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(54) Title: LOW LATENCY PRACH DESIGN IN UNLICENSED SPECTRUM

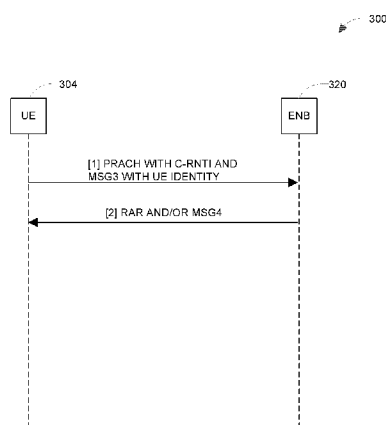


FIG. 3

(57) Abstract: Methods for low latency PRACH design in unlicensed spectrum are generally described herein. An exemplary apparatus of User Equipment (UE) includes memory; and processing circuitry, the processing circuitry to perform a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum. The processing circuitry further to, in response to a clear channel assessment (CCA), encode a first message for a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum. The first message includes a physical random-access channel (PRACH) preamble and a message part. The message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, and/or an identity of the UE. The processing circuitry further to, in response to receipt of an uplink (UL) grant based on the first step of low-latency RA procedure, encode UL data for transmission.



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LOW LATENCY PRACH DESIGN IN UNLICENSED SPECTRUM

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PRIORITY CLAIM

[0001] This patent application claims the benefit of priority to U.S. Provisional Patent Application Serial No. 62/307,202, filed on March 11, 2016, and U.S. Provisional Patent Application Serial Number 62/302,398, filed March 2, 2016, both of which are hereby incorporated by reference herein in their entirety.

TECHNICAL FIELD

15 [0002] Embodiments pertain to cellular networks. Some embodiments relate to carrier aggregation in Third Generation Partnership Project Long Term Evolution (3GPP LTE) networks and LTE advanced (LTE-A) networks, as well as 4th generation (4G) networks and 5th generation (5G) networks.

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BACKGROUND

[0003] An enhancement for LTE in 3GPP Release 13 is to enable operation in the unlicensed spectrum via Licensed-Assisted Access (LAA), which expands the system bandwidth by utilizing the flexible carrier aggregation (CA) framework. Potential LTE operation in unlicensed spectrum may include LTE operation in the unlicensed spectrum via dual connectivity (DC) or the standalone LTE system in the unlicensed spectrum (e.g., MuLTEfire).

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 a wireless telecommunications network 100 to perform a low latency RA procedure in accordance with some embodiments of the disclosure.

[0005] FIG. 2 illustrates a block diagram of components of a User Equipment (UE) device 1000 according to embodiments of the disclosure.

[0006] FIG. 3 illustrates a signal diagram for a low latency two-step RA procedure in accordance with some embodiments of the disclosure.

[0007] FIG. 4A illustrates a signal diagram for a failed low latency single-step RA procedure in accordance with some embodiments of the disclosure.

[0008] FIG. 4B illustrates a signal diagram for a successful low latency single-step RA procedure in accordance with some embodiments of the disclosure.

5 [0009] FIG. 5 illustrates a flow diagram of a method to perform a low latency RA procedure in accordance with some embodiments of the disclosure.

[0010] FIG. 6 illustrates a flow diagram of a method to perform a low latency RA procedure in accordance with some embodiments of the disclosure.

[0011] FIG. 7 illustrates a flow diagram of a method to perform a low
10 latency RA procedure in accordance with some embodiments of the disclosure.

[0012] FIG. 8 illustrates a block diagram of a machine in the example form of a computer system in accordance with some embodiments of the disclosure.

DETAILED DESCRIPTION

15 [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
20 encompass available equivalents of those claims.

[0014] Embodiments provide systems and methods for low latency physical random access channel (PRACH) signal transmission in unlicensed spectrum via License-Assisted Access (LAA) or MulteFire. The PRACH may be used for scheduling request (SR), uplink (UL) synchronization, and power control
25 for initial UL transmission. Typically, a SR may include a four-step contention-based random access procedure that includes the UE providing a PRACH preamble signal, an eNodeB responding with a random access request (RAR) signal, the UE providing a Message 3 signal with a cell radio network temporary identifier (C-RNTI) or a temporary C-RNTI, and the eNodeB responding with a
30 contention resolution message (e.g., Message 4). While operating in unlicensed spectrum, radio transmitters the RA procedure may be complicated by a listen-before-talk (LBT) protocol, which is a procedure whereby radio transmitters first sense the medium and transmit only if the medium is sensed to be idle, also called

clear channel assessment (CCA). The CCA utilizes at least energy detection (ED) to determine the presence of signals on a channel. With the adoption of LBT, both the UE and the eNodeB may perform a LBT procedure prior to transmitting their respective messages associated with the RACH, which may add large amount of delay to the random access procedure, and may limit UL transmissions.

[0015] FIG. 1 illustrates a wireless telecommunications network 100 to perform a low latency random access (RA) procedure in accordance with some embodiments of the disclosure. In some embodiments, the wireless telecommunications network 100 may implement 3rd Generation partnership Project (3GPP) fifth generation (5G) wireless network or 3rd Generation partnership Project (3GPP) long term evolution advanced (LTE-A) wireless network.

[0016] The illustrative telecommunications network includes an evolved Node B (eNodeB) 120 is are operable over corresponding a coverage area or cell 122, and a 104 within the coverage area of the cell 122. The telecommunications network 100 may include many more eNodeBs and/or UEs. The coverage area 122 of the eNodeB 120 may be further divided into three sectors. In some examples, each sector of the eNodeB 120 may also be viewed as a cell.

[0017] The UE 170 may provide transmissions to and receive transmissions from the eNodeB 120 in a licensed spectrum, an unlicensed spectrum, or combinations thereof. Operation in both the licensed spectrum and the unlicensed spectrum may include dual connectivity (DC). Operation in only the unlicensed spectrum may use MuLTEfire. In some examples, operation in the unlicensed spectrum may be via LAA, which may expand available bandwidth by utilizing a flexible carrier aggregation (CA) framework. To ensure coexistence with incumbent systems and other LAA/MuLTEfire systems, transmission in the unlicensed spectrum may include performing a LBT procedure, and holding transmission until completing CCA and sensing channel to be idle.

[0018] In operation, the wireless telecommunications network 100 may include a capability for the eNodeB 120 and the UE 104 to communicate over unlicensed spectrum. In order to provide UL data to the eNodeB 120, the UE 104 may initiate a SR that includes a PRACH signal transmission. In addition to the SR, the PRACH signal may be used for uplink (UL) synchronization and power

control for initial UL transmission. Because of implementation of LBT, the RA procedure may incur a large latency and may limit UL transmissions.

[0019] In one embodiment to support a low latency RA procedure in the unlicensed spectrum, the UE 104 and the eNodeB 120 may support a low latency two-step RA procedure (e.g., aside from the LBT procedures). In a first step of the low latency two-step RA procedure, in response to a CCA indicating a channel is idle (e.g., from LBT procedure), the UE 104 may provide a first transmission over allocated PRACH resources. In one example, the first transmission may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), buffer status report (BSR) information, capability of the UE 104, and Message 3, which may include an identity of the UE 104. In some examples, the message part may also include a common control channel (CCCH) subheader. The message part may include a medium access control (MAC) part containing the possible C-RNTI, BRS information, and layer 1(L1)/MAC UE capability and a radio resource control (RRC) part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity may be included in the MAC part.

[0020] Responsive to receipt of the first transmission, the eNodeB 120 may provide a second transmission that includes a RAR and/or a Message 4 that is scheduled via a physical downlink control channel (PDCCH) or an evolved PDCCH (ePDCCH) using one of the C-RNTI received from the UE 104 in the first transmission or a common random access RNTI (RA-RNTI) calculated based on time –frequency resources use by the preamble of the first transmission.

[0021] The C-RNTI or the RA-RNTI included in the second transmission may be based on a contention resolution result by the eNodeB 120. The contention resolution may be performed based on one of the PDCCH/ePDCCH or on either the MAC or RRC part (e.g., whichever was provided by the UE 104 in the first transmission). If based on the PDCCH/ePDCCH, contention resolution may be considered successful if the PDCCH/ePDCCH contains the assigned C-RNTI of the UE's. If based on the MAC part, contention resolution may be considered successful if the MAC part contains the assigned C-RNTI of the UE 104 or the UE 104 identity provided in the first transmission. If based on the RRC part, contention resolution may be considered successful if the RRC message of the

RRC part provided in the first transmission included the UE 104 identity provided in the first transmission.

[0022] The UL grant allocation may be included a message part of the RAR, the PDCCH/ePDCCH with the assigned C-RNTI of the UE 104, or the PDCCH/ePDCCH with the assigned RA-RNTI. If included in the PDCCH/ePDCCH with the assigned C-RNTI of the UE 104, the UE 104 may decode the downlink (DL) control information (DCI) for scheduling RAR/message 4 as well as UL grant masked with the assigned C-RNTI of the UE 104. If included in the PDCCH/ePDCCH with the RA-RNTI, the UE 104 may decode the DL grant for scheduling RAR/message 4 as well as UL grant for scheduling PUSCH masked with the assigned RA-RNTI.

[0023] In another embodiment to support a low latency RA procedure in the unlicensed spectrum, the UE 104 and the eNodeB 120 may support a low latency single-step RA procedure (e.g., aside from the LBT procedure). In a first step of the low latency single-step RA procedure, in response to a CCA indicating that a channel idle (e.g., from LBT procedure), the UE 104 may provide a first transmission over allocated PRACH resources. The first transmission may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), BSR information, a CCCH subheader, and/or Message 3, which may include an identity of the UE 104 (e.g., may be used for contention resolution). The message part may include a medium access control (MAC) part containing the C-RNTI, BRS information, CCCH subheader, layer 1(L1)/MAC UE capability, and/or a RRC part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity for contention resolution may be included in the MAC part. The first transmission may use a physical uplink control channel (PUCCH) waveform, where a first portion (e.g., n symbols) may be used for the PRACH preamble and a remaining portion (e.g., remaining m symbols) may be used for the message part. The duration of low latency PUCCH (sPUCCH) may be up to 4 symbols. The sPUCCH may have an interlace structure, with 10 physical resource blocks (PRBs)/interlaces in a 20 MHz system. One or multiple interlaces may be allocated to the UE 104 for UL transmission.

[0024] If a UL grant is received within a predetermined amount of time (e.g., within k subframes or before a MAC contention resolution timer for the C-

RNTI (indicating successful contention resolution) has expired), the UE 104 may transmit UL data normally. The UL grant may be included in a message scheduled via the PDCCH/ePDCCH with the C-RNTI received from the UE 104 for the UL grant. Otherwise, the UE 104 may transmit another first transmission with a new random preamble index at a configured PRACH subframe. The time window of k subframes may be counted in terms of absolute time (e.g., key management service (KMS) time) or in terms of a valid DL subframe (e.g., the subframe with a DL transmission).

[0025] For the first transmission by the UE 104 in either the 2-step RA procedure or the single-step RA procedure, the first N symbols may be used to transmit the PRACH preamble. The PRACH preamble may also be used for channel estimation after detection. The remaining M symbols may be used for data transmission (e.g., C-RNTI, BSR information, CCCH subheader, Message 3, etc.). For example, N and M may be equal to 2 when the first step PRACH transmission is on sPUCCH resources, which is the last 4 SC-FDMA symbols of a special subframe. If one interlace is allocated for the first transmission, in 20MHz systems, there are 20 PRBs available over the 2 symbols for data transmission. With quadrature phase-shift keying (QPSK) modulation, each interlace may carry up to 480 bits. In one example, a required payload size for initial access and BSR is 56 bits, with additional 24 cyclic redundancy check (CRC) bits. With a code rate of 1/3, a count of coded bits may be 240, which is much smaller than the 480 bits. If the payload size increases beyond the 480 bits, additional interlaces may be assigned to the UE 104 or the coding rate may be reduce to allow higher density transmissions.

[0026] When four symbols are needed for the PRACH preamble over the PUCCH resource, a physical uplink shared channel (PUSCH) subframe following the PUCCH resource may be used to carry the message part of the first transmission (e.g., the C-RNTI, the BSR information, CCCH subheader, and Message3). One or multiple interlaces of the PUSCH subframe may be allocated for the first transmission, and multiple UEs may be multiplexed in frequency domain and/or code domain. To reduce a collision probability, fewer users may be assigned to transmit over the PUSCH subframe. The PRACH preamble sequence may be used for channel estimation. The same structure as regular

PUSCH transmission can be used, where the demodulation reference signal (DMRS) symbols may be used for channel estimation. If the message part of the first transmission (e.g., the C-RNTI, BSR information, Message 3, and CCCH subheader) that is transmitted simultaneously over the allocated PRACH resources cannot be correctly detected, but the PRACH preamble sequence is
5 correctly detected, the two-step/single-step PRACH may fall back to a legacy RA procedure.

[0027] In systems where the eNodeB 120 and the UE 104 support more than one RA procedure (e.g., a combination of the legacy RA procedure, the two-
10 step RA procedure, and the single step RA procedures), the eNodeB 120 and/or the UE 104 may indicate which methods they support or intend to use. In a UE-specific example, the eNodeB 120 may indicate to the UE 104 which of the RA procedures to use while the UE 104 is in RRC-Connected mode.

[0028] In a cell-specific procedure, the eNodeB 120 may indicate (e.g.,
15 via RRC signaling) which of the legacy, two-step, and/or single step RA procedures it supports, and the UE 104 may determine which RA procedure to use. One example of a method to indicate the selected RA procedure to the eNodeB 120 by the UE 104 may include use of PRACH preamble signatures associated with the selected RA procedure. For example, the eNodeB 120 may
20 designate a specific set of preamble signatures for each supported RA procedure. The UE 104 may use a preamble signal of the set of preamble signatures associated with the selected RA procedure, and the eNodeB 120 may detect the selected RA procedure by detecting the preamble signature.

[0029] Another example of a method to indicate the selected RA
25 procedure to the eNodeB 120 by the UE 104 may include use of a specific resources (e.g., time or frequency subcarriers) associated with the selected RA procedure. For example, the eNodeB 120 may designate a specific set of resources for each supported RA procedure. The UE 104 may use resources from the set of resources associated with the selected RA procedure, and the eNodeB 120 may
30 detect the selected RA procedure by the resources on which a Message 1 is transmitted.

[0030] The eNodeB 120 may provide an indication to the UE 104 a selected RA procedure in a master information block (MIB). The eNodeB 120

may set the PRACH indication in the MIB to a specific value associated with the selected or supported RA procedures. In one example, the eNodeB 120 may indicate the selected RA procedure by setting of one or more reserved bits in a payload of the MIB block, or an additional bit or bits in an updated MIB payload to a specific value associated with the selected RA procedure.

[0031] Another example of a method the eNodeB 120 may provide an indication of the selected or supported RA procedures to the UE 104 in a system information block (SIB) or an extended SIB (eSIB). The eNodeB 120 may set the selected RA procedure indication in the SIB/eSIB to a specific value associated with the selected RA procedure, and the UE device 200 may detect the selected RA procedure based on the selected RA procedure indication in the SIB/eSIB. . In one example, a PRACH configuration index parameter of a SIB2/eSIB2 may be extended to include support for one or both of the two-step and single step RA procedures. The eNodeB 120 may indicate the selected RA procedure by setting the extended PRACH configuration index parameter in the SIB2/eSIB2 to a specific value associated with the selected RA procedure. In another example, a new parameter may be added to a SIB/eSIB (e.g., in a PRACH configuration field of the SIB2/eSIB2) for one or both of the two-step and single step RA procedures. The eNodeB 120 may indicate the selected RA procedure by setting a parameter associated with the selected RA procedure in the PRACH configuration field of the SIB2/eSIB2.

[0032] Another example may include providing the indication of the selected RA procedure in higher layer signaling (e.g., RRC signaling). In one example, while the UE 104 is in RRC_CONNECTED mode, the RRC signaling may configure the RA procedure type for the UE 104. This indication method may be limited to the cases where the UE 104 has completed an initial access, and may not be applicable to an indication of the selected RA procedure used for initial access. For example, this selected PRACH indication method may be used when the UE 104 is in RRC_CONNECTED mode and needs to perform the selected RA procedure for UL synchronization and/or scheduling request. This selected PRACH indication method may also be used in a handover case when contention-based PRACH has been issued. This selected PRACH indication method may also be used an RRC reconnected in which the UE 104 attempts to recover from a radio

link failure.

[0033] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 2 illustrates a block diagram of components of a User Equipment (UE) device 200 according to embodiments of the disclosure. The UE 200 may be implemented in the UE 104 of FIG. 1. In some embodiments, the UE device 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208 and one or more antennas 210, coupled together at least as shown.

[0034] The application circuitry 202 may include one or more application processors. For example, the application circuitry 202 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0035] The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 204 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuitry 204 may interface with the application circuitry 202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, and/or other baseband processor(s) 204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. 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 204 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include convolution, tail-biting convolution, turbo, Viterbi, and/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.

10 **[0036]** In some embodiments, the baseband circuitry 204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 204e of the baseband circuitry 204 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 204f. The audio DSP(s) 204f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 204 and the application circuitry 202 may be implemented together such as, for example, on a system on a chip (SOC).

25 **[0037]** In some embodiments, the baseband circuitry 204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 204 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0038] RF circuitry 206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 206 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 208 and provide baseband signals to the baseband circuitry 204. RF circuitry 206 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 204 and provide RF output signals to the FEM circuitry 208 for transmission.

[0039] In some embodiments, the RF circuitry 206 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 206 may include mixer circuitry 206a, amplifier circuitry 206b and filter circuitry 206c. The transmit signal path of the RF circuitry 206 may include filter circuitry 206c and mixer circuitry 206a. RF circuitry 206 may also include synthesizer circuitry 206d for synthesizing a frequency for use by the mixer circuitry 206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 208 based on the synthesized frequency provided by synthesizer circuitry 206d. The amplifier circuitry 206b may be configured to amplify the down-converted signals and the filter circuitry 206c 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 204 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 206a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0040] In some embodiments, the mixer circuitry 206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 206d to generate RF output signals for the FEM circuitry 208. The baseband signals may be provided

by the baseband circuitry 204 and may be filtered by filter circuitry 206c. The filter circuitry 206c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

5 [0041] In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley
10 image rejection). In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

15 [0042] 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 206 may include analog-
20 to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 204 may include a digital baseband interface to communicate with the RF circuitry 206.

[0043] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the
25 embodiments is not limited in this respect.

[0044] In some embodiments, the synthesizer circuitry 206d 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 206d may be a
30 delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0045] The synthesizer circuitry 206d may be configured to synthesize an output frequency for use by the mixer circuitry 206a of the RF circuitry 206 based

on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 206d may be a fractional $N/N+1$ synthesizer.

[0046] 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 204 or the applications processor 202 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 applications processor 202.

[0047] Synthesizer circuitry 206d of the RF circuitry 206 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.

[0048] In some embodiments, synthesizer circuitry 206d 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 (fLO). In some embodiments, the RF circuitry 206 may include an IQ/polar converter. In some embodiments, the RF circuitry 206 may include a MIMO transceiver.

[0049] FEM circuitry 208 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 210, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry

208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 206 for transmission by one or more of the one or more antennas 210.

[0050] In some embodiments, the FEM circuitry 208 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 210).

[0051] In some embodiments, the UE device 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[0052] In operation, the UE device 200 may communicate over both licensed spectrum and unlicensed spectrum (e.g., via the baseband circuitry 204, the RF circuitry 206, and the FEM circuitry 208). In some examples, the UE device 200 may support contemporaneous transmission over the licensed spectrum (e.g., PCell) and the unlicensed spectrum (e.g., SCell). In order to provide UL data to the eNodeB, the UE device 200 may initiate a SR via a PRACH signal transmission (e.g., via the FEM circuitry 208). In addition to the SR, the PRACH signal may be used for uplink (UL) synchronization and power control for initial UL transmission. Because of implementation of LBT, the RA procedure may incur a large latency and may limit UL transmissions. It is understood that the LBT procedure and PRACH transmissions may be performed by at least a combination of the baseband circuitry 204, the RF circuitry 206, and the FEM circuitry 208.

[0053] In one embodiment to support RA procedure a low latency RA procedure in the unlicensed spectrum, the UE device 200 may support a low latency two-step RA procedure (e.g., aside from the LBT procedures). In a first step of the low latency two-step RA procedure, in response to a CCA indicating the channel is idle (e.g., from LBT procedure), the UE device 200 may provide a

first transmission over allocated PRACH resources. In one example, the first transmission may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), BSR information, capability of the UE device 200, and Message 3, which may include an identity of the UE device 200 (e.g., may be used for contention resolution). In some examples, the message part may also include a CCCH subheader. The message part may include a MAC part containing the possible C-RNTI, BRS information, and L1/MAC UE capability and a RRC part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity used for contention resolution may be included in the MAC part. In a second step, the UE device 200 may receive a second transmission that includes a RAR and/or a Message 4 that is scheduled via the PDCCH/ePDCCH using one of the C-RNTI received from the UE 104 in the first transmission or a common random access RNTI (RA-RNTI) calculated based on time –frequency resources use by the preamble of the first transmission.

[0054] The UL grant allocation may be included a message part of the RAR, the PDCCH/ePDCCH with the assigned C-RNTI of the UE device 200, or the PDCCH/ePDCCH with the assigned RA-RNTI. If included in the PDCCH/ePDCCH with the assigned C-RNTI of the UE device 200, the UE device 200 may decode the downlink DL DCI for scheduling RAR/message 4 as well as UL grant masked with the assigned C-RNTI of the UE device 200. If included in the PDCCH/ePDCCH with the RA-RNTI, the UE device 200 may decode the DL grant for scheduling RAR/message 4 as well as UL grant for scheduling PUSCH masked with the assigned RA-RNTI.

[0055] In another embodiment to support RA procedure a low latency RA procedure in the unlicensed spectrum, the UE device 200 may support a low latency single-step RA procedure (e.g., aside from the LBT procedure). For example, in response to a CCA indicating that the channel is idle (e.g., from LBT procedure), the UE device 200 may provide a first transmission over allocated PRACH resources. The first transmission may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), BSR information, a CCCH subheader, and Message 3, which may include an identity of the UE device 200 (e.g., may be used for contention resolution at the eNodeB). The message part may include a medium access control (MAC) part containing

the temporary C-RNTI, BRS information, CCCH subheader, and layer 1(L1)/MAC UE capability, and a RRC part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity for contention resolution may be included in the MAC part. The first transmission may use a physical uplink control channel (PUCCH) waveform, where the first n symbols may be used for the PRACH preamble and the remaining m symbols may be used for data (e.g., BSR, Message3) transmission. The duration of sPUCCH may be up to 4 symbols. The sPUCCH may have an interlace structure, with 10 physical resource blocks (PRBs)/interlaces in a 20 MHz system. One or multiple interlaces may be allocated to the UE device 200 for UL transmission.

[0056] If a UL grant is received within a predetermined amount of time (e.g., within k subframes or before a MAC contention resolution timer for the C-RNTI (indicating successful contention resolution) has expired), the UE device 200 may transmit UL data normally. The UL grant may be included in a message scheduled via the PDCCH/ePDCCH with the C-RNTI received from the UE device 200 for the UL grant. Otherwise, the UE device 200 may transmit another first transmission with a new random preamble index at a configured PRACH subframe. The time window of k subframes may be counted in terms of absolute time (e.g., key management service (KMS) time) or in terms of a valid DL subframe (e.g., the subframe with a DL transmission).

[0057] For the first transmission by the UE device 200 in either the 2-step procedure or the single procedure, the first N symbols may be used to transmit the PRACH preamble. The PRACH preamble may also be used for channel estimation after detection. The remaining M symbols may be used for data transmission (e.g., C-RNTI, BSR information, CCCH subheader, Message 3, etc.). In one embodiment, N and M may be equal to 2 when PRACH is transmitted over sPUCCH resource, which may occupy the last 4 SC-FDMA symbols of a special subframe. If the payload size increases beyond available payload for a single interlace, additional interlaces may be assigned to the UE device 200 or the coding rate may be reduced to allow higher density transmissions.

[0058] When four symbols are needed for the PRACH preamble over the PUCCH, a physical uplink shared channel (PUSCH) subframe following the PUCCH may be used to carry the message part of the first transmission (e.g., the

C-RNTI, the BSR information, CCCH subheader, and Message3). One or multiple interlaces of the PUSCH subframe may be allocated for the first transmission, and multiple UEs may be multiplexed in frequency domain and/or code domain. To reduce a collision probability, fewer users may be assigned to transmit over the PUSCH subframe. The PRACH preamble sequence may be used for channel estimation. The same structure as regular PUSCH transmission can be used, where the demodulation reference signal (DMRS) symbols may be used for channel estimation. If the message part of the first transmission (e.g., the C-RNTI, BSR information, Message 3, and CCCH subheader) that is transmitted simultaneously over the allocated PRACH resources cannot be correctly detected, but the PRACH preamble sequence is correctly detected, the two-step/single-step PRACH may fall back to a legacy RA procedure.

[0059] In systems where the UE device 200 supports more than one RA procedure (e.g., a combination of the legacy RA procedure, the two-step RA procedure, and the single step RA procedures), the eNodeB and/or the UE device 200 may indicate which methods they support or intend to use. In a UE-specific example, the UE device 200 may receive assignment of a RA procedure from the eNodeB while the UE device 200 is in the RRC mode.

[0060] In a cell-specific procedure, the UE device 200 may receive, from the eNodeB, an indication of which of the legacy, two-step, and/or single step RA procedures are supported by the eNodeB, and the UE device 200 may determine which RA procedure to use. One example of a method to indicate the selected RA procedure to the eNodeB by the UE device 200 may include use of PRACH preamble signatures associated with the selected RA procedure. For example, the eNodeB may designate a specific set of preamble signatures for each supported RA procedure. The UE device 200 may use a preamble signal of the set of preamble signatures associated with the selected RA procedure, and the eNodeB may detect the selected RA procedure by detecting the preamble signature.

[0061] The UE device 200 may receive the indication of the selected RA procedure in a master information block (MIB). The eNodeB may set the PRACH indication in the MIB to a specific value associated with the selected or supported RA procedures. In one example, the eNodeB 120 may indicate the selected RA procedure by setting of one or more reserved bits in a payload of the MIB block,

or an additional bit or bits in an updated MIB block payload to a specific value associated with the selected RA procedure.

[0062] Another example of a method for the UE device 200 to receive the indication of the selected or supported RA procedures is in a system information block (SIB) or an extended SIB (eSIB). The eNodeB may set the selected RA procedure indication in the SIB/eSIB to a specific value associated with the selected RA procedure, and the UE device 200 may detect the selected RA procedure based on the selected RA procedure indication in the SIB/eSIB. In one example, a PRACH configuration index parameter of a SIB2/eSIB2 may be extended to include support for one or both of the two-step and single step RA procedures. The eNodeB may indicate the selected RA procedure by setting the extended PRACH configuration index parameter in the SIB2/eSIB2 to a specific value associated with the selected RA procedure. In another example, a new parameter may be added to a SIB/eSIB (e.g., in a PRACH configuration field of the SIB2/eSIB2) for one or both of the two-step and single step RA procedures. The eNodeB may indicate the selected RA procedure by setting a parameter associated with the selected RA procedure in the PRACH configuration field of the SIB2/eSIB2.

[0063] Another example of a method to indicate the selected RA procedure to the eNodeB by the UE device 200 may include a selected RA procedure indication (e.g., extension of PRACH configuration parameter or additional parameters in PRACH configuration field of SIB2/eSIB2) associated with the SIB/eSIB.

[0064] Another example may include providing the indication of the selected RA procedure in higher layer signaling (e.g., RRC signaling). In one example, while the UE device 200 is in RRC_CONNECTED mode, the RRC signaling may configure the RA procedure type for the UE device 200. This indication method may be limited to the cases where the UE device 200 has completed an initial access, and may not be applicable to an indication of the selected RA procedure used for initial access.

[0065] FIG. 3 illustrates a signal diagram 300 for a low latency two-step RA procedure in accordance with some embodiments of the disclosure. In an example, the low latency two-step RA procedure may be setup between a UE 304

and an eNodeB 320. The UE 304 may be implemented in the UE 104 of FIG. 1, the UE device 200 of FIG. 2, or combinations thereof. The eNodeB 320 may be implemented in the eNodeB 120 of FIG. 1.

[0066] The UE 304 may communicate with the eNodeB using unlicensed spectrum. Initially, the UE 304 may perform a LBT procedure. In response to a CCA, the UE 304 may provide a first transmission [1] to the UE 304. In one example, the first transmission [1] may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), buffer status report (BSR) information, capability of the UE 304, and Message 3, which may include an identity of the UE 304 (e.g., may be used for contention resolution). In some examples, the message part may also include a common control channel (CCCH) subheader. The message part may include a medium access control (MAC) part containing the possible C-RNTI, BRS information, and layer 1(L1)/MAC UE capability and a radio resource control (RRC) part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity used for contention resolution may be included in the MAC part.

[0067] In a second step, in response to a CCA (e.g., from LBT procedure), the eNodeB 320 may provide a second transmission [2] that includes a RAR and/or a Message 4 that is scheduled via a PDCCH/ePDCCH using C-RNTI received from the UE 304 in the first transmission or a common random access RNTI (RA-RNTI) calculated based on time –frequency resources use by the preamble of the first transmission.

[0068] Contention resolution may be performed based on one of PDCCH/ePDCCH or on either the MAC or RRC part (e.g., whichever was provided by the UE 304 in the first transmission). If based on the PDCCH/ePDCCH, contention resolution may be considered successful if the PDCCH/ePDCCH contains the assigned C-RNTI of the UE's. If based on the MAC part, contention resolution may be considered successful if the MAC part contains the assigned C-RNTI of the UE 304 or the UE 304 identity provided in the first transmission. If based on the RRC part, contention resolution may be considered successful if the RRC message of the RRC part provided in the first transmission included the assigned C-RNTI of the UE 304 or the UE 304 identity provided in the first transmission.

[0069] The UL grant allocation may be included a message part of the RAR, the PDCCH/ePDCCH with the assigned C-RNTI of the UE 304, or the PDCCH/ePDCCH with the assigned RA-RNTI. If included in the PDCCH/ePDCCH with the assigned C-RNTI of the UE 304, the UE 304 may
5 decode the downlink DL DCI for scheduling RAR/message 4 as well as UL grant masked with the assigned C-RNTI of the UE 304. If included in the PDCCH/ePDCCH with the RA-RNTI, the UE 304 may decode the DL grant for scheduling RAR/message 4 as well as UL grant for scheduling PUSCH masked with the assigned RA-RNTI.

10 [0070] FIG. 4A illustrates a signal diagram 400 for a failed low latency single-step RA procedure in accordance with some embodiments of the disclosure. FIG. 4B illustrates a signal diagram 401 for a successful low latency single-step RA procedure in accordance with some embodiments of the disclosure. In an example, the low latency single-step RA procedure may be setup between a UE
15 404 and an eNodeB 420. The UE 404 may be implemented in the UE 104 of FIG. 1, the UE device 200 of FIG. 2, or combinations thereof. The eNodeB 420 may be implemented in the eNodeB 120 of FIG. 1.

[0071] The UE 404 may communicate with the eNodeB using unlicensed spectrum. Initially, the UE 404 may perform a LBT procedure. In response to a
20 CCA, the UE 404 may provide a first transmission [1] over allocated PRACH resources. The first transmission may include a PRACH preamble with a message part that includes a C-RNTI (e.g., temporary or assigned), BSR information, a CCCH subheader, and Message 3, which may include an identity of the UE 404 (e.g., may be used for contention resolution). The message part may include a
25 MAC part containing the temporary C-RNTI, BRS information, CCCH subheader, and L1/MAC UE capability, and a RRC part containing a RRC message with the UE identity for contention resolution. Alternatively, the UE identity for contention resolution may be included in the MAC part. The first transmission may use a PUCCH waveform, where the first n symbols may be used
30 for the PRACH preamble and the remaining m symbols may be used for data (e.g., BSR, Message3) transmission. The duration of the sPUCCH may be up to 4 symbols. The sPUCCH may have an interlace structure, with 10 physical resource blocks (PRBs)/interlaces in a 20 MHz system. One or multiple interlaces may be

allocated to the UE 404 for UL transmission.

[0072] Contention resolution may be performed based on one of PDCCH/ePDCCH or on either the MAC or RRC part (e.g., whichever was provided by the UE 404 in the first transmission). If based on the PDCCH/ePDCCH, contention resolution may be considered successful if the PDCCH/ePDCCH contains the assigned C-RNTI of the UE's. If based on the MAC part, contention resolution may be considered successful if the MAC part contains the assigned C-RNTI of the UE 404 or the UE 404 identity provided in the first transmission. If based on the RRC part, contention resolution may be considered successful if the RRC message of the RRC part provided in the first transmission included the assigned C-RNTI of the UE 404 or the UE 404 identity provided in the first transmission.

[0073] The UL grant allocation may be included a message part of the RAR, the PDCCH/ePDCCH with the assigned C-RNTI of the UE 404, or the PDCCH/ePDCCH with the assigned RA-RNTI. If included in the PDCCH/ePDCCH with the assigned C-RNTI of the UE 404, the UE 404 may decode the downlink DL DCI for scheduling RAR/message 4 as well as UL grant masked with the assigned C-RNTI of the UE 404. If included in the PDCCH/ePDCCH with the RA-RNTI, the UE 404 may decode the DL grant for scheduling RAR/message 4 as well as UL grant for scheduling PUSCH masked with the assigned RA-RNTI.

[0074] If a UL grant is received within a predetermined amount of time (e.g., within k subframes or before a MAC contention resolution timer for the C-RNTI (indicating successful contention resolution) has expired), the UE 404 may transmit UL data normally. The UL grant may be included in a message scheduled via the PDCCH/ePDCCH with the C-RNTI received from the UE 104 for the UL grant. Otherwise, the UE 104 may transmit another first transmission [4], as shown in signal diagram 400, with a new random preamble index at a configured PRACH subframe. The time window of k subframes may be counted in terms of absolute time (e.g., key management service (KMS) time) or in terms of a valid DL subframe (e.g., the subframe with a DL transmission).

[0075] FIG. 5 illustrates a flow diagram of a method 500 to perform a low latency RA procedure in accordance with some embodiments of the disclosure.

The method 500 may be implemented in any of the UE 104 of FIG. 1, the UE device 200 of FIG. 2, the UE 304 of FIG. 3, the UE 304 of FIG. 3, or combinations thereof.

[0076] The method 500 may include performing a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum, at 510.

[0077] The method 500 may further include in response to a clear channel assessment (CCA), encode a first message for a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum, at 520. The first message may include a PRACH preamble and a message part. The message part may include at least one of a C-RNTI, BSR information, capability of the UE, and an identity of the UE. In some examples, the message part includes a MAC part that includes a MAC message. The MAC message may include at least one of the C-RNTI, the BSR information, and the capability of the UE. The MAC message may further include the identity of the UE. In some examples, the message part may further include a RRC part that includes a RRC message. The RRC message may include the identity of the UE. The capability of the UE may include one of a layer 1 UE capability or MAC UE capability. The message part may further include a CCCH subheader. The first transmission may a shortened physical uplink control channel (sPUCCH) waveform, where a first portion includes the PRACH preamble and a remaining portion includes the message part. In some examples, the first portion includes a first two symbols of Message 3 and the remaining portion includes a next two symbols after the first two symbols of the Message 3.

[0078] In some examples, the first message may be encoded based on receipt of an indication that a serving eNodeB (e.g., the eNodeB 120 of FIG. 1, the eNodeB 420 of FIG. 4, and/or the eNodeB 520 of FIG. 5) supports or has selected the low-latency RA procedure (e.g., via the MIB, SIB/eSIB, or RRC signaling).

[0079] The method 500 may further include decoding a second message received in a second transmission associated with the low latency RA procedure scheduled via a physical downlink control channel (PDCCH). The second message may include a physical downlink shared channel (PDSCH) transmission including the UL grant and at least one of a random access response or a Message

4. In some examples, DCI used to schedule the second message is scrambled via one of the C-RNTI or a RA-RNTI.

[0080] The low-latency RA procedure may further include in response to receipt of the UL grant based on the first transmission, schedule an UL transmission.

5 [0081] The method may further include, in response to lack of receipt of the UL grant based on the first transmission within a predetermined length of time after the first transmission, encode a second message for a second transmission on the unlicensed spectrum. The second message may include a second PRACH preamble and the message part. The predetermined length of time may be based
10 on one of an absolute time, a count of valid downlink subframe, or a MAC contention resolution timer. The method 500 may further include, in response to receipt of an uplink (UL) grant based on the first step of low-latency RA procedure, encode UL data for transmission, at 530.

[0082] FIG. 6 illustrates a flow diagram of a method 600 to perform a low
15 latency RA procedure in accordance with some embodiments of the disclosure. The method 600 may be implemented in any of the UE 104 of FIG. 1, the UE device 200 of FIG. 2, the UE 304 of FIG. 3, the UE 404 of FIG. 4, or combinations thereof.

[0083] The method 600 may include receiving an indication that a serving
20 eNodeB supports a low-latency RA procedure and a legacy RA procedure, at 610.

[0084] The method 600 may further include encode a first message for a first transmission associated with the low latency RA procedure that includes a PRACH preamble and a message part, at 620. The message 600 may further include providing an indication of selection of the low-latency RA procedure to
25 the serving eNodeB. In some examples, providing the indication may include selecting a preamble a set of PRACH preambles designated for the low-latency RA procedure. In some examples, providing the indication may include selecting time and/or frequency resources for PRACH preamble transmission. The time and/or frequency resources may be dedicated for the low-latency RA procedure.
30 The method 600 may further include receiving the time and/or frequency resources dedicated for PRACH preamble transmission from the serving eNodeB.

[0085] In some examples, the method 600 may include receiving an indication of selection of the low-latency RA procedure from the serving eNodeB. In some

examples, the method 600 may include receiving an indication of selection of the low-latency RA procedure from the serving eNodeB. For example, receiving the indication of selection of the low-latency RA procedure from the serving eNodeB may include determining selection of the low latency RA procedure based on a PRACH_ConfigIndex parameter in a system information block 2 (SIB2) or an extended SIB2 (eSIB2). In another example, receiving the indication of selection of the low-latency RA procedure from the serving eNodeB may include determining selection of the low latency RA procedure based on a PRACH configuration field in a SIB2 or an eSIB2. In some examples, receiving the indication of selection of the low-latency RA procedure from the serving eNodeB may include determining selection of the low latency RA procedure based on a value of one or more reserved bits in a master information block. In some examples, receiving the indication of selection of the low-latency RA procedure from the serving eNodeB may include receiving the selected RA procedure in radio resource control signaling.

[0086] FIG. 7 illustrates a flow diagram of a method 700 to perform a low latency RA procedure in accordance with some embodiments of the disclosure. The method 700 may be implemented in any of the eNodeB 120 of FIG. 1, the eNodeB 320 of FIG. 3, the eNodeB 420 of FIG. 4, or combinations thereof.

[0087] The method 700 may include decoding a first message received in a first transmission associated with a low latency RA procedure on the unlicensed spectrum from a UE, at 710. The first message may include a PRACH preamble and a message part. The message part may include at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, or an identity of the UE. The message part may include a medium access control (MAC) part that includes a MAC message. The MAC message may include at least one of the C-RNTI, the BSR information, or the capability of the UE, wherein to perform contention resolution comprises the processing circuitry to determine if the MAC part includes the C-RNTI. In some examples, the message part may further include a radio resource control (RRC) part that includes a RRC message. The RRC message may include the identity of the UE. In some examples, the message party may further include a common control channel (CCCH) subheader.

[0088] The method 700 may further include performing a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum, at 720. The method 700 may further include, in response to a clear channel assessment, encode a second message for a second transmission associated with the low latency RA procedure, at 730. The second message may include at least one of a RAR or a Message 4. The second message may be at least one of scheduled via a physical downlink control channel (PDCCH) or includes an uplink (UL) grant. In some examples, the second message PDSCH may be scheduled via downlink control information (DCI) that is scrambled by one of the C-RNTI or a random access RNTI (RA-RNTI).

[0089] In some examples, the method 700 may further include determining selection of the low-latency RA procedure by the UE based on a comparison of the PRACH preamble with a set of PRACH preambles designated for the low-latency RA procedure. In some examples, determining selection of the low-latency RA procedure may include determining selection based on a set of time and/or frequency resources used for the first transmission. In some examples, the method 700 may further include indicating selection of the low latency RA procedures by based on one or more bits in the master information block or the system information blocks.

[0090] FIG. 8 illustrates generally an example of a block diagram of a machine 800 upon which any one or more of the techniques (e.g., methodologies) discussed herein can perform in accordance with some embodiments. In alternative embodiments, the machine 800 can operate as a standalone device or can be connected (e.g., networked) to other machines. In a networked deployment, the machine 800 can operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 800 can act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 800 can be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or

jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0091] Examples, as described herein, can include, or can operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations when operating. A module includes hardware. In an example, the hardware can be specifically configured to carry out a specific operation (e.g., hardwired). In an example, the hardware can include configurable execution units (e.g., transistors, circuits, etc.) and a computer readable medium containing instructions, where the instructions configure the execution units to carry out a specific operation when in operation. The configuring can occur under the direction of the executions units or a loading mechanism. Accordingly, the execution units are communicatively coupled to the computer readable medium when the device is operating. In this example, the execution units can be a member of more than one module. For example, under operation, the execution units can be configured by a first set of instructions to implement a first module at one point in time and reconfigured by a second set of instructions to implement a second module.

[0092] Machine (e.g., computer system) 800 can include a hardware processor 802 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 804 and a static memory 806, some or all of which can communicate with each other via an interlink (e.g., bus) 808. The machine 800 can further include a display unit 810, an alphanumeric input device 812 (e.g., a keyboard), and a user interface (UI) navigation device 814 (e.g., a mouse). In an example, the display unit 810, alphanumeric input device 812 and UI navigation device 814 can be a touch screen display. The machine 800 can additionally include a storage device (e.g., drive unit) 816, a signal generation device 818 (e.g., a speaker), a network interface device 820, and one or more sensors 821, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 800 can include an output controller 828, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more

peripheral devices (e.g., a printer, card reader, etc.).

[0093] The storage device 816 can include a machine readable medium 822 that is non-transitory on which is stored one or more sets of data structures or instructions 824 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 824 can also reside, completely or at least partially, within the main memory 804, within static memory 806, or within the hardware processor 802 during execution thereof by the machine 800. In an example, one or any combination of the hardware processor 802, the main memory 804, the static memory 806, or the storage device 816 can constitute machine readable media.

[0094] While the machine readable medium 822 is illustrated as a single medium, the term "machine readable medium" can include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 824.

[0095] The term "machine readable medium" can include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 800 and that cause the machine 800 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples can include solid-state memories, and optical and magnetic media. In an example, a massed machine readable medium comprises a machine readable medium with a plurality of particles having invariant (e.g., rest) mass. Accordingly, massed machine-readable media are not transitory propagating signals. Specific examples of massed machine readable media can include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

[0096] The instructions 824 can further be transmitted or received over a communications network 826 using a transmission medium via the network interface device 820 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user

datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks can include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®, IEEE 802.15.4 family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 820 can include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 826. In an example, the network interface device 820 can include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 800, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0097] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[0098] In some embodiments, the UE device 1000 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

30

Additional Notes & Examples:

[0099] Example 1 is an apparatus of User Equipment (UE), the apparatus comprising: memory; and processing circuitry, the processing circuitry to:

perform a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; and in response to a clear channel assessment (CCA), encode a first message for a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum, wherein the first
5 message includes at least one of a PRACH preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, and/or an identity of the UE; and in response to receipt of an uplink (UL) grant based on the first step of low-latency RA procedure, encode UL data for transmission.

10 **[00100]** In Example 2, the subject matter of Example 1 optionally includes wherein the message part includes a medium access control (MAC) part that includes at least one of a MAC message, wherein the MAC message includes at least one of the C-RNTI, the BSR information, or the capability of the UE.

[00101] In Example 3, the subject matter of Example 2 optionally includes
15 wherein the MAC message further includes the identity of the UE.

[00102] In Example 4, the subject matter of any one or more of Examples 2–3 optionally include wherein the message part further includes a radio resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity of the UE.

20 **[00103]** In Example 5, the subject matter of any one or more of Examples 2–4 optionally include wherein the capability of the UE includes one of a layer 1 UE capability or MAC UE capability.

[00104] In Example 6, the subject matter of any one or more of Examples 1–5 optionally include wherein the message part further includes a common
25 control channel (CCCH) subheader.

[00105] In Example 7, the subject matter of Example 6 optionally includes wherein the processing circuitry to, in response to lack of receipt of the UL grant based on the first transmission within a predetermined length of time after the first transmission, encode a second message for a second transmission on the
30 unlicensed spectrum, wherein the second message includes a second PRACH preamble and the message part.

[00106] In Example 8, the subject matter of Example 7 optionally includes wherein the predetermined length of time is based on one of an absolute time, a count of valid downlink subframe, or a MAC contention resolution timer.

5 [00107] In Example 9, the subject matter of any one or more of Examples 1–8 optionally include wherein the first transmission uses a shortened physical uplink control channel (sPUCCH) waveform, wherein a first portion includes the PRACH preamble and a remaining portion includes the message part.

10 [00108] In Example 10, the subject matter of Example 9 optionally includes wherein the first portion includes a first two symbols of Message 3 and wherein the remaining portion includes a next two symbols after the first two symbols of the Message 3.

[00109] In Example 11, the subject matter of any one or more of Examples 1–10 optionally include wherein the first transmission includes transmitting the PRACH preamble over one or more symbols of a first shortened physical uplink control channel (sPUCCH) subframe and transmitting the message part over a second sPUCCH subframe.

20 [00110] In Example 12, the subject matter of any one or more of Examples 1–11 optionally include wherein the processing circuitry to decode a second message received in a second transmission associated with the low latency RA procedure scheduled via a physical downlink control channel (PDCCH), wherein the second message includes a physical downlink shared channel (PDSCH) transmission including the UL grant and at least one of a random access response or a contention resolution message.

25 [00111] In Example 13, the subject matter of Example 12 optionally includes wherein downlink control information (DCI) used to schedule the second message is scrambled via one of the C-RNTI or a random access RNTI (RA-RNTI).

30 [00112] In Example 14, the subject matter of any one or more of Examples 1–13 optionally include wherein initiation of the low-latency RA procedure by the processing circuitry is based on receipt of an indication that a serving evolved node B (eNodeB) supports the low-latency RA procedure.

[00113] In Example 15, the subject matter of Example 14 optionally includes wherein the processing circuitry to indicate to the eNodeB selection of

the low-latency RA procedure based on selection of the PRACH preamble from a set of PRACH preambles designated for the low-latency RA procedure.

5 **[00114]** In Example 16, the subject matter of any one or more of Examples 14–15 optionally include wherein the processing circuitry to indicate to the eNodeB selection of the low-latency RA procedure based on the selection of the time and/or frequency resources dedicated for PRACH preamble transmission of the low-latency RA procedure.

10 **[00115]** In Example 17, the subject matter of any one or more of Examples 1–16 optionally include wherein the processing circuitry to encode the first message for transmission over multiple PRACH interlaces in response to a size of the first message exceeding a size allocated to a single PRACH interlace.

[00116] In Example 18, the subject matter of any one or more of Examples 1–17 optionally include wherein the processing circuitry to encode the message part for transmission over multiple PRACH interlaces.

15 **[00117]** In Example 19, the subject matter of any one or more of Examples 1–18 optionally include wherein the processing circuitry to reduce a size of the first message in response to the size of the first message exceeding a size allocated to a single PRACH interlace.

20 **[00118]** Example 20 is an apparatus of User Equipment (UE), the apparatus comprising: memory; and processing circuitry, the processing circuitry to: receive an indication that a serving evolved node B (eNodeB) supports a low-latency random-access (RA) procedure and a legacy RA procedure; and encode a first message for a first transmission associated with the low latency RA procedure that includes a PRACH preamble and a message part.

25 **[00119]** In Example 21, the subject matter of Example 20 optionally includes wherein the processing circuitry to provide an indication of selection of the low-latency RA procedure to the serving eNodeB.

30 **[00120]** In Example 22, the subject matter of Example 21 optionally includes wherein to provide the indication of selection of the low-latency RA procedure to the serving eNodeB includes the processing circuitry to select a preamble a set of PRACH preambles designated for the low-latency RA procedure.

[00121] In Example 23, the subject matter of any one or more of Examples 21–22 optionally include wherein to provide the indication of selection of the low-latency RA procedure to the serving eNodeB includes the processing circuitry to select time and/or frequency resources for PRACH preamble transmission, where
5 the time and/or frequency resources are dedicated for the low-latency RA procedure.

[00122] In Example 24, the subject matter of Example 23 optionally includes wherein the processing circuitry to receive the time and/or frequency resources dedicated for PRACH preamble transmission from the serving eNodeB.

10 **[00123]** In Example 25, the subject matter of any one or more of Examples 20–24 optionally include wherein the processing circuitry to receive an indication of selection of the low-latency RA procedure from the serving eNodeB.

[00124] In Example 26, the subject matter of Example 25 optionally includes wherein to receive an indication of selection of the low-latency RA
15 procedure from the serving eNodeB includes the processing circuitry to determine selection of the low latency RA procedure based on a PRACH_ConfigIndex parameter in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

[00125] In Example 27, the subject matter of any one or more of Examples 25–26 optionally include wherein to receive an indication of selection of the low-
20 latency RA procedure from the serving eNodeB includes the processing circuitry to determine selection of the low latency RA procedure based on a PRACH configuration field in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

[00126] In Example 28, the subject matter of any one or more of Examples
25 25–27 optionally include wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes the processing circuitry to determine selection of the low latency RA procedure based on a value of one or more reserved bits in a master information block.

[00127] In Example 29, the subject matter of any one or more of Examples
30 25–28 optionally include wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes the processing circuitry to receive selection of the low latency RA procedure via radio resource control signaling.

[00128] Example 30 is an apparatus of an evolved node B (eNodeB), the apparatus comprising: memory; and processing circuitry, the processing circuitry to: decode a first message received in a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum from a user equipment (UE), wherein the first message includes a physical random-access channel (PRACH) preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, or an identity of the UE; perform a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; and in response to a clear channel assessment, encode a second message for a second transmission associated with the low latency RA procedure, wherein the second message includes at least one of a random access response (RAR) or a contention resolution message, wherein the second message is at least one of scheduled via a physical downlink control channel (PDCCH) or includes an uplink (UL) grant.

[00129] In Example 31, the subject matter of Example 30 optionally includes wherein the message part includes a medium access control (MAC) part that includes a MAC message, wherein the MAC message includes at least one of the C-RNTI, the BSR information, or the capability of the UE.

[00130] In Example 32, the subject matter of Example 31 optionally includes wherein the message part further includes a radio resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity of the UE.

[00131] In Example 33, the subject matter of any one or more of Examples 30–32 optionally include wherein the message part further includes a common control channel (CCCH) subheader.

[00132] In Example 34, the subject matter of any one or more of Examples 30–33 optionally include wherein the second message PDSCH is scheduled via downlink control information (DCI) that is scrambled by one of the C-RNTI or a random access RNTI (RA-RNTI).

[00133] In Example 35, the subject matter of any one or more of Examples 30–34 optionally include wherein the processing circuitry to provide an indication

signaling for support for a low-latency RA procedure via radio resource control (RRC) signaling.

[00134] In Example 36, the subject matter of Example 35 optionally includes wherein the processing circuitry to determine selection of the low-latency PRACH procedure by the UE based on a comparison of the PRACH preamble with a set of PRACH preambles designated for the low-latency PRACH procedure.

[00135] In Example 37, the subject matter of Example 36 optionally includes wherein the processing circuitry to determine selection of the low-latency PRACH procedure by the UE based on a set of time and/or frequency resources used for the first transmission.

[00136] In Example 38, the subject matter of any one or more of Examples 36–37 optionally include wherein the processing circuitry to allocate respective frequency resources and/or code domains to each of a plurality of UEs to allow multiplexing of transmissions from the plurality of UEs.

[00137] In Example 39, the subject matter of any one or more of Examples 35–38 optionally include wherein the processing circuitry to indicate selection of the low latency RA procedures by based on one or more bits in the master information block or the system information block.

[00138] In Example 40, the subject matter of any one or more of Examples 30–39 optionally include wherein the processing circuitry to perform channel estimation based on a first subset of symbols of the PRACH preamble.

[00139] In Example 41, the subject matter of any one or more of Examples 30–40 optionally include wherein the processing circuitry to perform channel estimation based on a first subset of symbols of the PRACH preamble.

[00140] In Example 42, the subject matter of any one or more of Examples 30–41 optionally include wherein the processing circuitry to perform channel estimation based a PRACH preamble transmitted over a previous shortened physical uplink control channel (sPUCCH) subframe.

[00141] In Example 43, the subject matter of Example 42 optionally includes wherein the processing circuitry to decode a UL subframe for message transmission following the previous sPUCCH subframe lacks a demodulation reference signal.

[00142] In Example 44, the subject matter of any one or more of Examples 30–43 optionally include wherein the processing circuitry to revert to a legacy RA procedure in response to the message part of the first message being incorrectly detected.

5 **[00143]** Example 45 is at least one machine-readable medium including instructions to perform a physical random access channel (PRACH) procedure in unlicensed spectrum, which when executed by a machine, cause the machine to: perform a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; in response to a clear channel assessment (CCA), encode a
10 first message for a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum, wherein the first message includes at least one of a PRACH preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, or an identity of the UE;
15 and in response to receipt of an uplink (UL) grant based on the first step of low-latency RA procedure, encode UL data for transmission.

[00144] In Example 46, the subject matter of Example 45 optionally includes wherein the message part includes a medium access control (MAC) part that includes a MAC message, wherein the MAC message includes at least one of
20 the C-RNTI, the BSR information, or the capability of the UE.

[00145] In Example 47, the subject matter of Example 46 optionally includes wherein the MAC message further includes the identity of the UE.

[00146] In Example 48, the subject matter of any one or more of Examples 46–47 optionally include wherein the message part further includes a radio
25 resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity of the UE.

[00147] In Example 49, the subject matter of any one or more of Examples 46–48 optionally include wherein the capability of the UE includes one of a layer 1 UE capability or MAC UE capability.

30 **[00148]** In Example 50, the subject matter of any one or more of Examples 45–49 optionally include wherein the message part further includes a common control channel (CCCH) subheader.

[00149] In Example 51, the subject matter of Example 50 optionally includes instructions, which when executed by a machine, cause the machine to, in response to lack of receipt of the UL grant based on the first transmission within a predetermined length of time after the first transmission, encode a second message for a second transmission on the unlicensed spectrum, wherein the second message includes a second PRACH preamble and the message part.

[00150] In Example 52, the subject matter of Example 51 optionally includes wherein predetermined length of time is based on one of an absolute time, a count of valid downlink subframe, or a MAC contention resolution timer.

[00151] In Example 53, the subject matter of any one or more of Examples 45–52 optionally include wherein the first transmission uses a shortened physical uplink control channel (sPUCCH) waveform, where a first portion includes the PRACH preamble and a remaining portion includes the message part.

[00152] In Example 54, the subject matter of Example 53 optionally includes wherein the first portion includes a first two symbols of Message 3 and wherein the remaining portion includes a next two symbols after the first two symbols of the Message 3.

[00153] In Example 55, the subject matter of any one or more of Examples 45–54 optionally include instructions, which when executed by a machine, cause the machine to decode a second message received in a second transmission associated with the low latency RA procedure scheduled via a physical downlink control channel (PDCCH), wherein the second message includes a physical downlink shared channel (PDSCH) transmission including the UL grant and at least one of a random access response or a contention resolution message.

[00154] In Example 56, the subject matter of Example 55 optionally includes wherein downlink control information (DCI) used to schedule the second message is scrambled via one of the C-RNTI or a random access RNTI (RA-RNTI).

[00155] In Example 57, the subject matter of any one or more of Examples 45–56 optionally include wherein the first message is encoded based on receipt of an indication that a serving evolved node B (eNodeB) supports the low-latency RA procedure.

[00156] In Example 58, the subject matter of Example 57 optionally includes instructions, which when executed by a machine, cause the machine to indicate to the eNodeB selection of the low-latency RA procedure based on the selection of the time and/or frequency resources dedicated for PRACH preamble transmission of the low-latency RA procedure.

[00157] Example 59 is at least one machine-readable medium including instructions to perform a physical random access channel (PRACH) procedure in unlicensed spectrum, which when executed by a machine, cause the machine to: receive an indication that a serving evolved node B (eNodeB) supports a low-latency random-access (RA) procedure and a legacy RA procedure; and encode a first message for a first transmission associated with the low latency RA procedure that includes a PRACH preamble and a message part.

[00158] In Example 60, the subject matter of Example 59 optionally includes includes instructions, which when executed by a machine, cause the machine to provide an indication of selection of the low-latency RA procedure to the serving eNodeB.

[00159] In Example 61, the subject matter of Example 60 optionally includes wherein to provide the indication of selection of the low-latency RA procedure to the serving eNodeB includes instructions, which when executed by a machine, cause the machine to select a preamble a set of PRACH preambles designated for the low-latency RA procedure.

[00160] In Example 62, the subject matter of any one or more of Examples 60–61 optionally include wherein to provide the indication of selection of the low-latency RA procedure to the serving eNodeB includes instructions, which when executed by a machine, cause the machine to select time and/or frequency resources for PRACH preamble transmission, where the time and/or frequency resources are dedicated for the low-latency RA procedure.

[00161] In Example 63, the subject matter of Example 62 optionally includes includes instructions, which when executed by a machine, cause the machine to receive the time and/or frequency resources for PRACH preamble transmission from the serving eNodeB.

[00162] In Example 64, the subject matter of any one or more of Examples 59–63 optionally include includes instructions, which when executed by a

machine, cause the machine to receive an indication of selection of the low-latency RA procedure from the serving eNodeB.

5 **[00163]** In Example 65, the subject matter of Example 64 optionally includes wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause the machine to determine selection of the low latency RA procedure based on a PRACH_ConfigIndex parameter in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

10 **[00164]** In Example 66, the subject matter of any one or more of Examples 64–65 optionally include wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause the machine to determine selection of the low latency RA procedure based on a PRACH configuration field in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

15 **[00165]** In Example 67, the subject matter of any one or more of Examples 64–66 optionally include wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause the machine to determine selection of the low latency RA procedure based on a value of one or more reserved bits in a master information block.

20 **[00166]** In Example 68, the subject matter of any one or more of Examples 59–67 optionally include wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause the machine to receive selection of the low latency RA procedure via radio resource control signaling.

25 **[00167]** Example 69 is at least one machine-readable medium including instructions to perform a physical random access channel (PRACH) procedure in unlicensed spectrum, which when executed by a machine, cause the machine to: decode a first message received in a first transmission associated with a low latency (RA) random access procedure on the unlicensed spectrum from a user equipment (UE), wherein the first message includes a PRACH preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information,

capability of the UE, or an identity of the UE; perform a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; and in response to a clear channel assessment, encode a second message for a second transmission associated with the low latency RA procedure, wherein the second message
5 includes at least one of a random access response (RAR) or a contention resolution message, wherein the second message is at least one of scheduled via a physical downlink control channel (PDCCH) or includes an uplink (UL) grant.

[00168] In Example 70, the subject matter of Example 69 optionally includes wherein the message part includes a medium access control (MAC) part
10 that includes a MAC message, wherein the MAC message includes at least one of the C-RNTI, the BSR information, or the capability of the UE.

[00169] In Example 71, the subject matter of Example 70 optionally includes wherein the message part further includes a radio resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity
15 of the UE.

[00170] In Example 72, the subject matter of any one or more of Examples 69–71 optionally include wherein the message part further includes a common control channel (CCCH) subheader.

[00171] In Example 73, the subject matter of any one or more of Examples
20 69–72 optionally include the second message PDSCH is scheduled via downlink control information (DCI) that is scrambled by one of the C-RNTI or a random access RNTI (RA-RNTI).

[00172] In Example 74, the subject matter of any one or more of Examples 69–73 optionally include instructions, which when executed by a machine, cause
25 the machine to provide an indication signaling for support for a low-latency RA procedure via radio resource control (RRC) signaling.

[00173] In Example 75, the subject matter of Example 74 optionally includes instructions, which when executed by a machine, cause the machine to determine selection of the low-latency RA procedure by the UE based on a
30 comparison of the PRACH preamble with a set of PRACH preambles designated for the low-latency RA procedure.

[00174] In Example 76, the subject matter of Example 75 optionally includes instructions, which when executed by a machine, cause the machine to

determine selection of the low-latency PRACH procedure by the UE based on a set of time and/or frequency resources used for the first transmission.

[00175] In Example 77, the subject matter of any one or more of Examples 74–76 optionally include instructions, which when executed by a machine, cause the machine to indicate selection of the low latency RA procedures by based on one or more bits in the master information block or the system information block.

[00176] Example 78 is an apparatus, the apparatus comprising: means for performing a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; means for, in response to a clear channel assessment (CCA), encoding a first message for a first transmission associated with a low latency random access (RA) procedure on the unlicensed spectrum, wherein the first message includes at least one of a PRACH preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, or an identity of the UE; and means for, in response to receipt of an uplink (UL) grant based on the first step of low-latency RA procedure, encoding UL data for transmission.

[00177] In Example 79, the subject matter of Example 78 optionally includes wherein the message part includes a medium access control (MAC) part that includes a MAC message, wherein the MAC message includes at least one of the C-RNTI, the BSR information, or the capability of the UE.

[00178] In Example 80, the subject matter of Example 79 optionally includes wherein the MAC message further includes the identity of the UE.

[00179] In Example 81, the subject matter of any one or more of Examples 79–80 optionally include wherein the message part further includes a radio resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity of the UE.

[00180] In Example 82, the subject matter of any one or more of Examples 79–81 optionally include wherein the capability of the UE includes one of a layer 1 UE capability or MAC UE capability.

[00181] In Example 83, the subject matter of any one or more of Examples 78–82 optionally include wherein the message part further includes a common control channel (CCCH) subheader.

[00182] In Example 84, the subject matter of Example 83 optionally includes means for, in response to lack of receipt of the UL grant based on the first transmission within a predetermined length of time after the first transmission, encoding a second message for a second transmission on the unlicensed spectrum, wherein the second message includes a second PRACH preamble and the message part.

[00183] In Example 85, the subject matter of Example 84 optionally includes wherein predetermined length of time is based on one of an absolute time, a count of valid downlink subframe, or a MAC contention resolution timer.

10 [00184] In Example 86, the subject matter of any one or more of Examples 78–85 optionally include wherein the first transmission uses a shortened physical uplink control channel (sPUCCH) waveform, where a first portion includes the PRACH preamble and a remaining portion includes the message part.

[00185] In Example 87, the subject matter of Example 86 optionally includes wherein the first portion includes a first two symbols of Message 3 and wherein the remaining portion includes a next two symbols after the first two symbols of the Message 3.

[00186] In Example 88, the subject matter of any one or more of Examples 78–87 optionally include means for decoding a second message received in a second transmission associated with the low latency RA procedure scheduled via a physical downlink control channel (PDCCH), wherein the second message includes a physical downlink shared channel (PDSCH) transmission including the UL grant and at least one of a random access response or a contention resolution message.

25 [00187] In Example 89, the subject matter of Example 88 optionally includes wherein downlink control information (DCI) used to schedule the second message is scrambled via one of the C-RNTI or a random access RNTI (RA-RNTI).

[00188] In Example 90, the subject matter of any one or more of Examples 78–89 optionally include wherein the first message is encoded based on receipt of an indication that a serving evolved node B (eNodeB) supports the low-latency RA procedure.

[00189] In Example 91, the subject matter of Example 90 optionally includes means for indicating to the eNodeB selection of the low-latency RA procedure based on the selection of the time and/or frequency resources dedicated for PRACH preamble transmission of the low-latency RA procedure.

5 [00190] Example 92 is an apparatus, the apparatus comprising: means for receiving an indication that a serving evolved node B (eNodeB) supports a low-latency random-access (RA) procedure and a legacy RA procedure; and means for encoding a first message for a first transmission associated with the low latency RA procedure that includes a PRACH preamble and a message part.

10 [00191] In Example 93, the subject matter of Example 92 optionally includes means for providing an indication of selection of the low-latency RA procedure to the serving eNodeB.

[00192] In Example 94, the subject matter of Example 93 optionally includes wherein means providing the indication of selection of the low-latency
15 RA procedure to the serving eNodeB further includes means for selecting a preamble a set of PRACH preambles designated for the low-latency RA procedure.

[00193] In Example 95, the subject matter of any one or more of Examples 93–94 optionally include wherein means for providing the indication of selection
20 of the low-latency RA procedure to the serving eNodeB further includes means for selecting time and/or frequency resources for PRACH preamble transmission, where the time and/or frequency resources are dedicated for the low-latency RA procedure.

[00194] In Example 96, the subject matter of Example 95 optionally
25 includes means for receiving the time and/or frequency resources for PRACH preamble transmission from the serving eNodeB.

[00195] In Example 97, the subject matter of any one or more of Examples 92–96 optionally include means for receiving an indication of selection of the low-latency RA procedure from the serving eNodeB.

30 [00196] In Example 98, the subject matter of Example 97 optionally includes wherein means for receiving an indication of selection of the low-latency RA procedure from the serving eNodeB further includes means for determining

selection of the low latency RA procedure based on a PRACH_ConfigIndex parameter in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

[00197] In Example 99, the subject matter of any one or more of Examples 97–98 optionally include wherein means for receiving an indication of selection of the low-latency RA procedure from the serving eNodeB further includes means for determining selection of the low latency RA procedure based on a PRACH configuration field in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

[00198] In Example 100, the subject matter of any one or more of Examples 97–99 optionally include wherein means for receiving an indication of selection of the low-latency RA procedure from the serving eNodeB further includes means for determining selection of the low latency RA procedure based on a value of one or more reserved bits in a master information block.

[00199] In Example 101, the subject matter of any one or more of Examples 92–100 optionally include wherein means for receiving an indication of selection of the low-latency RA procedure from the serving eNodeB further includes means for receiving selection of the low latency RA procedure via radio resource control signaling.

[00200] Example 102 is an apparatus, the apparatus comprising: means for determining decoding a first message received in a first transmission associated with a low latency (RA) random access procedure on the unlicensed spectrum from a user equipment (UE), wherein the first message includes a PRACH preamble and a message part, wherein the message part includes at least one of a cell radio network temporary identifier (C-RNTI), buffer status report (BSR) information, capability of the UE, or an identity of the UE; means for performing a listen-before-talk (LBT) procedure on one or more channels of an unlicensed spectrum; and means for, in response to a clear channel assessment, encoding a second message for a second transmission associated with the low latency RA procedure, wherein the second message includes at least one of a random access response (RAR) or a contention resolution message, wherein the second message is at least one of scheduled via a physical downlink control channel (PDCCH) or includes an uplink (UL) grant.

[00201] In Example 103, the subject matter of Example 102 optionally includes wherein the message part includes a medium access control (MAC) part that includes a MAC message, wherein the MAC message includes at least one of the C-RNTI, the BSR information, or the capability of the UE.

5 **[00202]** In Example 104, the subject matter of Example 103 optionally includes wherein the message part further includes a radio resource control (RRC) part that includes a RRC message, wherein the RRC message includes the identity of the UE.

[00203] In Example 105, the subject matter of any one or more of Examples 10 **102–104** optionally include wherein the message part further includes a common control channel (CCCH) subheader.

[00204] In Example 106, the subject matter of any one or more of Examples 102–105 optionally include the second message PDSCH is scheduled via downlink control information (DCI) that is scrambled by one of the C-RNTI or a 15 random access RNTI (RA-RNTI).

[00205] In Example 107, the subject matter of any one or more of Examples 102–106 optionally include means for providing an indication signaling for support for a low-latency RA procedure via radio resource control (RRC) signaling.

20 **[00206]** In Example 108, the subject matter of Example 107 optionally includes means for determining selection of the low-latency RA procedure by the UE based on a comparison of the PRACH preamble with a set of PRACH preambles designated for the low-latency RA procedure.

[00207] In Example 109, the subject matter of Example 108 optionally 25 includes means for determining selection of the low-latency PRACH procedure by the UE based on a set of time and/or frequency resources used for the first transmission.

[00208] In Example 110, the subject matter of any one or more of Examples 107–109 optionally include means for indicating selection of the low latency RA 30 procedures by based on one or more bits in the master information block or the system information block.

[00209] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The

drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as “examples.” Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described.

5 Moreover, also contemplate are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[00210] Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though
10 individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) are supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

15 **[00211]** In this document, the terms “a” or “an” are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of “at least one” or “one or more.” In this document, the term “or” is used to refer to a nonexclusive or, such that “A or B” includes “A but not B,” “B but not A,” and “A and B,” unless otherwise indicated. In the appended
20 claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Also, in the following claims, the terms “including” and “comprising” are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that
25 claim. Moreover, in the following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to suggest a numerical order for their objects.

[00212] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects
30 thereof) may be used in combination with others. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure, for example, to comply with 37 C.F.R. §1.72(b) in the

United States of America. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth features disclosed herein

5 because embodiments may include a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended

10 claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

What is claimed is:

- 5 1. An apparatus of User Equipment (UE), the apparatus comprising:
 memory; and processing circuitry, the processing circuitry to:
 perform a listen-before-talk (LBT) procedure on one or more channels
 of an unlicensed spectrum; and
 in response to a clear channel assessment (CCA), encode a first message
10 for a first transmission associated with a low latency random access (RA)
 procedure on the unlicensed spectrum, wherein the first message includes
 at least one of a PRACH preamble and a message part, wherein the
 message part includes at least one of a cell radio network temporary
 identifier (C-RNTI), buffer status report (BSR) information, capability of
15 the UE, and/or an identity of the UE; and
 in response to receipt of an uplink (UL) grant based on the low-latency
 RA procedure, encode UL data for transmission.
- 20 2. The apparatus of claim 1, wherein the message part includes a medium
 access control (MAC) part that includes at least one of a MAC message, wherein
 the MAC message includes at least one of the C-RNTI, the BSR information, or
 the capability of the UE.
- 25 3. The apparatus of claim 2, wherein the MAC message further includes
 the identity of the UE.
- 30 4. The apparatus of claim 2, wherein the message part further includes a
 radio resource control (RRC) part that includes a RRC message, wherein the RRC
 message includes the identity of the UE.
5. The apparatus of claim 2, wherein the capability of the UE includes one
 of a layer 1 UE capability or MAC UE capability.

6. The apparatus of claims 1 - 5, wherein the message part further includes a common control channel (CCCH) subheader.

7. The apparatus of claims 1 - 5, wherein the processing circuitry to, in response to lack of receipt of the UL grant based on the first transmission within a predetermined length of time after the first transmission, encode a second message for a second transmission on the unlicensed spectrum, wherein the second message includes a second PRACH preamble and the message part.

8. The apparatus of claim 7, wherein the predetermined length of time is based on one of an absolute time, a count of valid downlink subframe, or a MAC contention resolution timer.

9. The apparatus of claim 1, wherein the first transmission uses a shortened physical uplink control channel (sPUCCH) waveform, wherein a first portion includes the PRACH preamble and a remaining portion includes the message part.

10. The apparatus of claim 9, wherein the first portion includes a first two symbols of Message 3 and wherein the remaining portion includes a next two symbols after the first two symbols of the Message 3.

11. The apparatus of claim 1, wherein the first transmission includes transmitting the PRACH preamble over one or more symbols of a first shortened physical uplink control channel (sPUCCH) subframe and transmitting the message part over a second sPUCCH subframe.

12. The apparatus of claim 1, wherein the processing circuitry to decode a second message received in a second transmission associated with the low latency RA procedure scheduled via a physical downlink control channel (PDCCH), wherein the second message includes a physical downlink shared channel (PDSCH) transmission including the UL grant and at least one of a random access response or a contention resolution message.

13. The apparatus of claim 12, wherein downlink control information (DCI) used to schedule the second message is scrambled via one of the C-RNTI or a random access RNTI (RA-RNTI).

5 14. An apparatus of an evolved node B (eNodeB), the apparatus comprising:
memory; and processing circuitry, the processing circuitry to:
decode a first message received in a first transmission associated with a
low latency random access (RA) procedure on the unlicensed spectrum
from a user equipment (UE), wherein the first message includes a physical
10 random-access channel (PRACH) preamble and a message part, wherein
the message part includes at least one of a cell radio network temporary
identifier (C-RNTI), buffer status report (BSR) information, capability of
the UE, or an identity of the UE;
perform a listen-before-talk (LBT) procedure on one or more channels
15 of an unlicensed spectrum; and
in response to a clear channel assessment, encode a second message for
a second transmission associated with the low latency RA procedure,
wherein the second message includes at least one of a random access
response (RAR) or a contention resolution message, wherein the second
20 message is at least one of scheduled via a physical downlink control
channel (PDCCH) or includes an uplink (UL) grant.

15. The apparatus of claim 14, wherein the processing circuitry to provide
an indication signaling for support for a low-latency RA procedure via radio
25 resource control (RRC) signaling.

16. The apparatus of claim 15, wherein the processing circuitry to determine
selection of the low-latency PRACH procedure by the UE based on a comparison
of the PRACH preamble with a set of PRACH preambles designated for the low-
30 latency PRACH procedure.

17. The apparatus of claim 16, wherein the processing circuitry to determine selection of the low-latency PRACH procedure by the UE based on a set of time and/or frequency resources used for the first transmission.
- 5 18. The apparatus of claim 16, wherein the processing circuitry to allocate respective frequency resources and/or code domains to each of a plurality of UEs to allow multiplexing of transmissions from the plurality of UEs.
19. At least one machine-readable medium including instructions to perform
10 a physical random access channel (PRACH) procedure in unlicensed spectrum, which when executed by a machine, cause the machine to:
receive an indication that a serving evolved node B (eNodeB) supports a low-latency random-access (RA) procedure and a legacy RA procedure; and
encode a first message for a first transmission associated with the low
15 latency RA procedure that includes a PRACH preamble and a message part.
20. The at least one machine-readable medium of claim 19, further including includes instructions, which when executed by a machine, cause the machine to provide an indication of selection of the low-latency RA procedure to the serving
20 eNodeB.
21. The at least one machine-readable medium of claim 20, wherein to provide the indication of selection of the low-latency RA procedure to the serving eNodeB includes instructions, which when executed by a machine, cause the
25 machine to select a preamble a set of PRACH preambles designated for the low-latency RA procedure.
22. The at least one machine-readable medium of claim 20, wherein to provide the indication of selection of the low-latency RA procedure to the serving
30 eNodeB includes instructions, which when executed by a machine, cause the machine to select time and/or frequency resources for PRACH preamble transmission, where the time and/or frequency resources are dedicated for the low-latency RA procedure.

23. The at least one machine-readable medium of claim 19, further including includes instructions, which when executed by a machine, cause the machine to receive an indication of selection of the low-latency RA procedure from the
5 serving eNodeB.

24. The at least one machine-readable medium of claim 23, wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause
10 the machine to determine selection of the low latency RA procedure based on a PRACH_ConfigIndex parameter in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

25. The at least one machine-readable medium of claim 23, wherein to receive an indication of selection of the low-latency RA procedure from the serving eNodeB includes instructions, which when executed by a machine, cause
15 the machine to determine selection of the low latency RA procedure based on a PRACH configuration field in a system information block 2 (SIB2) or an extended SIB2 (eSIB2).

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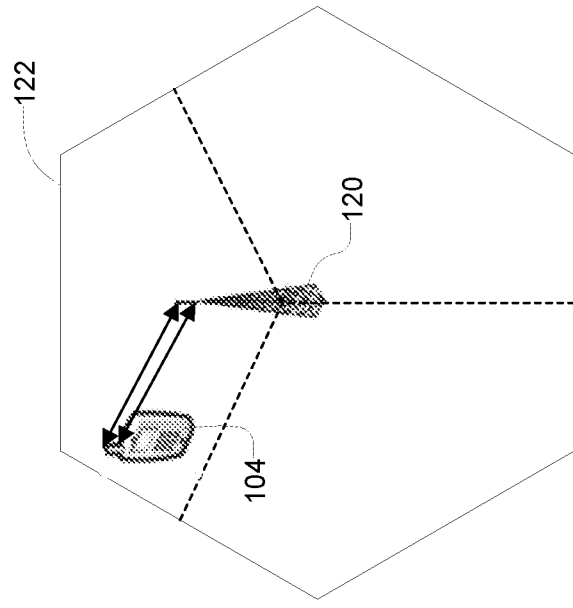
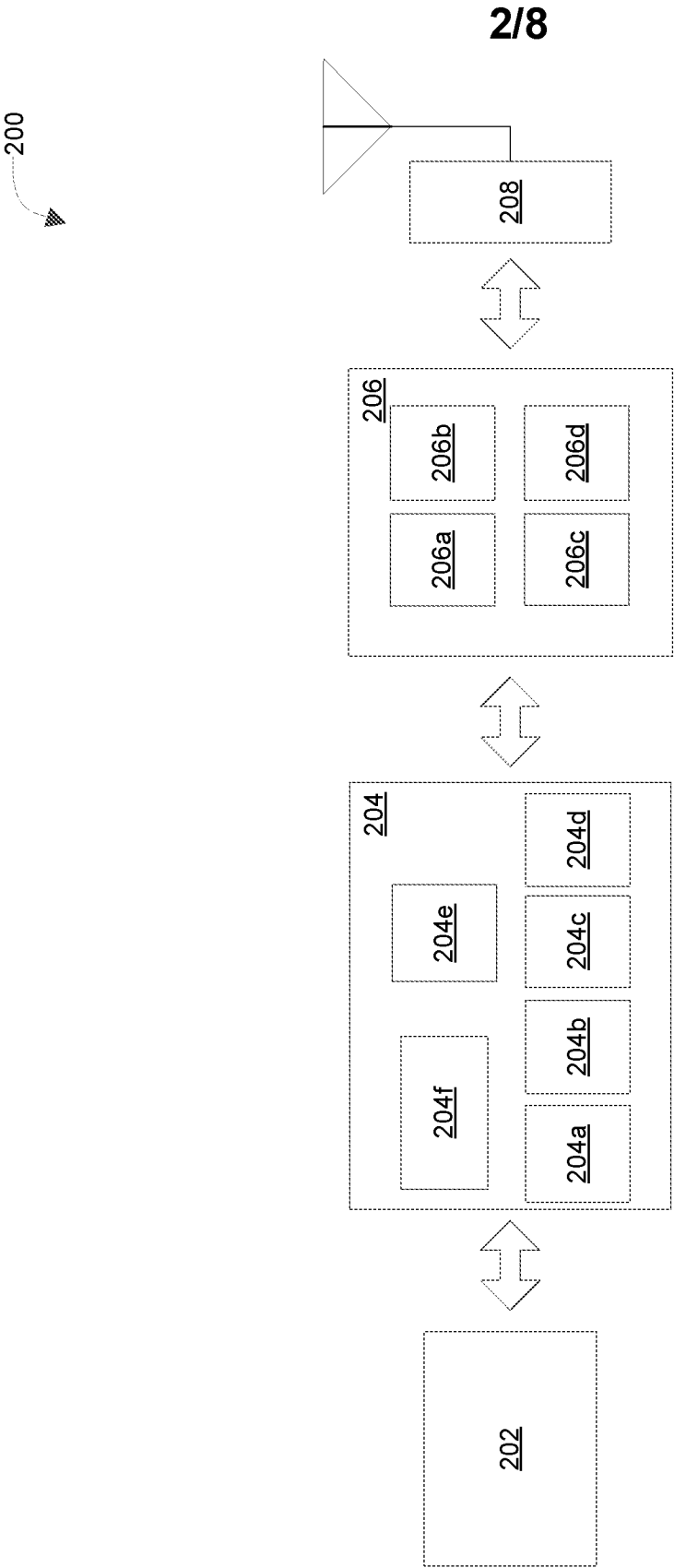


FIG. 1



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FIG. 2

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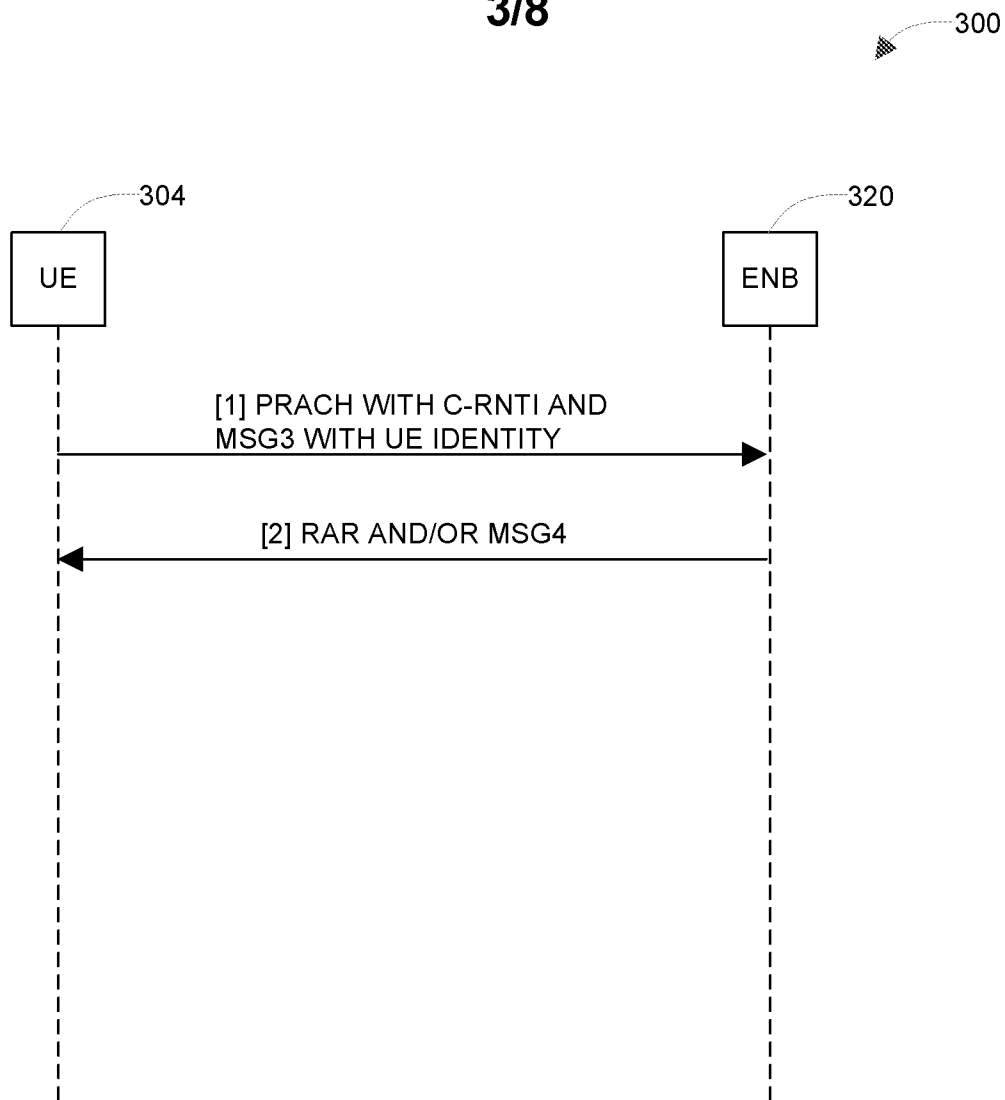


FIG. 3

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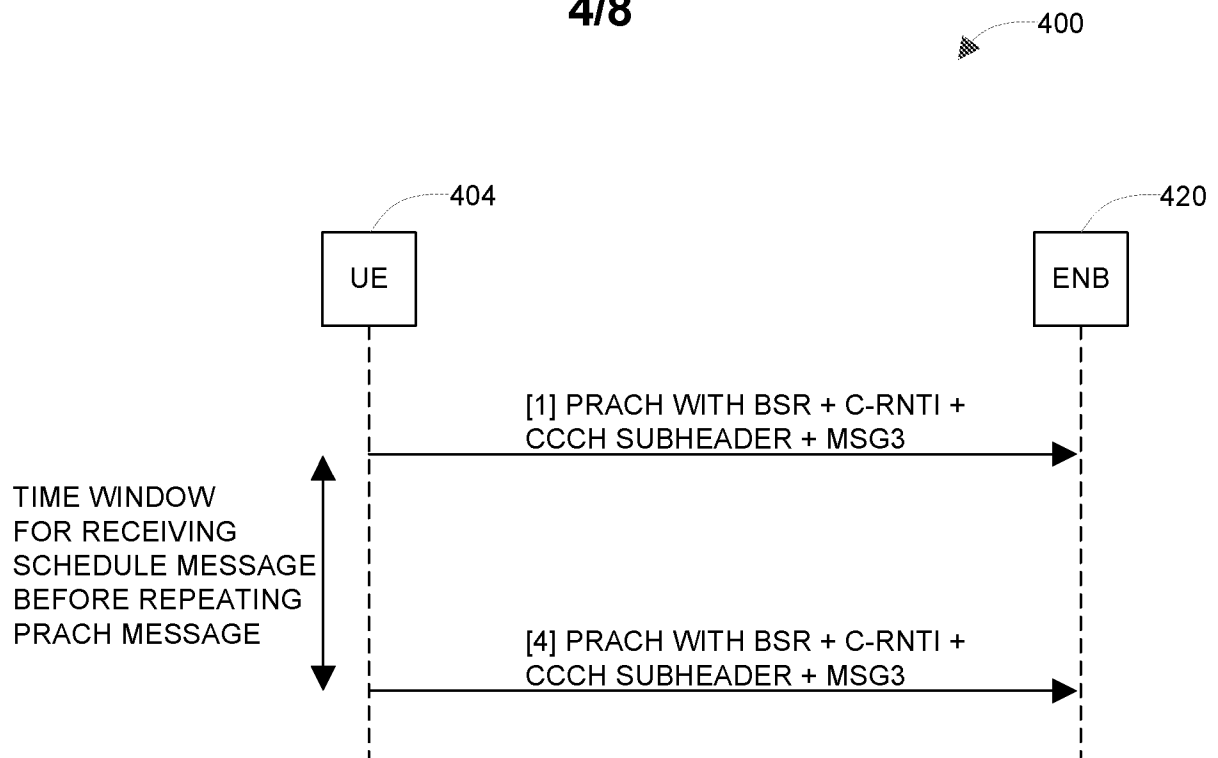


FIG. 4A

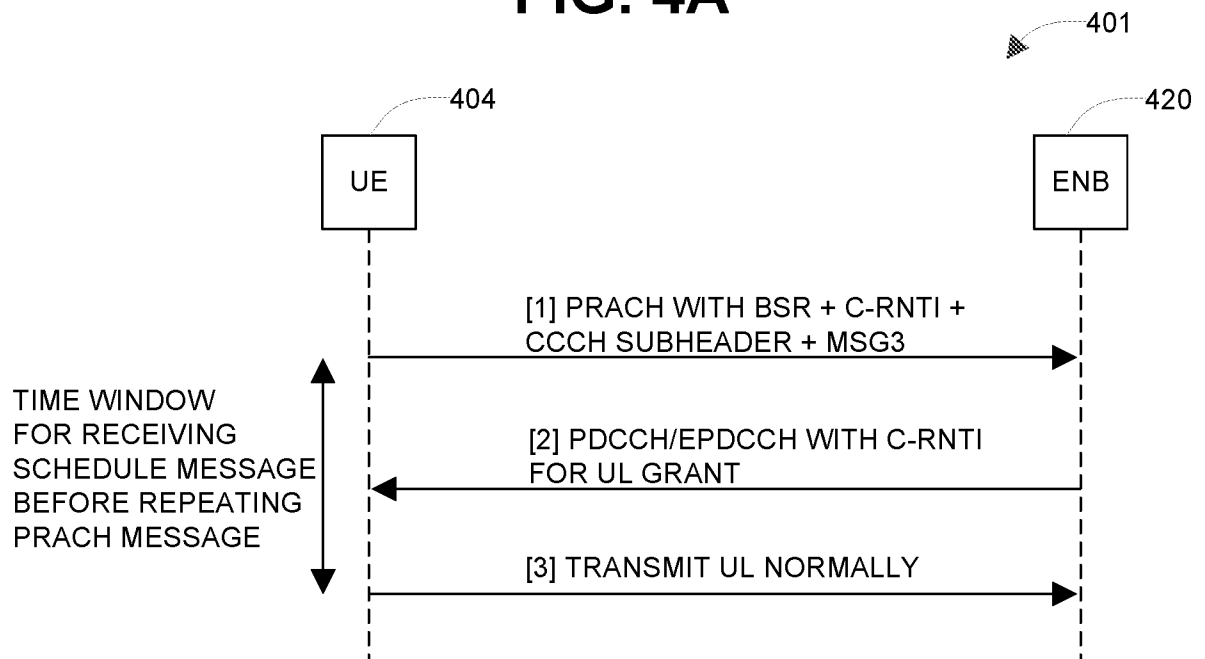


FIG. 4B

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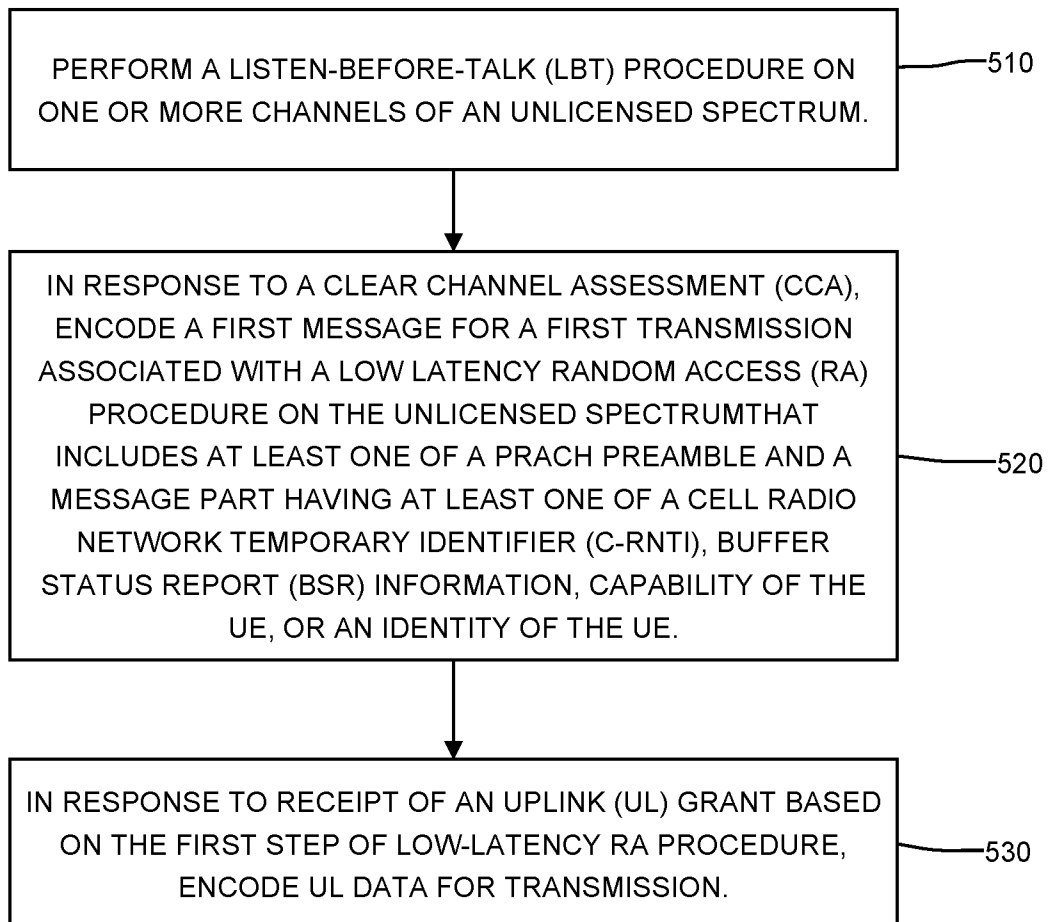


FIG. 5

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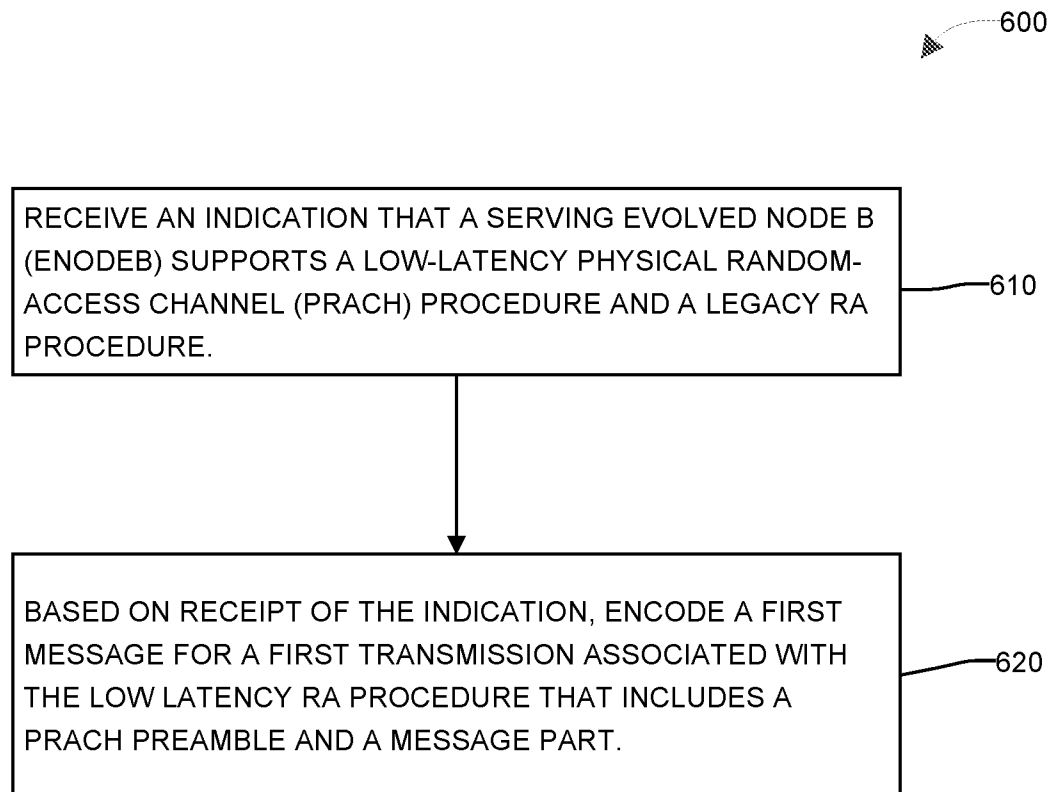


FIG. 6

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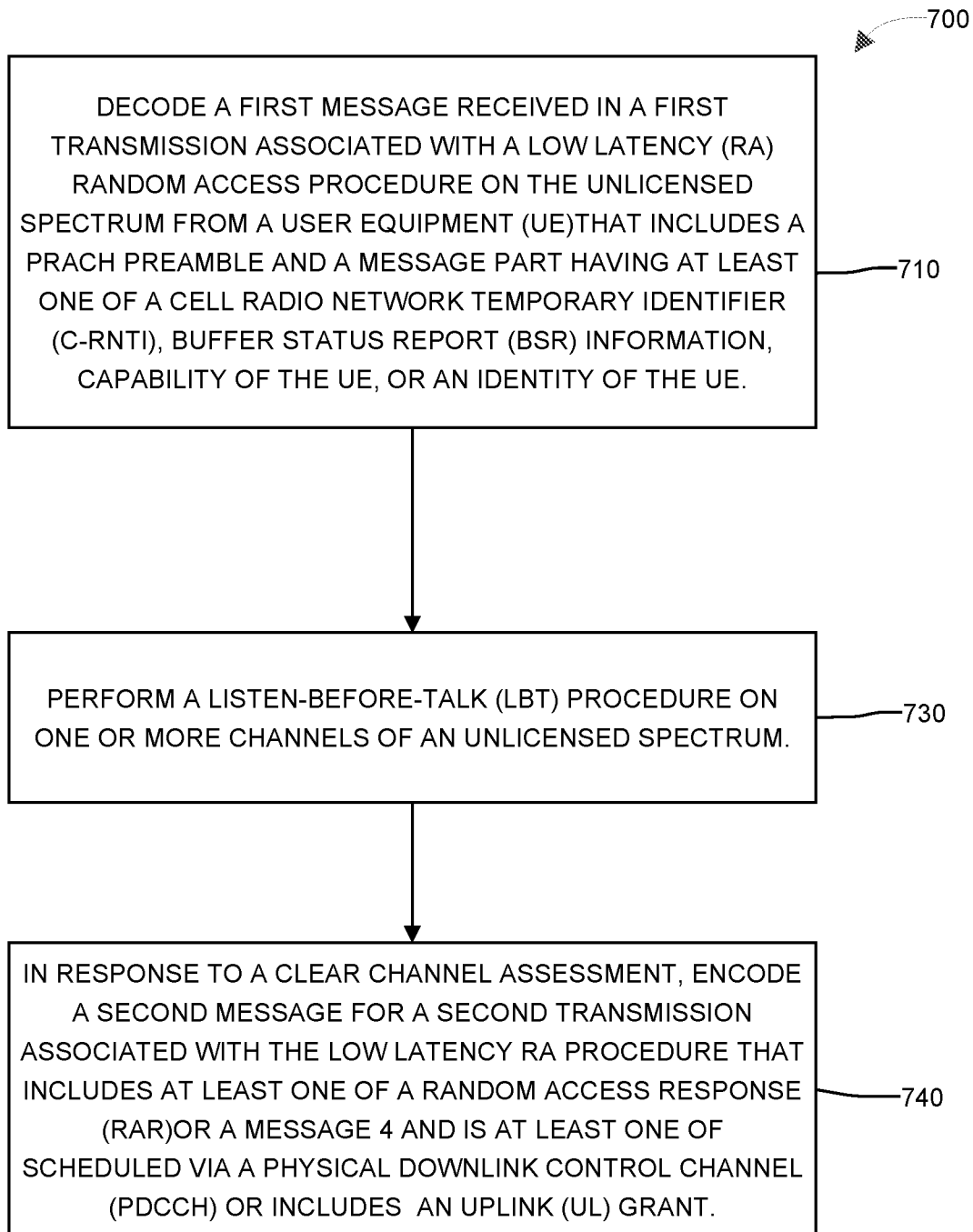
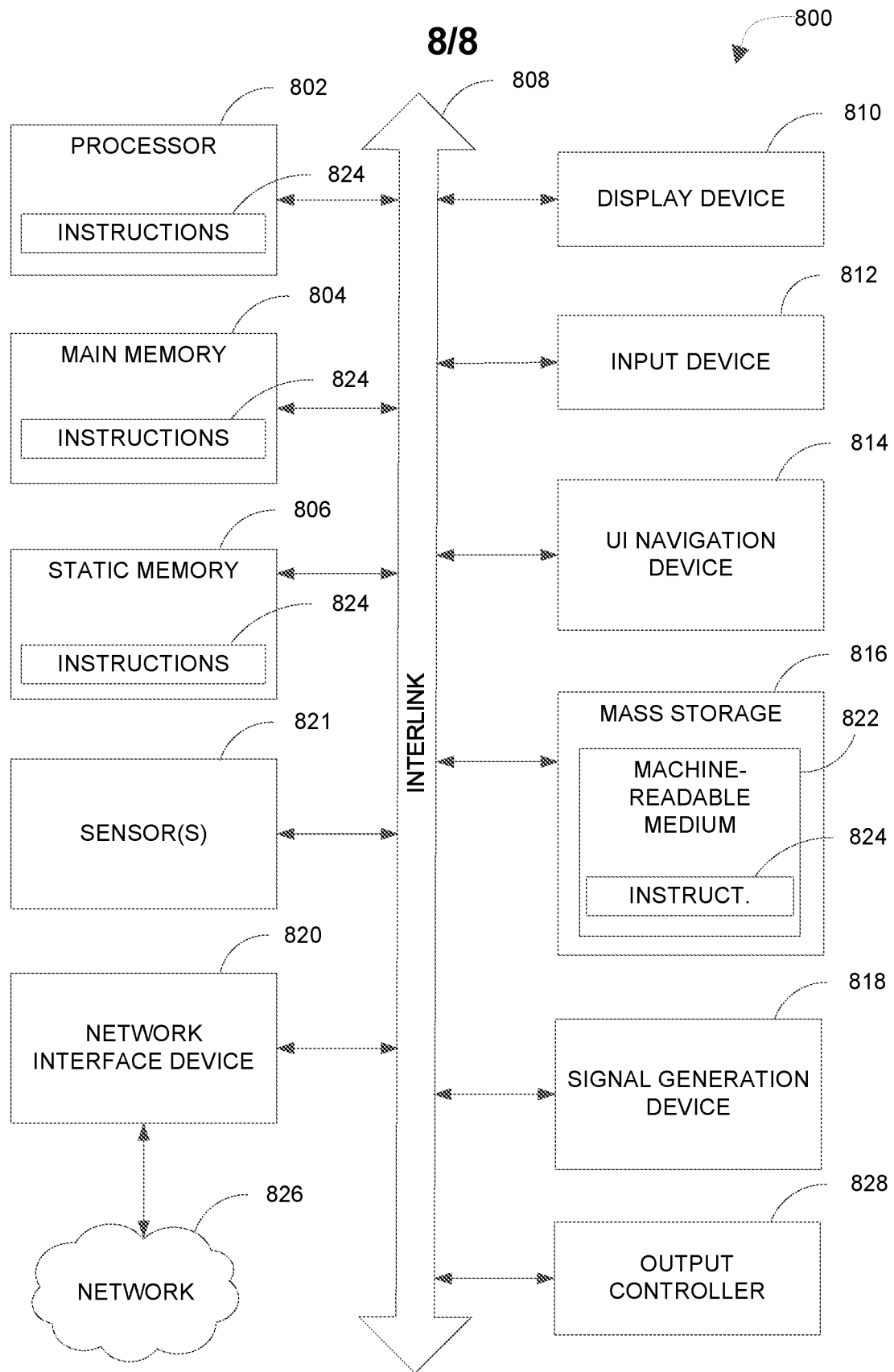


FIG. 7



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/054544**A. CLASSIFICATION OF SUBJECT MATTER****H04W 74/00(2009.01)i, H04W 74/08(2009.01)i, H04W 72/14(2009.01)i, H04W 28/06(2009.01)i, H04W 28/02(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 74/00; H04W 74/08; H04J 11/00; H04W 16/32; H04L 1/18; H04W 72/04; H04W 16/14; H04W 72/14; H04W 28/06; H04W 28/02

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: UE, eNodeB, LBT (listen-before-talk), unlicensed spectrum, CCA (clear channel assessment), low latency random access procedure, C-RNTI, BSR, capability of the UE, identity of the UE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 2015-184216 A1 (QUALCOMM INCORPORATED) 03 December 2015 See paragraphs [0133]-[0141]; and figure 10.	1-13, 19-25



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

10 January 2017 (10.01.2017)

Date of mailing of the international search report

11 January 2017 (11.01.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

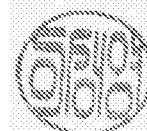


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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/054544

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INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US2016/054544**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-13, 19-25

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Group I: Claims 1-13 and 19-25 are directed to an apparatus of a User Equipment (UE) configured to encode a first message for a first transmission associated with a low latency random access (RA) procedure on an unlicensed spectrum that includes a PRACH preamble and a message part.

Group II: Claims 14-18 are directed to an apparatus of an evolved nodeB (eNodeB) configured to decode a first message received in a first transmission associated with a low latency random access (RA) procedure on an unlicensed spectrum from a user equipment (UE), perform a listen-before-talk (LBT) procedure on one or more channels of the unlicensed spectrum, and in response to a clear channel assessment, encode a second message for a second transmission associated with the low latency RA procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/054544

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