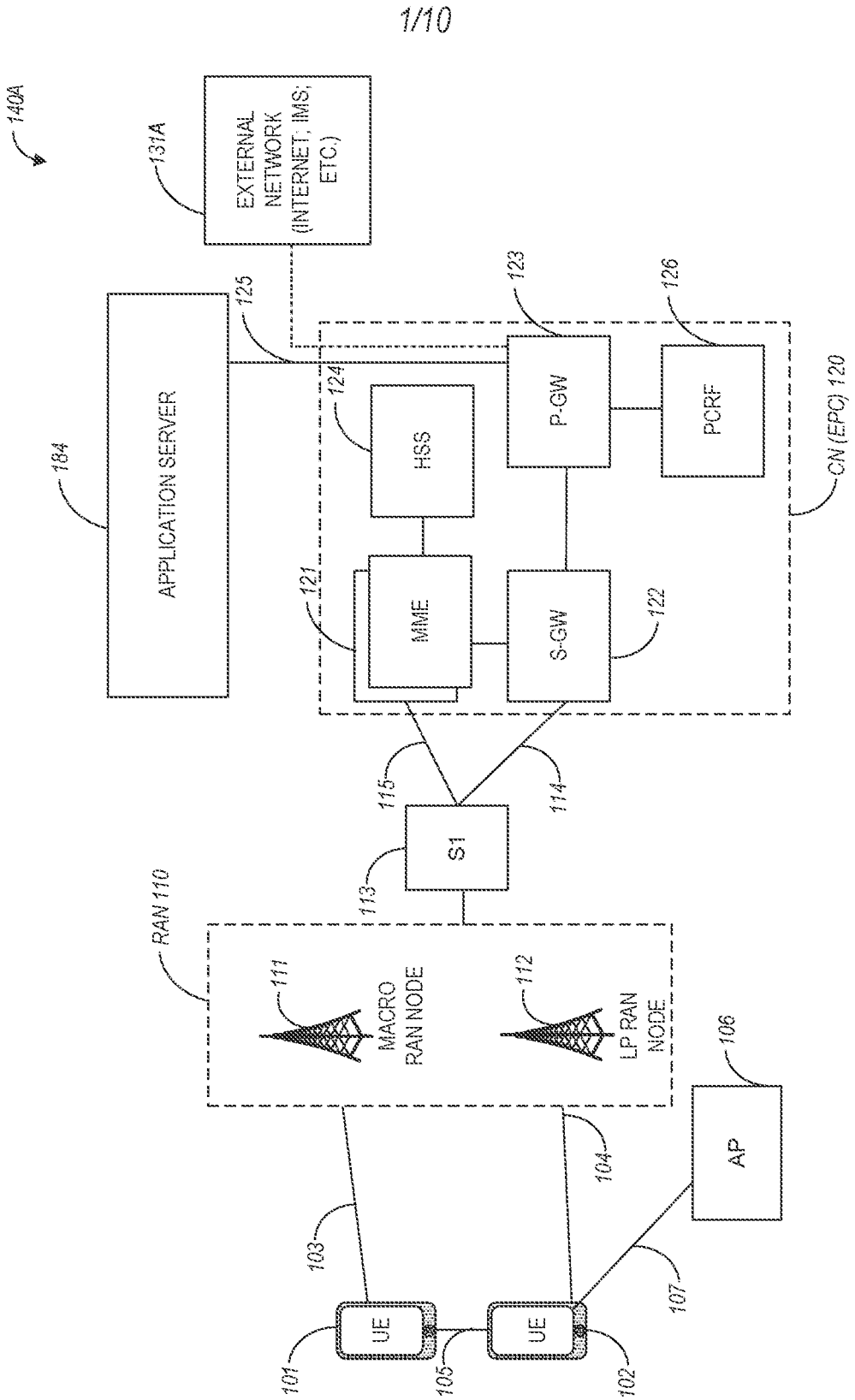

1/10
140A
131A
EXTERNAL NETWORK (INTERNET, IMS, ETC.)
125
123
126
APPLICATION SERVER
184
124
HSS
P-GW
PCRF
CN (EPC) 120
121
MME
S-GW
122
115
114
S1
113
RAN 110
111
MACRO RAN NODE
112
LP RAN NODE
106
AP
104
103
107
UE
UE
101
105
102

FIG. 1A

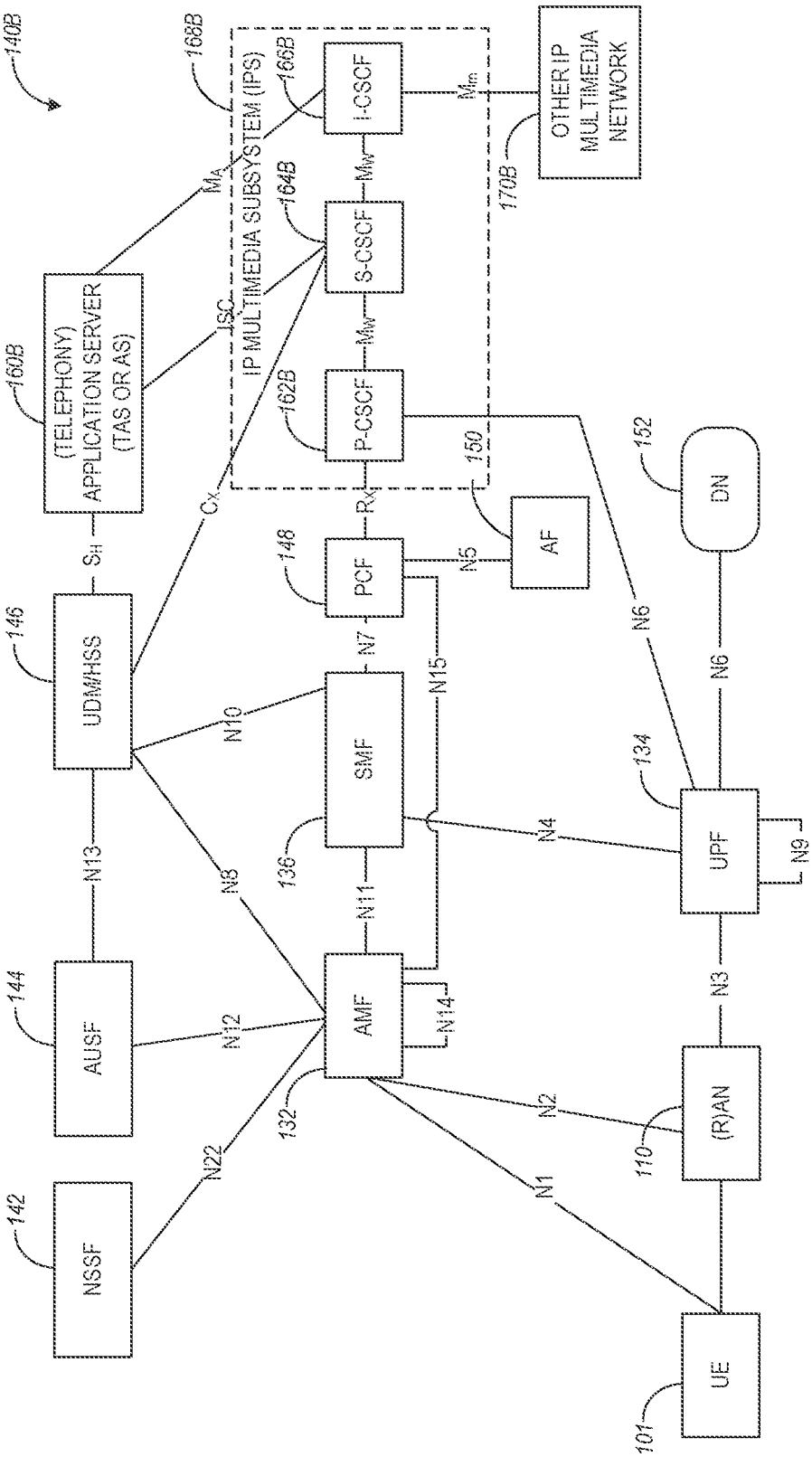
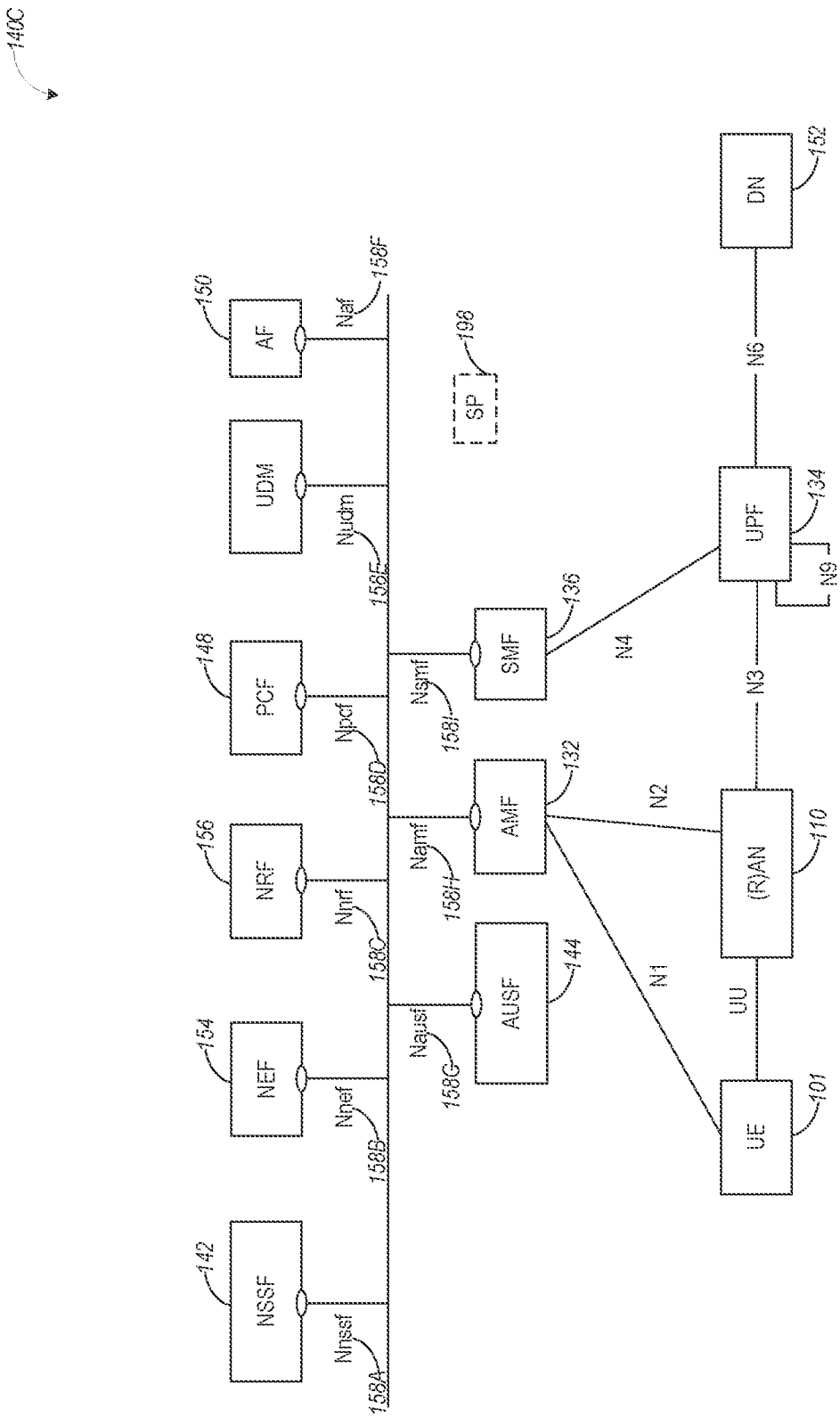

140B
166B
IP MULTIMEDIA SUBSYSTEM (IPS)
I-CSCF
OTHER IP MULTIMEDIA NETWORK
170B
164B
S-CSCF
160B
(TELEPHONY) APPLICATION SERVER (TAS OR AS)
162B
P-CSCF
150
152
DN
148
PCF
AF
146
UDM/HSS
SMF
134
UPF
136
AMF
144
AUSF
142
NSSF
132
110
(R)AN
101
UE
MA
ISC
Mw
Mm
SH
Cx
Rx
N5
N6
N7
N10
N15
N13
N3
N4
N9
N11
N12
N14
N22
N2
N1

FIG. 1B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Nnssf
158A
NEF
154
Nnef
158B
NRF
156
Nnrf
158C
PCF
148
Npcf
158D
UDM
Nudm
158E
AF
150
Naf
158F
SP
198
AUSF
144
Nausf
158G
AMF
132
Namf
158H
SMF
136
Nsmf
158I
UPF
134
N9
N6
DN
152
N4
N3
N2
N1
(R)AN
110
UU
UE
101

FIG. 1C

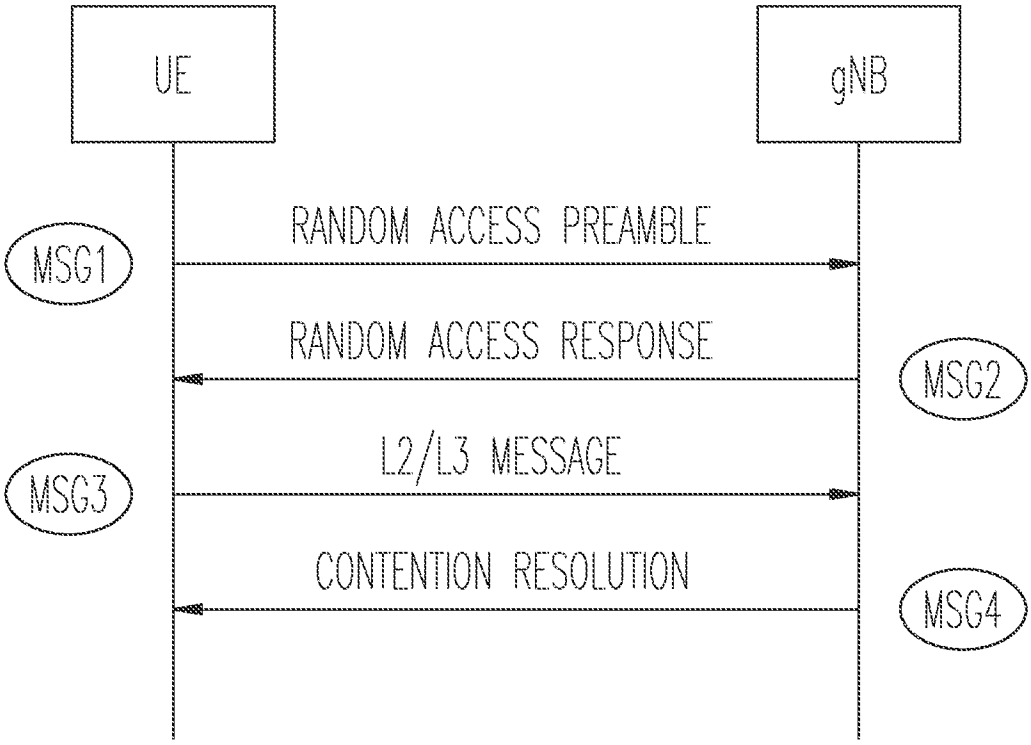

UE
gNB
RANDOM ACCESS PREAMBLE
MSG1
RANDOM ACCESS RESPONSE
MSG2
L2/L3 MESSAGE
MSG3
CONTENTION RESOLUTION
MSG4
4-STEP RACH PROCEDURE

FIG. 2A

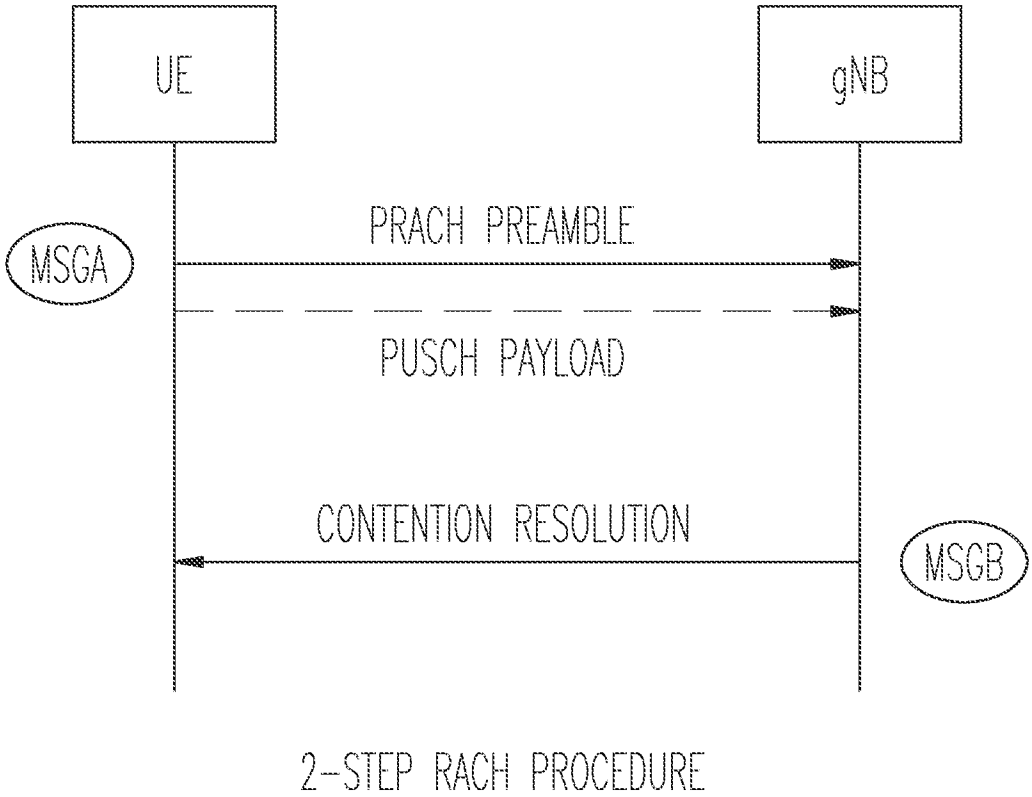

UE
gNB
MSGA
PRACH PREAMBLE
PUSCH PAYLOAD
CONTENTION RESOLUTION
MSGB
2-STEP RACH PROCEDURE

FIG. 2B

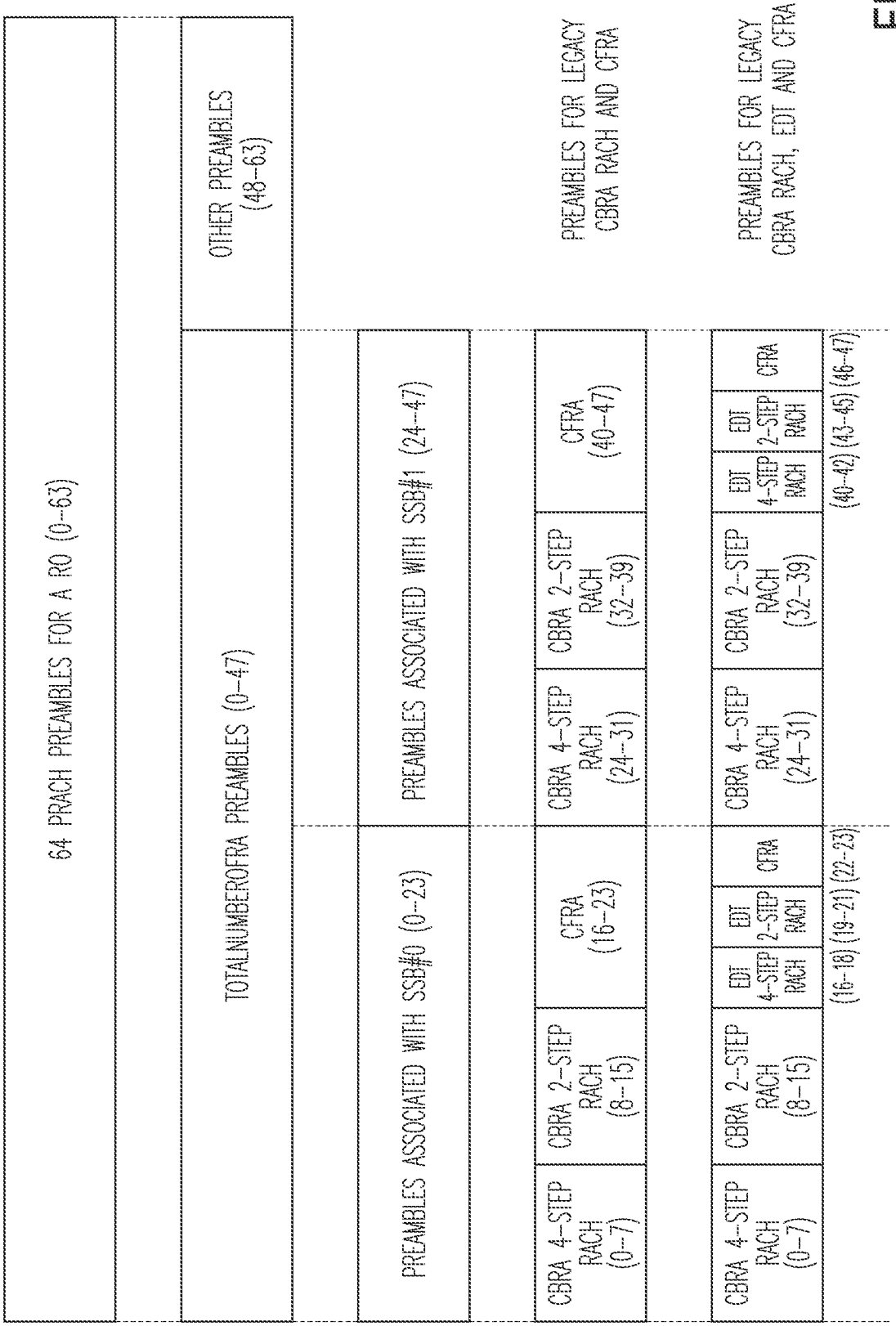

64 PRACH PREAMBLES FOR A RO (0–63)
TOTALNUMBEROFRA PREAMBLES (0–47)
OTHER PREAMBLES (48–63)
PREAMBLES ASSOCIATED WITH SSB#0 (0–23)
PREAMBLES ASSOCIATED WITH SSB#1 (24–47)
PREAMBLES FOR LEGACY CBRA RACH AND CFRA
PREAMBLES FOR LEGACY CBRA RACH, EDT AND CFRA
CBRA 4–STEP RACH (0–7)
CBRA 2–STEP RACH (8–15)
EDT 4–STEP RACH
EDT 2–STEP RACH
CFRA (16–23)
CBRA 4–STEP RACH (24–31)
CBRA 2–STEP RACH (32–39)
CFRA (40–47)
(16–18) (19–21) (22–23)
(40–42) (43–45) (46–47)

FIG. 3

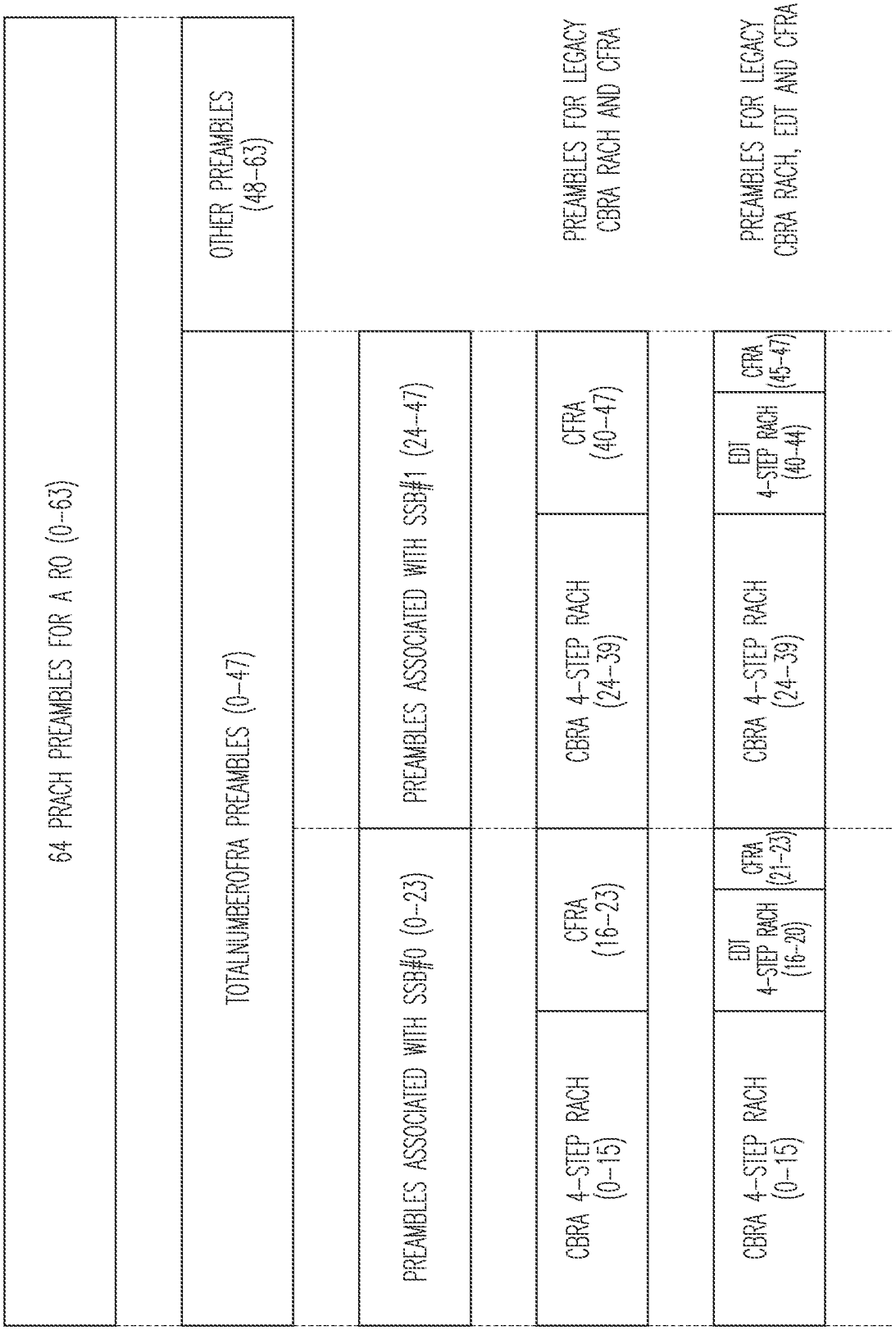

64 PRACH PREAMBLES FOR A RO (0-63)
TOTALNUMBEROFRA PREAMBLES (0-47)
OTHER PREAMBLES (48-63)
PREAMBLES ASSOCIATED WITH SSB#0 (0-23)
PREAMBLES ASSOCIATED WITH SSB#1 (24-47)
CBRA 4-STEP RACH (0-15)
CFRA (16-23)
CBRA 4-STEP RACH (24-39)
CFRA (40-47)
CBRA 4-STEP RACH (0-15)
EDT 4-STEP RACH (16-20)
CFRA (21-23)
CBRA 4-STEP RACH (24-39)
EDT 4-STEP RACH (40-44)
CFRA (45-47)
PREAMBLES FOR LEGACY CBRA RACH AND CFRA
PREAMBLES FOR LEGACY CBRA RACH, EDT AND CFRA

FIG. 4

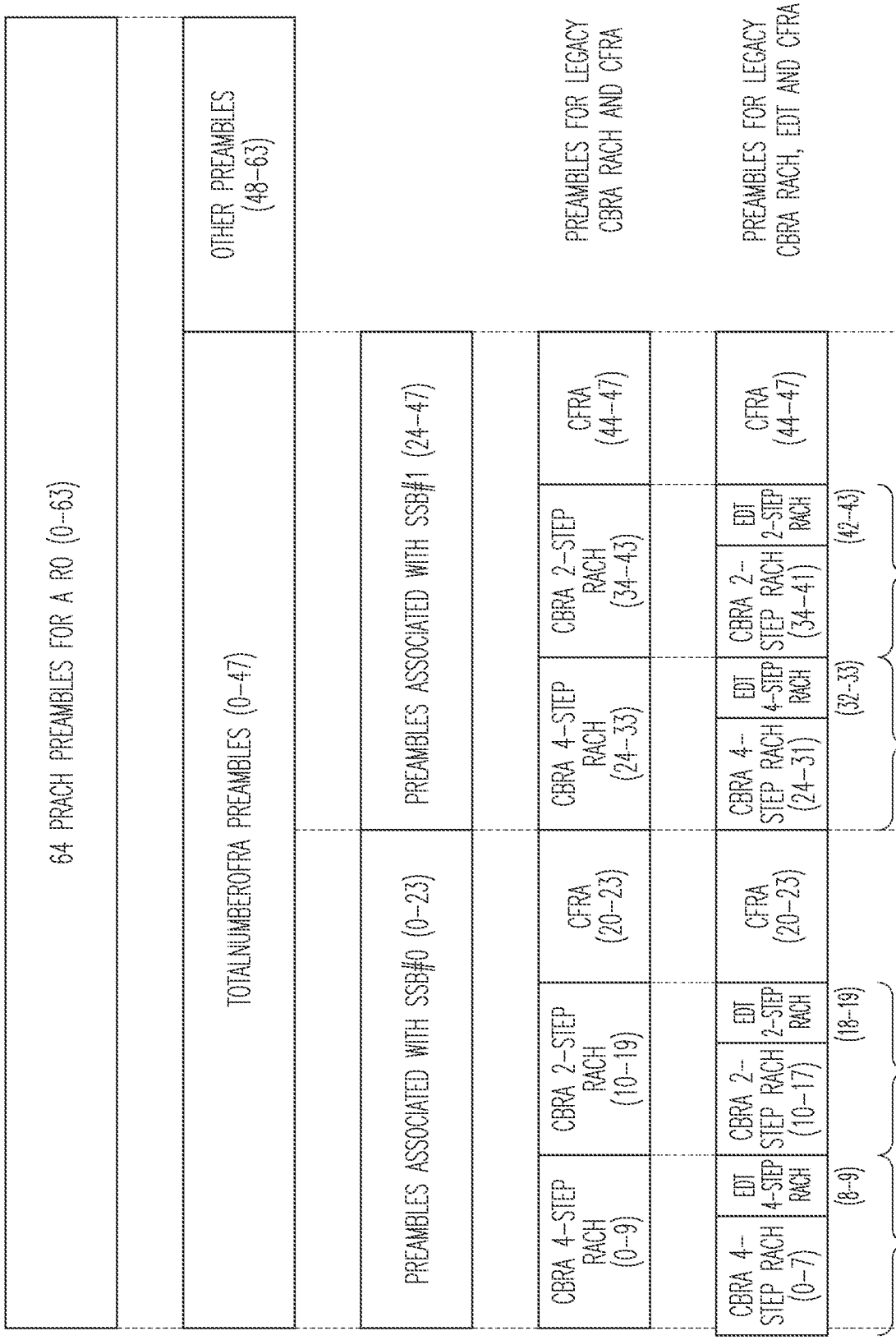

64 PRACH PREAMBLES FOR A RO (0–63)
TOTALNUMBEROFRA PREAMBLES (0–47)
OTHER PREAMBLES (48–63)
PREAMBLES ASSOCIATED WITH SSB#0 (0–23)
PREAMBLES ASSOCIATED WITH SSB#1 (24–47)
PREAMBLES FOR LEGACY CBRA RACH AND CFRA
PREAMBLES FOR LEGACY CBRA RACH, EDT AND CFRA
CBRA 4–STEP RACH (0–9)
CBRA 2–STEP RACH (10–19)
CFRA (20–23)
CBRA 4–STEP RACH (24–33)
CBRA 2–STEP RACH (34–43)
CFRA (44–47)
CBRA 4–STEP RACH (0–7)
EDT 4–STEP RACH (8–9)
CBRA 2–STEP RACH (10–17)
EDT 2–STEP RACH (18–19)
CBRA 4–STEP RACH (24–31)
EDT 4–STEP RACH (32–33)
CBRA 2–STEP RACH (34–41)
EDT 2–STEP RACH (42–43)
4–STEP RACH
2–STEP RACH
4–STEP RACH
2–STEP RACH

FIG. 5

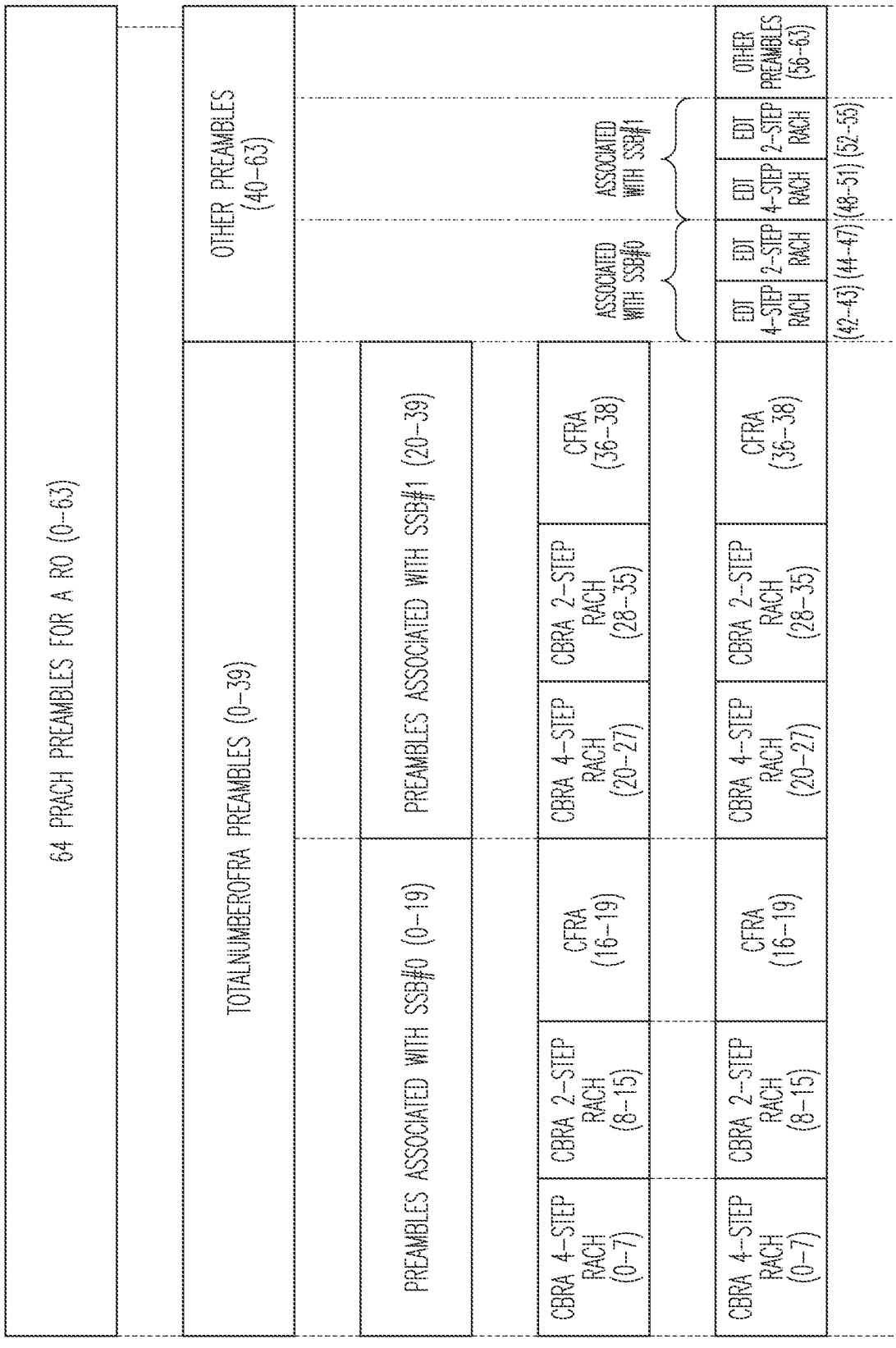
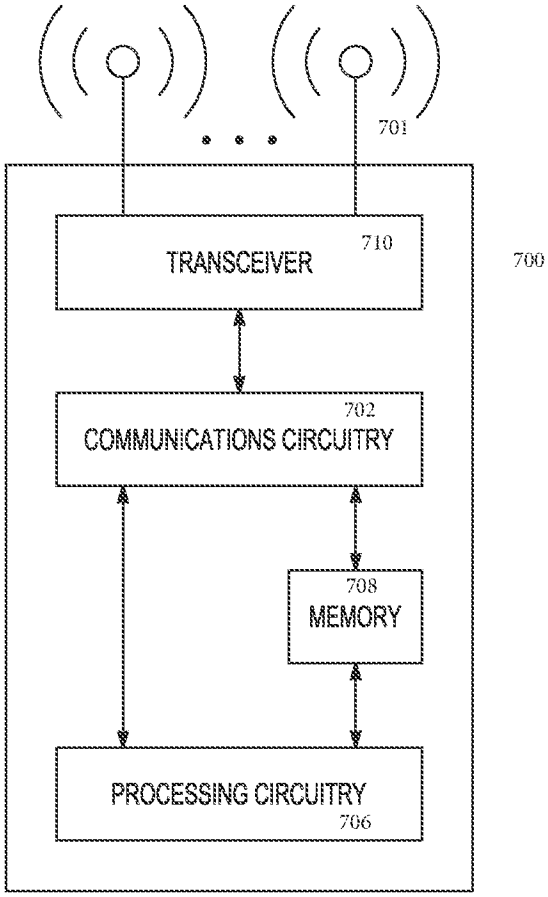

64 PRACH PREAMBLES FOR A RO (0–63)
TOTALNUMBEROFRA PREAMBLES (0–39)
OTHER PREAMBLES (40–63)
PREAMBLES ASSOCIATED WITH SSB#0 (0–19)
PREAMBLES ASSOCIATED WITH SSB#1 (20–39)
CBRA 4–STEP RACH (0–7)
CBRA 2–STEP RACH (8–15)
CFRA (16–19)
CBRA 4–STEP RACH (20–27)
CBRA 2–STEP RACH (28–35)
CFRA (36–38)
ASSOCIATED WITH SSB#0
ASSOCIATED WITH SSB#1
EDT 4–STEP RACH
EDT 2–STEP RACH
EDT 4–STEP RACH
EDT 2–STEP RACH
OTHER PREAMBLES (56–63)
(42–43) (44–47) (48–51) (52–55)
PREAMBLES FOR LEGACY CBRA RACH AND CFRA
PREAMBLES FOR LEGACY CBRA RACH, EDT AND CFRA

FIG. 6

FIG. 7


701
TRANSCEIVER
710
700
COMMUNICATIONS CIRCUITRY
702
MEMORY
708
PROCESSING CIRCUITRY
706

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/036010

A. CLASSIFICATION OF SUBJECT MATTER

H04W 74/08(2009.01)i; **H04W 74/00**(2009.01)i; **H04W 72/04**(2009.01)i; **H04W 72/12**(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 74/08(2009.01); H04W 72/04(2009.01); H04W 76/19(2018.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: small data transmission (SDT), physical random-access channel (PRACH), random access response (RAR), preamble, different, non-SDT, share, occasion, synchronization signal block (SSB), 4-step, contention free random access (CFRA), contention based random access (CBRA)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NOKIA et al., `On 2-step RACH Procedure', R1-1908342, 3GPP TSG RAN WG1 #98, Prague, Czech Republic, 16 August 2019 sections 2.3, 2.5.1, 2.5.3.1.2, 2.5.3.2.2, 2.8; and figure 5	1-20
Y	HUAWEI, `Report of the Email discussion [101#57][NB-IoT/MTC R15] EDT remaining issues', R2-1805 078, 3GPP TSG-RAN WG2 Meeting#101bis, Sanya, China, 05 April 2018 sections 2.8, 3	1-20
A	INTEL CORPORATION, `Report on [106#65][R16 NB-IoT/eMTC] CP MT-EDT', R2-1910386, 3GPP TSG RAN WG2 Meeting #107, Prague, the Czech Republic, 16 August 2019 section 3.3	1-20
A	WO 2020-088097 A1 (QUALCOMM INCORPORATED) 07 May 2020 (2020-05-07) paragraphs [0056]-[0067]	1-20
A	US 2019-0364600 A1 (TELEFONAKTIEBOIAGET LM ERICSSON (PUBL)) 28 November 2019 (2019-11-28) paragraphs [0062]-[0088]	1-20

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

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

Date of the actual completion of the international search	Date of mailing of the international search report
16 September 2021	**16 September 2021**

Name and mailing address of the ISA/KR	Authorized officer
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Facsimile No. **+82-42-481-8578**	Telephone No. **+82-42-481-8710**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2021/036010

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2020-088097 A1	07 May 2020	CN 112913315 A	04 June 2021
		WO 2020-087280 A1	07 May 2020
US 2019-0364600 A1	28 November 2019	CN 110583075 A	17 December 2019
		EP 3498017 A1	19 June 2019
		WO 2018-201803 A1	08 November 2018