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(54) Title: LISTEN-BEFORE-TALK (LBT) FAILURE DURING A RANDOM ACCESS PROCEDURE

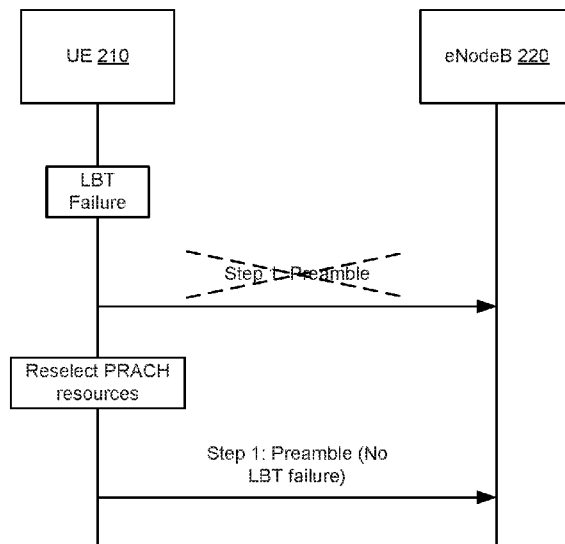


FIG. 2

(57) Abstract: Technology for a user equipment (UE) operable to perform a physical random access channel (PRACH) procedure with an eNodeB is disclosed. The UE can select a PRACH preamble for transmission to an eNodeB during the PRACH procedure. The UE can perform a listen-before-talk (LBT) to determine whether an unlicensed channel is available. The UE can detect a LBT failure at the UE. The LBT failure can indicate that the unlicensed channel is unavailable to transmit the PRACH preamble during a PRACH opportunity. The UE can select new PRACH resources for a subsequent PRACH opportunity. The UE can be configured to perform a PRACH preamble transmission during the subsequent PRACH opportunity when the UE is not subject to the LBT failure.

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LISTEN-BEFORE-TALK (LBT) FAILURE DURING A RANDOM ACCESS PROCEDURE

BACKGROUND

5 **[0001]** Wireless mobile communication technology uses various standards and protocols to transmit data between a node (e.g., a transmission station) and a wireless device (e.g., a mobile device). Some wireless devices communicate using orthogonal frequency-division multiple access (OFDMA) in a downlink (DL) transmission and single carrier frequency division multiple access (SC-FDMA) in uplink (UL). Standards
10 and protocols that use orthogonal frequency-division multiplexing (OFDM) for signal transmission include the third generation partnership project (3GPP) long term evolution (LTE) Release 8, 9, 10, 11, 12 and 13, the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard (e.g., 802.16e, 802.16m), which is commonly known to industry groups as WiMAX (Worldwide interoperability for
15 Microwave Access), and the IEEE 802.11 standard, which is commonly known to industry groups as WiFi.

[0002] In 3GPP radio access network (RAN) LTE systems (e.g., Release 13 and earlier), the node can be a combination of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node Bs (also commonly denoted as evolved Node Bs, enhanced
20 Node Bs, eNodeBs, or eNBs) and Radio Network Controllers (RNCs), which communicates with the wireless device, known as a user equipment (UE). The downlink (DL) transmission can be a communication from the node (e.g., eNodeB) to the wireless device (e.g., UE), and the uplink (UL) transmission can be a communication from the wireless device to the node.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Features and advantages of the disclosure will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the disclosure; and, wherein:

30 **[0004]** FIG. 1 illustrates a random access procedure in accordance with an example;

[0005] FIG. 2 illustrates a listen-before-talk (LBT) failure that prevents a user equipment (UE) from sending a preamble to an eNodeB during a random access procedure in accordance with an example;

5 [0006] FIG. 3 illustrates a listen-before-talk (LBT) failure that prevents an eNodeB from sending a random access response to a user equipment (UE) during a random access procedure in accordance with an example;

[0007] FIG. 4 illustrates a listen-before-talk (LBT) failure that prevents a user equipment (UE) from sending a connection request message to an eNodeB during a random access procedure in accordance with an example;

10 [0008] FIG. 5 depicts functionality of a user equipment (UE) operable to perform a physical random access channel (PRACH) procedure with an eNodeB in accordance with an example;

[0009] FIG. 6 depicts functionality of an eNodeB operable to perform a physical random access channel (PRACH) procedure with a user equipment (UE) in accordance
15 with an example;

[0010] FIG. 7 depicts a flowchart of a machine readable storage medium having instructions embodied thereon for performing a physical random access channel (PRACH) procedure between a user equipment (UE) and an eNodeB in accordance with an example;

20 [0011] FIG. 8 illustrates a diagram of a wireless device (e.g., UE) and a base station (e.g., eNodeB) in accordance with an example; and

[0012] FIG. 9 illustrates a diagram of a wireless device (e.g., UE) in accordance with an example.

25 [0013] Reference will now be made to the exemplary embodiments illustrated, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the technology is thereby intended.

DETAILED DESCRIPTION

[0014] Before the present technology is disclosed and described, it is to be understood

that this technology is not limited to the particular structures, process actions, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular
5 examples only and is not intended to be limiting. The same reference numerals in different drawings represent the same element. Numbers provided in flow charts and processes are provided for clarity in illustrating actions and operations and do not necessarily indicate a particular order or sequence.

10 **EXAMPLE EMBODIMENTS**

[0015] An initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail later. This initial summary is intended to aid readers in understanding the technology more quickly but is not intended to identify key features or essential features of the technology nor is it
15 intended to limit the scope of the claimed subject matter.

[0016] The explosive growth in wireless traffic has led to a demand for rate improvement. However, with mature physical layer techniques, further improvement in spectral efficiency has been marginal. In addition, the scarcity of licensed spectrum in the low frequency band results in a deficit in the data rate boost. There are emerging
20 interests in the operation of LTE systems in unlicensed spectrum. In 3GPP LTE Release 13, one enhancement has been to enable operation in the unlicensed spectrum via licensed-assisted access (LAA). LAA can expand the system bandwidth by utilizing a flexible carrier aggregation (CA) framework, as introduced in the LTE-Advanced system (3GPP LTE Release 10 system). Release 13 LAA focuses on the downlink (DL)
25 design, while Release 14 enhanced LAA (or eLAA) focuses on the uplink (UL) design. Enhanced operation of LTE systems in the unlicensed spectrum is expected in Fifth Generation (5G) wireless communication systems. In one example, LTE operation in the unlicensed spectrum can be achieved using dual connectivity (DC) based LAA. In DC based LAA, an anchor deployed in the licensed spectrum can be utilized. In
30 another example, Release 14 describes that LTE operation in the unlicensed system can be achieved using a MuLTEfire system, which does not utilize an anchor in the licensed

spectrum. The MuLTEfire system is a standalone LTE system that operates in the unlicensed spectrum. Therefore, Release 14 eLAA and MuLTEfire systems can potentially be significant evolutions in future wireless networks.

[0017] In one example, the unlicensed frequency band of current interest for 3GPP systems is the 5 gigahertz (GHz) band, which has wide spectrum with global common availability. The 5 GHz band in the United States is governed using Unlicensed National Information Infrastructure (U-NII) rules by the Federal Communications Commission (FCC). The main incumbent system in the 5 GHz band is the wireless local area networks (WLAN), specifically those based on the IEEE 802.11 a/n/ac technologies. WLAN systems are widely deployed both by individuals and operators for carrier-grade access service and data offloading. Therefore, listen-before-talk (LBT) in the unlicensed spectrum is a mandatory feature in the Release 13 LAA system, which can enable fair coexistence with the incumbent system. LBT is a procedure in which radio transmitters first sense the medium, and transmit only if the medium is sensed to be idle.

[0018] In one configuration, a random access procedure can be initiated for the following scenarios: initial access (from idle mode), uplink (UL) scheduling request (in connected mode), UL time alignment (in connected mode), handover (in connected mode), or radio resource control (RRC) connection re-establishment (in connected mode).

[0019] In Release 12 and Release 13 Licensed Assisted Access (LAA) systems, an unlicensed cell (i.e., a cell operating in an unlicensed spectrum) can only be used in RRC connected mode as a secondary cell (SCell). Furthermore, the unlicensed cell can only be used for downlink DL transmission. Hence, no random access is performed on the unlicensed cell. In MuLTEfire systems, in which an unlicensed cell can be a primary cell (PCell) and with the support of UL in LAA, random access can be performed on the unlicensed cell for the scenarios described above.

[0020] As described herein, a UE can be a LTE UE or a MuLTEfire UE or any UE operating in the unlicensed spectrum. In addition, as described herein, an eNodeB can be an LTE eNodeB or a MuLTEfire eNodeB or any base station or network node operating in the unlicensed spectrum.

[0021] FIG. 1 illustrates an example of a random access procedure between a user equipment (UE) 110 and an eNodeB 120. The random access procedure can include four operations. In a first operation, the UE 110 can send a preamble to the eNodeB 120. In a second operation, the eNodeB 120 can send a random access response to the UE 210. The random access response can include a temporary cell radio network temporary identity (C-RNTI), a timing advance value and an uplink grant resource. In a third operation, the UE 110 can send a connection request message to the eNodeB 120. The connection request message can include a temporary mobile subscriber identity (TMSI) and a connection establishment cause. In a fourth operation, the eNodeB 120 can send a contention resolution message to the UE 210. The contention resolution message can include a new C-RNTI to be used for subsequent communications by the UE 210.

[0022] In one example, before a node (e.g., the UE 110 or eNodeB 120) accesses the channel, the node can perform LBT by listening to the channel and determining whether the channel is busy. When the channel is busy, the node may not access the channel. This is referred to as LBT failure. On the other hand, when the channel is not busy, this indicates that there is no LBT failure, and the node is able to perform a transmission on the channel.

[0023] In one configuration, with respect to the first operation, due to LBT failure at the UE 110, the UE 110 may not be able to transmit a preamble sequence to the eNodeB 120 at a next physical random access channel (PRACH) opportunity. The operations performed by the UE 110 when the preamble is unable to be transmitted due to LBT failure are further described below.

[0024] With respect to the second operation, due to LBT failure at the eNodeB 120, the eNodeB 120 may be unable to send a response message (e.g., the random access response in LTE or LAA or MuLTEfire systems) to the UE 110. In previous LTE systems, the eNodeB 120 can send the response message to the UE 110 within a random access window, which can be in the range of 1-10 milliseconds (ms). However, as described in further detail below, the random access window (as found in the previous LTE systems) can be modified to accommodate for the LBT failure at the eNodeB 120. If the random access window is not modified, even if the eNodeB 120 receives the

preamble from the UE 110, the UE 110 may restart the random access procedure when the eNodeB 120 fails to respond within the random access window. As a result, the RACH latency can be increased, which can increase an interruption time of handover and re-establishment. In addition, this can generate unnecessary UL interference because of power ramping in a subsequent preamble transmission, as well as increase UE power consumption. Therefore, as described in further detail below, the random access window can be modified.

[0025] With respect to the third operation, due to LBT failure at the UE, the UE may skip the transmission of the connection request message (message3) on the UL grant scheduled by the eNodeB. The operations performed by the UE when the connection request message (message3) is unable to be transmitted due to LBT failure are further described below.

[0026] As described below, with respect to performance of the random access procedure in LAA, eLAA and MuLTEfire, UE operations and network operations to be performed upon LBT failure can be defined.

[0027] FIG. 2 illustrates an example of a listen-before-talk (LBT) failure that prevents a user equipment (UE) 210 from sending a preamble (or preamble sequence) to an eNodeB 220 during a random access procedure. The LBT failure can occur at the UE 210, and as a result, the UE 210 may be unable to transmit the preamble to the eNodeB 220. For example, the UE 210 can perform LBT, and upon detecting that an unlicensed channel is busy, the UE 210 can determine the LBT failure. The UE 210 and the eNodeB 220 can be included in an LTE, LAA or MuLTEfire system. In addition, due to the LBT failure at the UE 210, the UE 210 may be unable to transmit the preamble at a subsequent physical random access channel (PRACH) opportunity.

[0028] In one example, upon skipping the transmission of the preamble, the UE 210 can reselect PRACH resources for the subsequent PRACH opportunity. The UE 210 can reselect the PRACH resources for the subsequent PRACH opportunity to randomize the preamble, as well as the time and frequency resources to be used. In other words, if LBT failure occurs at the UE 210 during preamble transmission, the UE 210 can perform PRACH resource selection (e.g., select a new preamble, as well as time and frequency resources for the subsequent PRACH opportunity). In addition, when the UE

210 selects the PRACH resources, the UE 210 can maintain a transmit (Tx) power to prevent unnecessary UL interference due to redundant power ramping for a skipped preamble transmission. In other words, the UE 210 can maintain the transmit (Tx) power since the preamble was not actually transmitted (i.e., the preamble transmission was skipped due to the LBT failure at the UE 210). The UE 210 can maintain the transmit (Tx) power by performing power ramping (i.e., not incrementing an attempt counter).

[0029] FIG. 3 illustrates an example of a listen-before-talk (LBT) failure that prevents an eNodeB 320 from sending a random access response to a user equipment (UE) 310 during a random access procedure. The LBT failure can occur at the eNodeB 320, and as a result, the eNodeB 320 may be unable to transmit the random access response to the UE 310. For example, the eNodeB 320 can perform LBT, and upon detecting that an unlicensed channel is busy, the eNodeB 320 can determine the LBT failure. The UE 310 and the eNodeB 320 can be included in an LTE, LAA or MuLTEfire system.

[0030] In existing LTE systems, the eNodeB 320 can send the random access response within a random access window (which can range from 1-10 ms). However, when LBT failure occurs at the eNodeB 320, this random access window can be insufficient for the eNodeB 320 to respond with the random access response to the UE 310. In other words, due to the occurrence of the LBT failure, a length of the random access window can be insufficient for the eNodeB 310 transmit the random access response upon receiving the preamble from the UE 310.

[0031] In one configuration, in order to determine whether the eNodeB 320 receives the preamble from the UE 310, and taking into consideration the possible LBT failure at the eNodeB 320, three examples are described below.

[0032] In a first example, a window size associated with the random access window can be extended or increased, such that the UE 310 can confidently determine whether the eNodeB 320 has received its preamble. In other words, the window size can be extended or increased, such that there is ample time for the eNodeB 320 to receive the preamble and, in response, transmit the random access response to the UE 310. Due to the increase of the window size, the UE 310 can confidently determine whether its preamble transmission was successful or a failure. As a non-limiting example, the

window size can be increased from 10 ms to 20 ms. As a result, a probability that the eNodeB 320 will be able to send the random access response within the random access window can be increased.

[0033] In a second example, rather than using the random access window as a timer, the same window size can be used and the random access window can act as a maximum counter. The UE 310 can only count valid DL subframes indicated in a common physical downlink control channel (PDCCH) or subframes where discovery reference signal (DRS) or other control signaling (e.g., channel state information reference signal, or CSI-RS) are being sent. The UE 310 can only count these valid DL subframes, and the UE 310 can attempt to detect the random access response, which can be indicated in downlink control information (DCI) of the PDCCH/ePDCCH and masked with a random access radio network temporary identifier (RA-RNTI). Once the UE 310 detects the random access response with a match preamble ID, the UE 310 can stop the counter. If the maximum counter has been reached, the UE 310 can consider that the eNodeB 320 did not receive the preamble and the UE 310 can perform PRACH again. In addition, these valid DL subframes are subframes that contain DRS and other control signaling and data burst, as indicated in the common PDCCH. The RA-RNTI can be a function of the time and frequency index of PRACH resources used for sending the preamble sequence (in the first operation). In this second example, rather than simply counting the random access window (e.g., from 1-10 ms), in which every subframe is counted as one, the UE 310 can only count the DL subframes that are indicated by the eNodeB 320.

[0034] In a third example, the window size can be dynamically increased based on detection of valid DL subframes within the random access window. The window size of the random access window can be dynamically increased based on receipt of valid DL subframes. The eNodeB 320 can dynamically notify the UE 310 on the window size (depending on how busy the channel is), and this information can be indicated in one of the DL subframes. The UE 310 can use the transmission in DL subframes to detect whether the eNodeB 320 is in LBT. In one case, if there is no transmission in the DL subframes during the configured window period, then the window size can be increased by X ms, wherein X is a configurable integer value. The window size can be increased

by a total of Y times, wherein Y is a configurable integer value. As a non-limiting example, X can range between 1-10 ms and Y can have an integer value between 0 and 7. If there are transmissions in the DL subframes during the configured window period, then the UE 310 can assume that the preamble transmission has failed once a
5 configured window size period expires.

[0035] FIG. 4 illustrates an example of a listen-before-talk (LBT) failure that prevents a user equipment (UE) 410 from sending a connection request message (message 3) to an eNodeB 420 during a random access procedure. The LBT failure can occur at the UE 410, and as a result, the UE 410 may be unable to transmit the connection request
10 message (message 3) to the eNodeB 420. For example, the UE 410 can perform LBT, and upon detecting that an unlicensed channel is busy, the UE 410 can determine the LBT failure. The UE 410 and the eNodeB 420 can be included in an LTE, LAA or MuLTEfire system.

[0036] In one example, due to LBT failure at the UE 410, the UE 410 can skip the
15 transmission of the connection request message (message 3) on an UL grant scheduled by the eNodeB 420. Upon skipping the UL grant, the UE 410 can start a medium access channel (MAC) contention resolution timer. In addition, to reduce RACH latency, the UE 410 can detect whether the UL grant is used by another UE (due to preamble collision) by monitoring a control channel (e.g., PDCCH/ePDCCH) for a matching
20 temporary cell radio network temporary identifier (C-RNTI) assigned in the random access response.

[0037] In one example, the UE 410 can receive the random access response with the UL grant, UL time adjustment information and temporary C-RNTI (or C-RNTI) for the
25 connection request message (message 3). Upon receiving the random access response with the UL grant, the UL time adjustment information and temporary C-RNTI (or C-RNTI) for the connection request message (message 3), the UE 410 can handle the case where LBT fails at the UE 410 for the UL grant. If LBT fails at the UE 410 for the UL grant of the connection request message (message 3), the UE 410 can skip the UL grant. The UE 410 can start the MAC contention resolution timer, and the UE 410 can assume
30 an adaptive UL hybrid automatic repeat request (HARQ).

[0038] In one example, the eNodeB 420 can send a negative acknowledgement

(NACK) with a retransmission UL grant for the retransmission, and the UE 410 can attempt to send the connection request message (message 3) using the retransmission UL grant. In this case, the UE 410 may not increment a HARQ retransmission counter. In another example, the eNodeB 420 may not send a NACK with the retransmission UL grant when another RACH UE has performed the transmission (e.g., preamble collision) or due to asynchronous HARQ. In this example, the situation can be resolved using the MAC contention resolution timer, and a HARQ buffer can be flushed upon expiry. In addition, the UE 410 can attempt to detect DCI in the PDCCH/ePDCCH, which can be masked with the temporary C-RNTI. If detected, the UE 410 can stop the MAC contention resolution timer and reattempt the RACH procedure again, which can be useful in reducing latency.

[0039] In one example, after the connection request message (message 3) is sent from the UE 410, the MAC contention resolution timer can be (re)started. In addition, the MAC contention resolution timer can be extended to accommodate for LBT at the eNodeB 420 when receiving an RRC connection setup complete message (message 5).

[0040] In one configuration, a user equipment (UE) can be configured to operate in a 3GPP LTE network or MuLTEfire network. The UE can perform contention free or contention based random access. The UE can consider listen-before-talk (LBT) at an eNodeB or the UE when deciding to send a preamble to the eNodeB. The UE can consider LBT at the eNodeB or the UE when determining whether the preamble is successfully received by the eNodeB based on receipt of a response message from the eNodeB. The UE can consider LBT at the eNodeB or the UE when attempting to send a connection request message (message 3) according to an UL grant received in the response message from the eNodeB.

[0041] In one example, the UE can skip a preamble transmission in a subsequent PRACH opportunity when LBT fails for the subsequent PRACH opportunity. The UE can perform a PRACH resource selection (e.g., preamble sequences, time and frequency resources) for the subsequent PRACH opportunity. In addition, the UE can maintain a transmit (Tx) power.

[0042] In one example, the UE can determine a successful preamble transmission based on receiving a response message (e.g., a random access response message in LTE) from

the eNodeB within an extended random access window time.

[0043] In one example, the UE can determine a successful preamble transmission based on receiving a response message (e.g., a random access response message in LTE) from the eNodeB before a random access window counter reaches a configured maximum
5 random window count. A counter can be incremented by one whenever a valid DL subframe is determined (e.g., DRS, PBCH/PSS/SSS, DL subframes with DL data burst as indicated in a common PDCCH sent by the eNodeB).

[0044] In one example, the UE can determine a successful preamble transmission based on receiving a response message (e.g., a random access response message in LTE) from
10 the eNodeB within an extended random access window time. A random access window time can be dynamically extendable based on whether the UE detects valid DL subframes from the eNodeB within the random access window time.

[0045] In one example, the random access window time can be extended by configurable X ms (e.g., X=1 to 10 ms) if the UE does not detect valid DL subframes
15 during the random access window time, and can extend for a configurable amount of time Y (e.g., Y=1 to 8 ms).

[0046] In one example, the UE can skip an UL grant when LBT fails at the UE for the UL grant of the connection request message (message 3), and the UE can start a medium access channel (MAC) contention resolution timer even if the UE skips the UL
20 grant.

[0047] In one example, the UE can detect contention resolution failure when the UE detects control signaling for a DL transmission that the UL grant has been used by another UE.

[0048] Another example provides functionality 500 of a user equipment (UE) operable
25 to perform a physical random access channel (PRACH) procedure with an eNodeB, as shown in FIG. 5. The UE can comprise memory and one or more processors. The one or more processors can be configured to: select, at the UE, a PRACH preamble for transmission to an eNodeB during the PRACH procedure, as in block 510. The one or more processors can be configured to: perform a listen-before-talk (LBT) to determine
30 whether an unlicensed channel is available, as in block 520. The one or more processors

can be configured to: detect a LBT failure at the UE, wherein the LBT failure indicates that the unlicensed channel is unavailable to transmit the PRACH preamble during a PRACH opportunity, as in block 530. The one or more processors can be configured to: select, at the UE, new PRACH resources for a subsequent PRACH opportunity, wherein
5 the UE is configured to perform a PRACH preamble transmission during the subsequent PRACH opportunity when the UE is not subject to the LBT failure, as in block 540.

[0049] Another example provides functionality 600 of an eNodeB operable to perform a physical random access channel (PRACH) procedure with a user equipment (UE), as
10 shown in FIG. 6. The eNodeB can comprise memory and one or more processors. The one or more processors can be configured to: determine, at the eNodeB, to send a random access response to a UE within a random access window, as in block 610. The one or more processors can be configured to: perform a listen-before-talk (LBT) to determine whether an unlicensed channel is available, as in block 620. The one or more
15 processors can be configured to: detect a LBT failure at the eNodeB, wherein the LBT failure indicates that the unlicensed channel is unavailable to send the random access response during a PRACH opportunity, as in block 630. The one or more processors can be configured to: process, at the eNodeB, the random access response for transmission to the UE when the eNodeB is not subject to the LBT failure and during the random
20 access window, as in block 640.

[0050] Another example provides at least one machine readable storage medium having instructions 700 embodied thereon for performing a physical random access channel (PRACH) procedure between a user equipment (UE) and an eNodeB, as shown in FIG.
7. The instructions can be executed on a machine, where the instructions are included
25 on at least one computer readable medium or one non-transitory machine readable storage medium. The instructions when executed perform: determining, at the UE, to send a radio resource control (RRC) connection request message to an eNodeB, wherein the RRC connection request message is scheduled via an uplink grant from the eNodeB, as in block 710. The instructions when executed perform: performing a listen-before-talk (LBT) to determine whether an unlicensed channel is available, as in block 720.
30 The instructions when executed perform: detecting a LBT failure at the UE, wherein the

LBT failure indicates that the unlicensed channel is unavailable to send the RRC connection request message during the uplink grant scheduled by the eNodeB, as in block 730. The instructions when executed perform: decoding a negative acknowledgement (NACK) with a retransmission uplink grant received from the eNodeB, as in block 740. The instructions when executed perform: processing, at the UE, the RRC connection request message for transmission to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure, as in block 750.

[0051] FIG. 8 provides an example illustration of a user equipment (UE) device 800 and a node 820. The UE device 800 can include a wireless device, a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The UE device 800 can include one or more antennas configured to communicate with the node 820 or transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), a remote radio unit (RRU), a central processing module (CPM), or other type of wireless wide area network (WWAN) access point. The node 820 can include one or more processors 822, memory 824 and a transceiver 826. The UE device 800 can be configured to communicate using at least one wireless communication standard including 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The UE device 800 can communicate using separate antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The UE device 800 can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN.

[0052] In some embodiments, the UE device 800 may include application circuitry 802, baseband circuitry 804, Radio Frequency (RF) circuitry 806, front-end module (FEM) circuitry 808 and one or more antennas 810, coupled together at least as shown. In addition, the node 820 may include, similar to that described for the UE device 800, application circuitry, baseband circuitry, Radio Frequency (RF) circuitry, front-end module (FEM) circuitry and one or more antennas

[0053] The application circuitry 802 may include one or more application processors.

For example, the application circuitry 802 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
5 may include a storage medium, and may be configured to execute instructions stored in the storage medium to enable various applications and/or operating systems to run on the system.

[0054] The baseband circuitry 804 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 804 may
10 include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 806 and to generate baseband signals for a transmit signal path of the RF circuitry 806. Baseband processing circuitry 804 may interface with the application circuitry 802 for generation and processing of the baseband signals and for controlling operations of the RF circuitry
15 806. For example, in some embodiments, the baseband circuitry 804 may include a second generation (2G) baseband processor 804a, third generation (3G) baseband processor 804b, fourth generation (4G) baseband processor 804c, and/or other baseband processor(s) 804d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry
20 804 (e.g., one or more of baseband processors 804a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 806. 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 804 may
25 include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 804 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
30 limited to these examples and may include other suitable functionality in other embodiments.

[0055] In some embodiments, the baseband circuitry 804 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) 804e of the baseband circuitry 804 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) 804f. The audio DSP(s) 804f 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 804 and the application circuitry 802 may be implemented together such as, for example, on a system on a chip (SOC).

[0056] In some embodiments, the baseband circuitry 804 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 804 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 804 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0057] The RF circuitry 806 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 806 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 806 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 808 and provide baseband signals to the baseband circuitry 804. RF circuitry 806 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 804 and provide RF

output signals to the FEM circuitry 808 for transmission.

[0058] In some embodiments, the RF circuitry 806 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 806 may include mixer circuitry 806a, amplifier circuitry 806b and filter circuitry 806c. The transmit
5 signal path of the RF circuitry 806 may include filter circuitry 806c and mixer circuitry 806a. RF circuitry 806 may also include synthesizer circuitry 806d for synthesizing a frequency for use by the mixer circuitry 806a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 806a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 808
10 based on the synthesized frequency provided by synthesizer circuitry 806d. The amplifier circuitry 806b may be configured to amplify the down-converted signals and the filter circuitry 806c 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
15 circuitry 804 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a necessity. In some embodiments, mixer circuitry 806a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0059] In some embodiments, the mixer circuitry 806a of the transmit signal path may
20 be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 806d to generate RF output signals for the FEM circuitry 808. The baseband signals may be provided by the baseband circuitry 804 and may be filtered by filter circuitry 806c. The filter circuitry 806c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0060] In some embodiments, the mixer circuitry 806a of the receive signal path and
25 the mixer circuitry 806a of the transmit signal path may include two or more mixers and may be arranged for quadrature down-conversion and/or up-conversion respectively. In some embodiments, the mixer circuitry 806a of the receive signal path and the mixer circuitry 806a of the transmit signal path may include two or more mixers and may be
30 arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 806a of the receive signal path and the mixer circuitry 806a may be

arranged for direct down-conversion and/or direct up-conversion, respectively. In some embodiments, the mixer circuitry 806a of the receive signal path and the mixer circuitry 806a of the transmit signal path may be configured for super-heterodyne operation.

[0061] 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 806 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 804 may include a digital baseband interface to communicate with the RF circuitry 806.

[0062] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[0063] In some embodiments, the synthesizer circuitry 806d 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 806d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0064] The synthesizer circuitry 806d may be configured to synthesize an output frequency for use by the mixer circuitry 806a of the RF circuitry 806 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 806d may be a fractional $N/N+1$ synthesizer.

[0065] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a necessity. Divider control input may be provided by either the baseband circuitry 804 or the applications processor 802 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 802.

[0066] Synthesizer circuitry 806d of the RF circuitry 806 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

5 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.

10 **[0067]** In some embodiments, synthesizer circuitry 806d 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

15 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 806 may include an IQ/polar converter.

[0068] FEM circuitry 808 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 810,

20 amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 806 for further processing. FEM circuitry 808 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 806 for transmission by one or more of the one or more antennas 810.

25 **[0069]** In some embodiments, the FEM circuitry 808 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

30 806). The transmit signal path of the FEM circuitry 808 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 806), and one or more

filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 810).

[0070] FIG. 9 provides an example illustration of the wireless device, such as a user equipment (UE), a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The wireless device can include one or more antennas configured to communicate with a node, macro node, low power node (LPN), or, transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband processing unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), or other type of wireless wide area network (WWAN) access point. The wireless device can be configured to communicate using at least one wireless communication standard such as, but not limited to, 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The wireless device can communicate using separate antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The wireless device can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN. The wireless device can also comprise a wireless modem. The wireless modem can comprise, for example, a wireless radio transceiver and baseband circuitry (e.g., a baseband processor). The wireless modem can, in one example, modulate signals that the wireless device transmits via the one or more antennas and demodulate signals that the wireless device receives via the one or more antennas.

[0071] FIG. 9 also provides an illustration of a microphone and one or more speakers that can be used for audio input and output from the wireless device. The display screen can be a liquid crystal display (LCD) screen, or other type of display screen such as an organic light emitting diode (OLED) display. The display screen can be configured as a touch screen. The touch screen can use capacitive, resistive, or another type of touch screen technology. An application processor and a graphics processor can be coupled to internal memory to provide processing and display capabilities. A non-volatile memory port can also be used to provide data input/output options to a user. The non-volatile memory port can also be used to expand the memory capabilities of the wireless device. A keyboard can be integrated with the wireless device or wirelessly connected to the

wireless device to provide additional user input. A virtual keyboard can also be provided using the touch screen.

Examples

[0072] The following examples pertain to specific technology embodiments and point out specific features, elements, or actions that can be used or otherwise combined in achieving such embodiments.

[0073] Example 1 includes an apparatus of a user equipment (UE) operable to perform a physical random access channel (PRACH) procedure with an eNodeB, the apparatus comprising: memory; and one or more processors configured to: select, at the UE, a PRACH preamble for transmission to an eNodeB during the PRACH procedure; perform a listen-before-talk (LBT) to determine whether an unlicensed channel is available; detect a LBT failure at the UE, wherein the LBT failure indicates that the unlicensed channel is unavailable to transmit the PRACH preamble during a PRACH opportunity; and select, at the UE, new PRACH resources for a subsequent PRACH opportunity, wherein the UE is configured to perform a PRACH preamble transmission during the subsequent PRACH opportunity when the UE is not subject to the LBT failure.

[0074] Example 2 includes the apparatus of Example 1, further comprising a transceiver configured to transmit the PRACH preamble to the eNodeB during the subsequent PRACH opportunity.

[0075] Example 3 includes the apparatus of Examples 1 to 2, wherein the one or more processors are configured to initiate the PRACH procedure during one of: an initial access from idle mode, an uplink scheduling request in connected mode, an uplink time alignment in connected mode, a handover in connected mode or a radio resource control (RRC) connection reestablishment in connected mode.

[0076] Example 4 includes the apparatus of any of Examples 1 to 3, wherein the one or more processors are configured to maintain a transmit power at the UE after detection of the LBT failure to prevent uplink interference at the UE due to redundant power ramping.

[0077] Example 5 includes the apparatus of any of Examples 1 to 4, wherein the one or

more processors are configured to select the new PRACH resources for the subsequent PRACH opportunity to randomize the PRACH preamble and time and frequency resources utilized at the UE.

5 **[0078]** Example 6 includes the apparatus of any of Examples 1 to 5, wherein the UE is configured for MuLTEfire or Licensed Assisted Access (LAA).

10 **[0079]** Example 7 includes an apparatus of an eNodeB operable to perform a physical random access channel (PRACH) procedure with a user equipment (UE), the apparatus comprising: memory; and one or more processors configured to: determine, at the eNodeB, to send a random access response to a UE within a random access window and
15 in response to receiving a PRACH preamble from the UE; perform a listen-before-talk (LBT) to determine whether an unlicensed channel is available; detect a LBT failure at the eNodeB, wherein the LBT failure indicates that the unlicensed channel is unavailable to send the random access response during a PRACH opportunity; and process, at the eNodeB, the random access response for transmission to the UE when
the eNodeB is not subject to the LBT failure and during the random access window.

[0080] Example 8 includes the apparatus of Example 7, further comprising a transceiver configured to transmit the random access response to the UE during the random access window.

20 **[0081]** Example 9 includes the apparatus of any of Examples 7 to 8, wherein the one or more processors are further configured to extend the random access window to enable the UE to receive the random access response from the eNodeB within the random access window, and transmission of the random access response is delayed within the random access window due to the LBT failure at the eNodeB.

25 **[0082]** Example 10 includes the apparatus of any of Examples 7 to 9, wherein the random access window is utilized as a counter, wherein valid downlink subframes are counted during the random access window and the counter is stopped upon detection of the random access response.

30 **[0083]** Example 11 includes the apparatus of any of Examples 7 to 10, wherein the valid downlink subframes include subframes with a discovery reference signal (DRS), physical broadcast channel (PBCH) signal, primary synchronization signal (PSS),

secondary synchronization signal (SSS), a downlink data burst, or other control signaling, as indicated in a common physical downlink control channel (PDCCH) sent by the eNodeB.

5 **[0084]** Example 12 includes the apparatus of any of Examples 7 to 11, wherein the one or more processors are further configured to: dynamically configure a size of the random access window, wherein the random access window is dynamically configured based on a detection of valid downlink subframes at the UE within the random access window; and provide an indication of the size of the random access window to the UE during a downlink subframe.

10 **[0085]** Example 13 includes the apparatus of any of Examples 7 to 12, wherein the one or more processors are further configured to extend the size of the random access window by a defined period of time when the UE does not detect valid downlink subframes within the random access window, and the size of the random access window can be extended a defined number of times.

15 **[0086]** Example 14 includes the apparatus of any of Examples 7 to 13, wherein the eNodeB is configured for MuLTEfire or Licensed Assisted Access (LAA).

20 **[0087]** Example 15 includes at least one machine readable storage medium having instructions embodied thereon for performing a physical random access channel (PRACH) procedure between a user equipment (UE) and an eNodeB, the instructions when executed by one or more processors at the UE perform the following:
determining, at the UE, to send a radio resource control (RRC) connection request message to an eNodeB, wherein the RRC connection request message is scheduled via an uplink grant from the eNodeB; performing a listen-before-talk (LBT) to determine whether an unlicensed channel is available; detecting a LBT failure at the UE, wherein
25 the LBT failure indicates that the unlicensed channel is unavailable to send the RRC connection request message during the uplink grant scheduled by the eNodeB; decoding a negative acknowledgement (NACK) with a retransmission uplink grant received from the eNodeB; and processing, at the UE, the RRC connection request message for
30 transmission to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.

[0088] Example 16 includes the at least one machine readable storage medium of Example 15, further comprising instructions which when executed perform the following: starting a medium access control (MAC) contention resolution timer when the UE skips the uplink grant scheduled by the eNodeB due to the LBT failure at the
5 UE.

[0089] Example 17 includes the at least one machine readable storage medium of any of Examples 15 to 16, further comprising instructions which when executed perform the following: determining to not increment a hybrid automatic repeat request (HARQ) retransmission counter after the UE attempts to transmit the RRC connection request
10 message to the eNodeB on the retransmission uplink grant.

[0090] Example 18 includes the at least one machine readable storage medium of any of Examples 15 to 17, further comprising instructions which when executed perform the following: detecting downlink control information (DCI) in a physical downlink control channel (PDCCH) or enhanced PDCCH (ePDCCH); stopping a medium access control
15 (MAC) contention resolution timer upon detection of the DCI; and restarting the PRACH procedure.

[0091] Example 19 includes the at least one machine readable storage medium of any of Examples 15 to 18, wherein a medium access control (MAC) contention resolution timer is extended to accommodate the UE sending an RRC connection setup complete
20 message to the eNodeB after an LBT failure at the eNodeB.

[0092] Example 20 includes the at least one machine readable storage medium of any of Examples 15 to 19, further comprising instructions which when executed perform the following: starting a medium access control (MAC) contention resolution timer upon
25 transmitting the RRC connection request message to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.

[0093] Example 21 includes the at least one machine readable storage medium of any of Examples 15 to 20, further comprising instructions which when executed perform the following: detecting whether the uplink grant is used by a second UE due to a preamble collision by monitoring a physical downlink control channel (PDCCH) or enhanced
30 PDCCH (ePDCCH) for a matching temporary cell radio network temporary identifier

(C-RNTI) assigned in a random access response received from the eNodeB.

[0094] Example 22 includes the at least one machine readable storage medium of any of Examples 15 to 21, wherein the UE is configured for MuLTEfire or Licensed Assisted Access (LAA).

5 **[0095]** Example 23 includes a user equipment (UE) operable to perform a physical random access channel (PRACH) procedure with an eNodeB, the UE comprising:
means for determining, at the UE, to send a radio resource control (RRC) connection request message to an eNodeB, wherein the RRC connection request message is scheduled via an uplink grant from the eNodeB; means for performing a listen-before-talk (LBT) to determine whether an unlicensed channel is available; means for detecting
10 a LBT failure at the UE, wherein the LBT failure indicates that the unlicensed channel is unavailable to send the RRC connection request message during the uplink grant scheduled by the eNodeB; means for decoding a negative acknowledgement (NACK) with a retransmission uplink grant received from the eNodeB; and means for
15 processing, at the UE, the RRC connection request message for transmission to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.

[0096] Example 24 includes the UE of Example 23, further comprising means for starting a medium access control (MAC) contention resolution timer when the UE skips
20 the uplink grant scheduled by the eNodeB due to the LBT failure at the UE.

[0097] Example 25 includes the UE of any of Examples 23 to 24, further comprising means for determining to not increment a hybrid automatic repeat request (HARQ) retransmission counter after the UE attempts to transmit the RRC connection request message to the eNodeB on the retransmission uplink grant.

25 **[0098]** Example 26 includes the UE of any of Examples 23 to 25, further comprising:
means for detecting downlink control information (DCI) in a physical downlink control channel (PDCCH) or enhanced PDCCH (ePDCCH); means for stopping a medium access control (MAC) contention resolution timer upon detection of the DCI; and
means for restarting the PRACH procedure.

30 **[0099]** Example 27 includes the UE of any of Examples 23 to 26, wherein a medium

access control (MAC) contention resolution timer is extended to accommodate the UE sending an RRC connection setup complete message to the eNodeB after an LBT failure at the eNodeB.

[00100] Example 28 includes the UE of any of Examples 23 to 27, further comprising means for starting a medium access control (MAC) contention resolution timer upon transmitting the RRC connection request message to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.

[00101] Example 29 includes the UE of any of Examples 23 to 28, further comprising means for detecting whether the uplink grant is used by a second UE due to a preamble collision by monitoring a physical downlink control channel (PDCCH) or enhanced PDCCH (ePDCCH) for a matching temporary cell radio network temporary identifier (C-RNTI) assigned in a random access response received from the eNodeB.

[00102] Example 30 includes the UE of any of Examples 23 to 29, wherein the UE is configured for MuLTEfire or Licensed Assisted Access (LAA).

[00103] Various techniques, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, compact disc-read-only memory (CD-ROMs), hard drives, non-transitory computer readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the various techniques. In the case of program code execution on programmable computers, the computing device may include a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. The volatile and non-volatile memory and/or storage elements may be a random-access memory (RAM), erasable programmable read only memory (EPROM), flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). In one example, selected components of the transceiver module can be located in a cloud radio access network (C-RAN). One or more programs that may implement or utilize the

various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[00104] 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.

[00105] It should be understood that many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very-large-scale integration (VLSI) circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00106] Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module may not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

[00107] Indeed, a module of executable code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among

different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

[00108] Reference throughout this specification to "an example" or "exemplary" means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment of the present technology. Thus, appearances of the phrases "in an example" or the word "exemplary" in various places throughout this specification are not necessarily all referring to the same embodiment.

[00109] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience.

However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and example of the present technology may be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as defacto equivalents of one another, but are to be considered as separate and autonomous representations of the present technology.

[00110] Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are provided, such as examples of layouts, distances, network examples, etc., to provide a thorough understanding of embodiments of the technology. One skilled in the relevant art will recognize, however, that the technology can be practiced without one or more of the specific details, or with other methods, components, layouts, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects

of the technology.

[00111] While the forgoing examples are illustrative of the principles of the present technology in one or more particular applications, it will be apparent to those of ordinary skill in the art that numerous modifications in form, usage and details of implementation can be made without the exercise of inventive faculty, and without
5 departing from the principles and concepts of the technology. Accordingly, it is not intended that the technology be limited, except as by the claims set forth below.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE) operable to perform a physical random access channel (PRACH) procedure with an eNodeB, the apparatus comprising:
5 memory; and
one or more processors configured to:
select, at the UE, a PRACH preamble for transmission to an eNodeB during the PRACH procedure;
perform a listen-before-talk (LBT) to determine whether an
10 unlicensed channel is available;
detect a LBT failure at the UE, wherein the LBT failure indicates that the unlicensed channel is unavailable to transmit the PRACH preamble during a PRACH opportunity; and
select, at the UE, new PRACH resources for a subsequent PRACH
15 opportunity, wherein the UE is configured to perform a PRACH preamble transmission during the subsequent PRACH opportunity when the UE is not subject to the LBT failure.
2. The apparatus of claim 1, further comprising a transceiver configured to transmit
20 the PRACH preamble to the eNodeB during the subsequent PRACH opportunity.
3. The apparatus of claim 1, wherein the one or more processors are configured to initiate the PRACH procedure during one of: an initial access from idle mode, an uplink scheduling request in connected mode, an uplink time alignment in
25 connected mode, a handover in connected mode or a radio resource control (RRC) connection reestablishment in connected mode.
4. The apparatus of claim 1, wherein the one or more processors are configured to maintain a transmit power at the UE after detection of the LBT failure to prevent
30 uplink interference at the UE due to redundant power ramping.

5. The apparatus of any of claims 1 to 4, wherein the one or more processors are configured to select the new PRACH resources for the subsequent PRACH opportunity to randomize the PRACH preamble and time and frequency resources utilized at the UE.
- 5 6. The apparatus of claim 1, wherein the UE is configured for MuLTEfire or Licensed Assisted Access (LAA).
7. An apparatus of an eNodeB operable to perform a physical random access channel (PRACH) procedure with a user equipment (UE), the apparatus comprising:
- 10 memory; and
one or more processors configured to:
determine, at the eNodeB, to send a random access response to a
UE within a random access window and in response to receiving a
15 PRACH preamble from the UE;
perform a listen-before-talk (LBT) to determine whether an
unlicensed channel is available;
detect a LBT failure at the eNodeB, wherein the LBT failure
indicates that the unlicensed channel is unavailable to send the random
20 access response during a PRACH opportunity; and
process, at the eNodeB, the random access response for
transmission to the UE when the eNodeB is not subject to the LBT failure
and during the random access window.
- 25 8. The apparatus of claim 7, further comprising a transceiver configured to transmit the random access response to the UE during the random access window.
9. The apparatus of claim 7, wherein the one or more processors are further configured to extend the random access window to enable the UE to receive the
30 random access response from the eNodeB within the random access window, and transmission of the random access response is delayed within the random access window due to the LBT failure at the eNodeB.

10. The apparatus of claim 7, wherein the random access window is utilized as a counter, wherein valid downlink subframes are counted during the random access window and the counter is stopped upon detection of the random access response.

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11. The apparatus of any of claims 7 to 10, wherein the valid downlink subframes include subframes with a discovery reference signal (DRS), physical broadcast channel (PBCH) signal, primary synchronization signal (PSS), secondary synchronization signal (SSS), a downlink data burst, or other control signaling, as indicated in a common physical downlink control channel (PDCCH) sent by the eNodeB.

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12. The apparatus of claim 7, wherein the one or more processors are further configured to:

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dynamically configure a size of the random access window, wherein the random access window is dynamically configured based on a detection of valid downlink subframes at the UE within the random access window; and

provide an indication of the size of the random access window to the UE during a downlink subframe.

20

13. The apparatus of claim 7, wherein the one or more processors are further configured to extend the size of the random access window by a defined period of time when the UE does not detect valid downlink subframes within the random access window, and the size of the random access window can be extended a defined number of times.

25

14. The apparatus of claim 7, wherein the eNodeB is configured for MuLTEfire or Licensed Assisted Access (LAA).

30

15. At least one machine readable storage medium having instructions embodied thereon for performing a physical random access channel (PRACH) procedure

between a user equipment (UE) and an eNodeB, the instructions when executed by one or more processors at the UE perform the following:

determining, at the UE, to send a radio resource control (RRC) connection request message to an eNodeB, wherein the RRC connection request message is scheduled via an uplink grant from the eNodeB;

performing a listen-before-talk (LBT) to determine whether an unlicensed channel is available;

detecting a LBT failure at the UE, wherein the LBT failure indicates that the unlicensed channel is unavailable to send the RRC connection request message during the uplink grant scheduled by the eNodeB;

decoding a negative acknowledgement (NACK) with a retransmission uplink grant received from the eNodeB; and

processing, at the UE, the RRC connection request message for transmission to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.

16. The at least one machine readable storage medium of claim 15, further comprising instructions which when executed perform the following: starting a medium access control (MAC) contention resolution timer when the UE skips the uplink grant scheduled by the eNodeB due to the LBT failure at the UE.

17. The at least one machine readable storage medium of claim 15, further comprising instructions which when executed perform the following: determining to not increment a hybrid automatic repeat request (HARQ) retransmission counter after the UE attempts to transmit the RRC connection request message to the eNodeB on the retransmission uplink grant.

18. The at least one machine readable storage medium of claim 15, further comprising instructions which when executed perform the following:
detecting downlink control information (DCI) in a physical downlink control channel (PDCCH) or enhanced PDCCH (ePDCCH);

stopping a medium access control (MAC) contention resolution timer upon detection of the DCI; and
restarting the PRACH procedure.

- 5 19. The at least one machine readable storage medium of any of claims 15 to 18, wherein a medium access control (MAC) contention resolution timer is extended to accommodate the UE sending an RRC connection setup complete message to the eNodeB after an LBT failure at the eNodeB.
- 10 20. The at least one machine readable storage medium of any of claims 15 to 18, further comprising instructions which when executed perform the following: starting a medium access control (MAC) contention resolution timer upon transmitting the RRC connection request message to the eNodeB using the retransmission uplink grant when the UE is not subject to the LBT failure.
- 15
21. The at least one machine readable storage medium of claim 15, further comprising instructions which when executed perform the following: detecting whether the uplink grant is used by a second UE due to a preamble collision by monitoring a physical downlink control channel (PDCCH) or enhanced PDCCH (ePDCCH) for
- 20 a matching temporary cell radio network temporary identifier (C-RNTI) assigned in a random access response received from the eNodeB.
22. The at least one machine readable storage medium of claim 15, wherein the UE is configured for MuLTEfire or Licensed Assisted Access (LAA).

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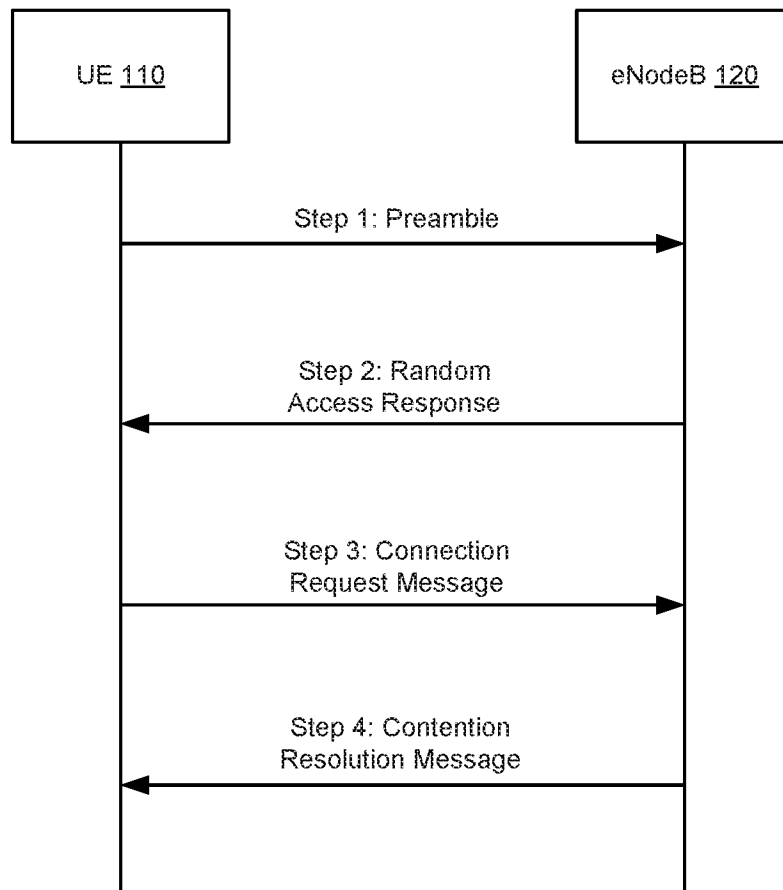


FIG. 1

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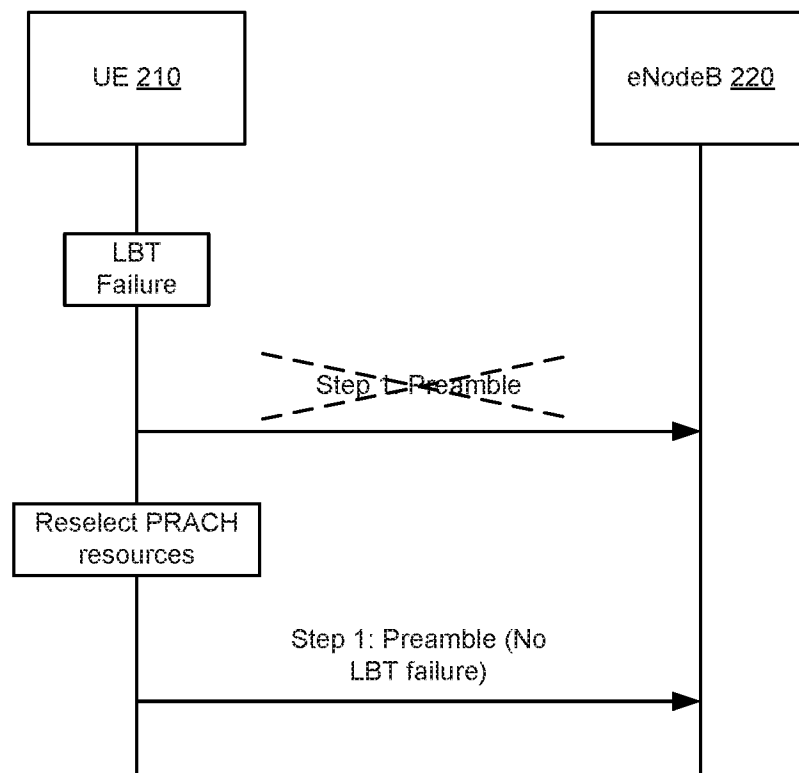


FIG. 2

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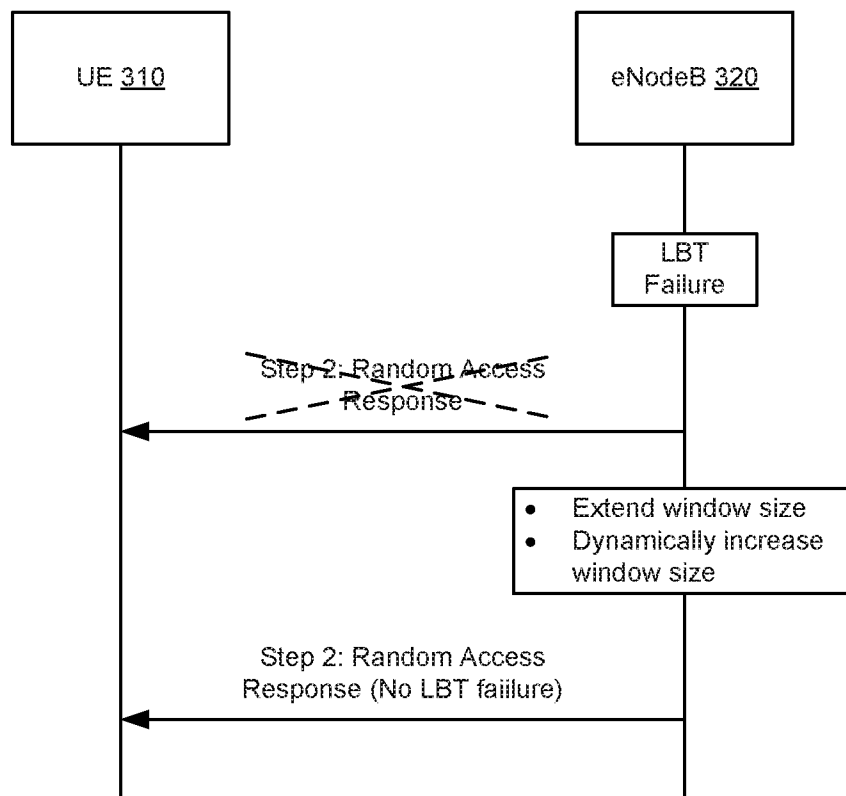


FIG. 3

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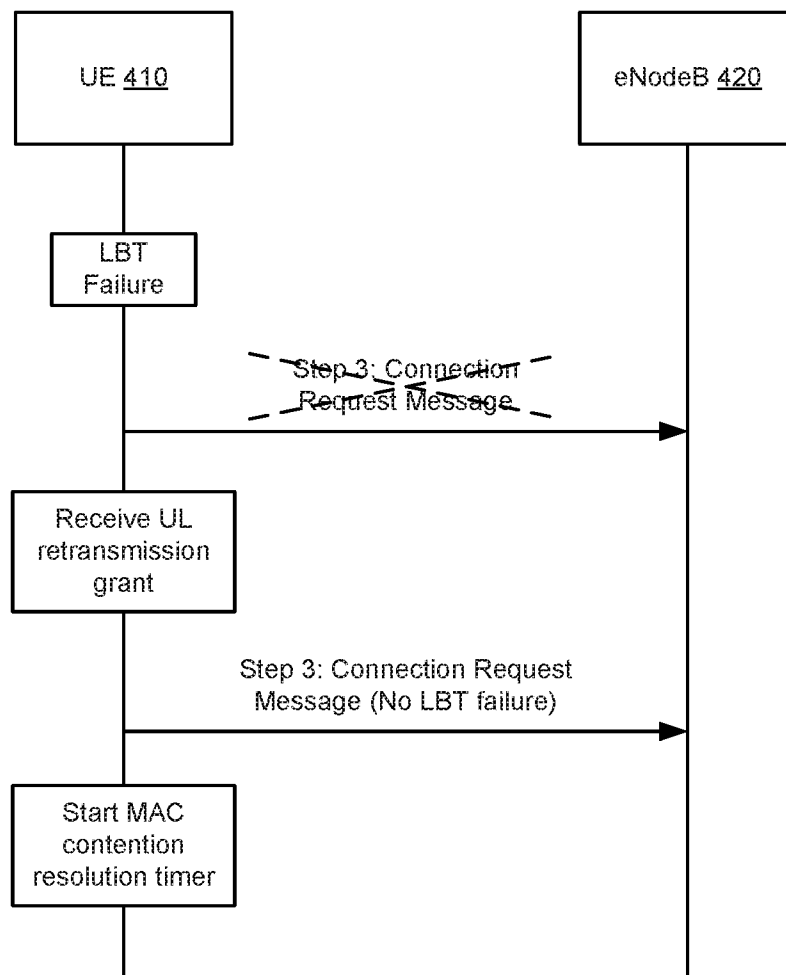


FIG. 4

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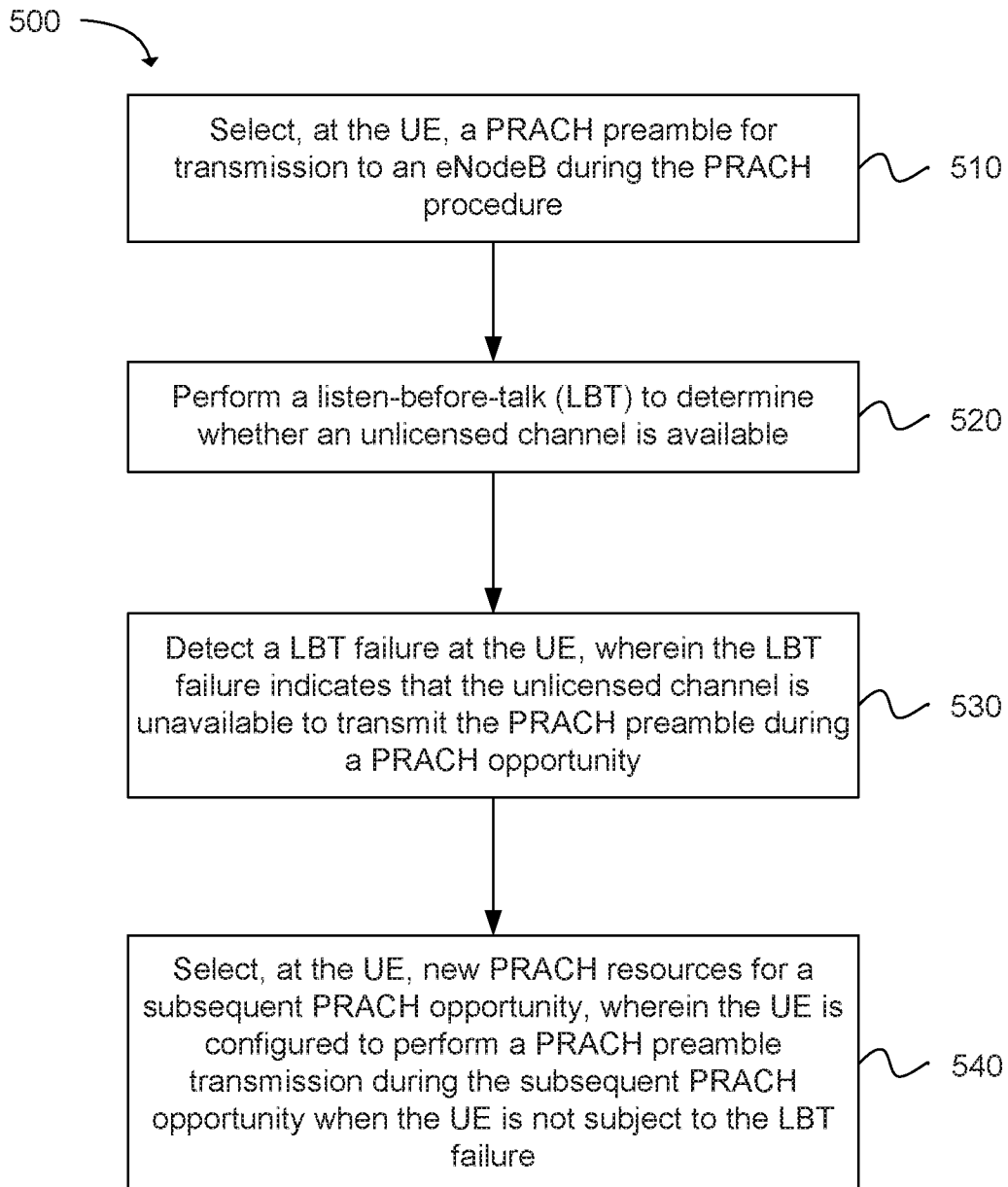


FIG. 5

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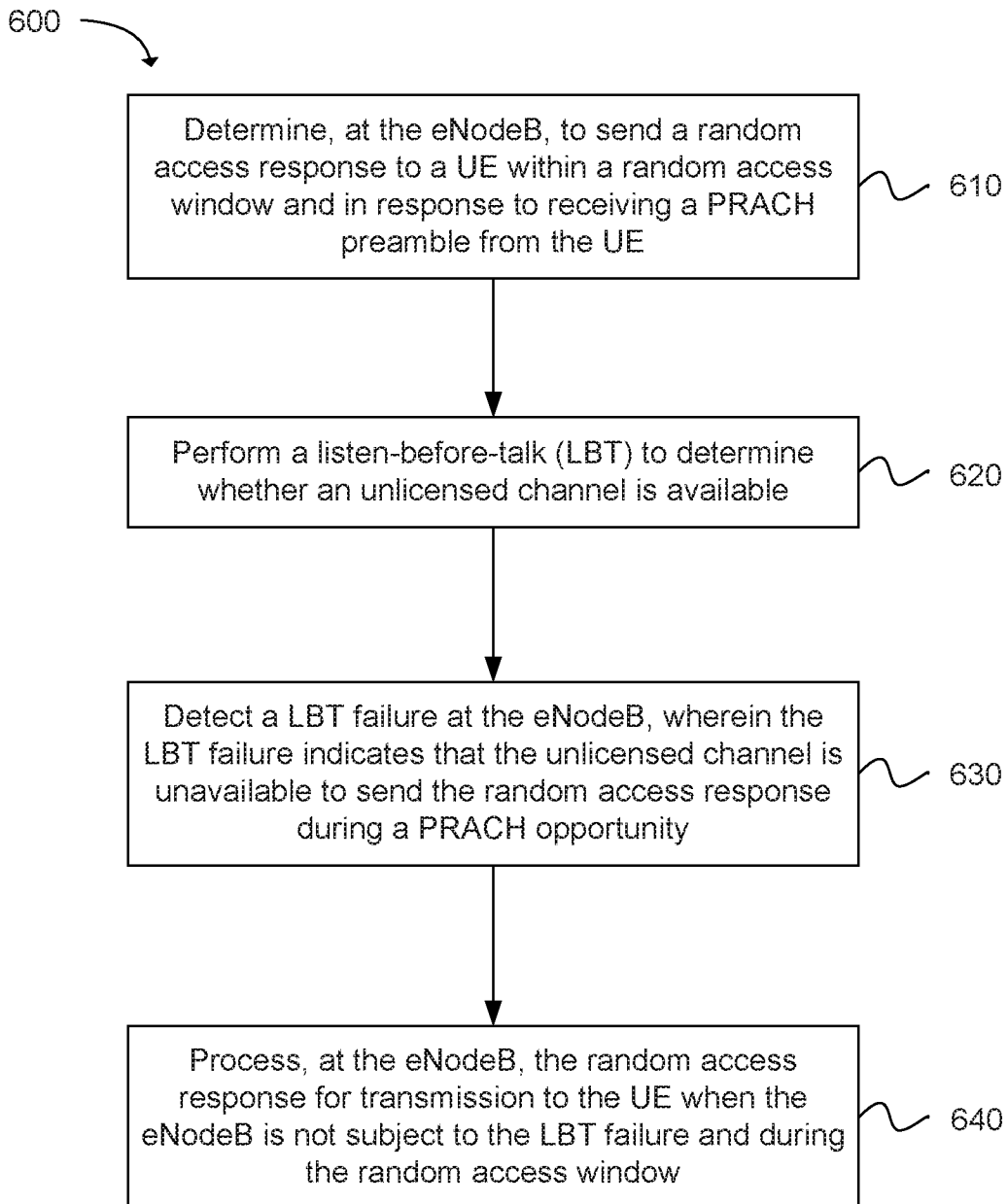


FIG. 6

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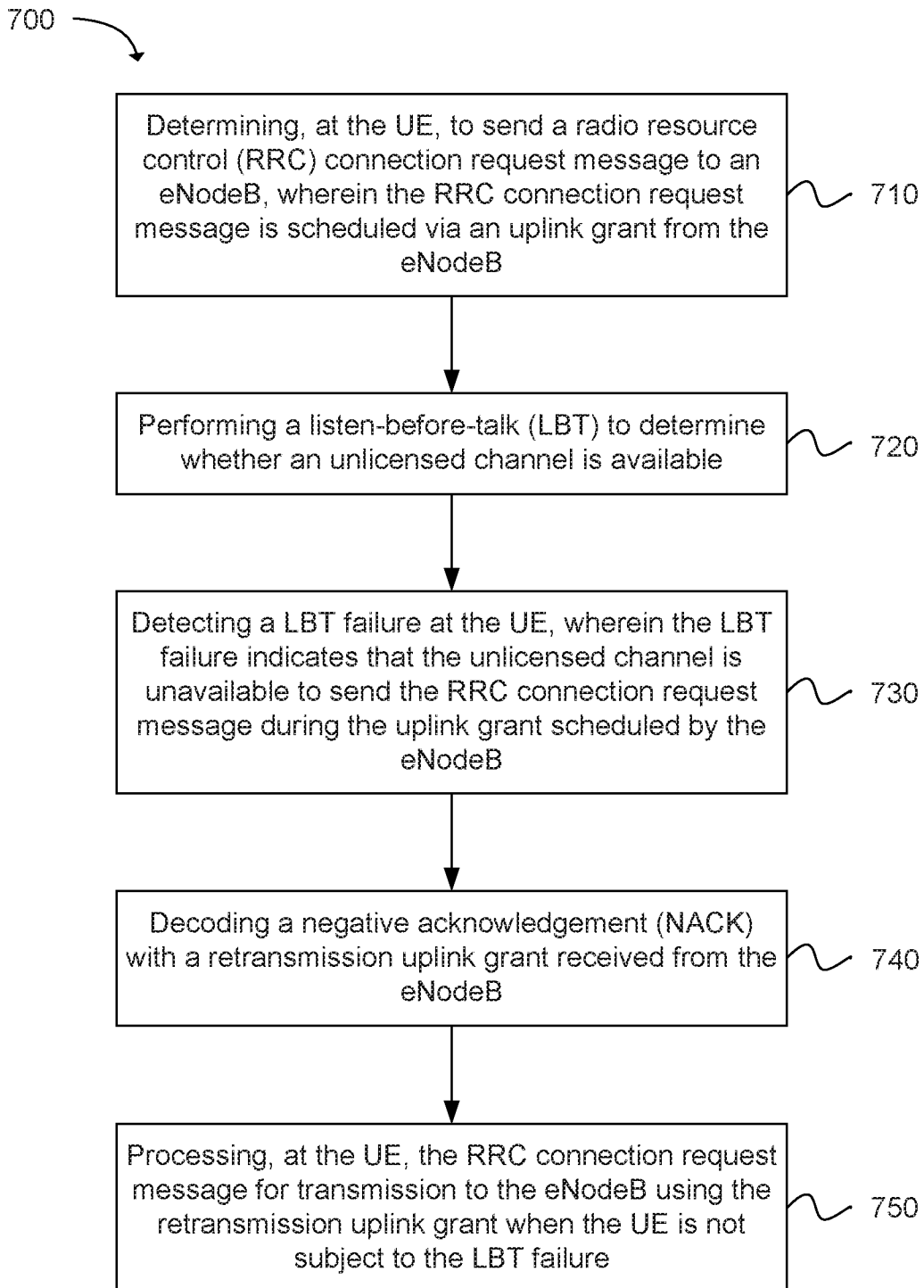


FIG. 7

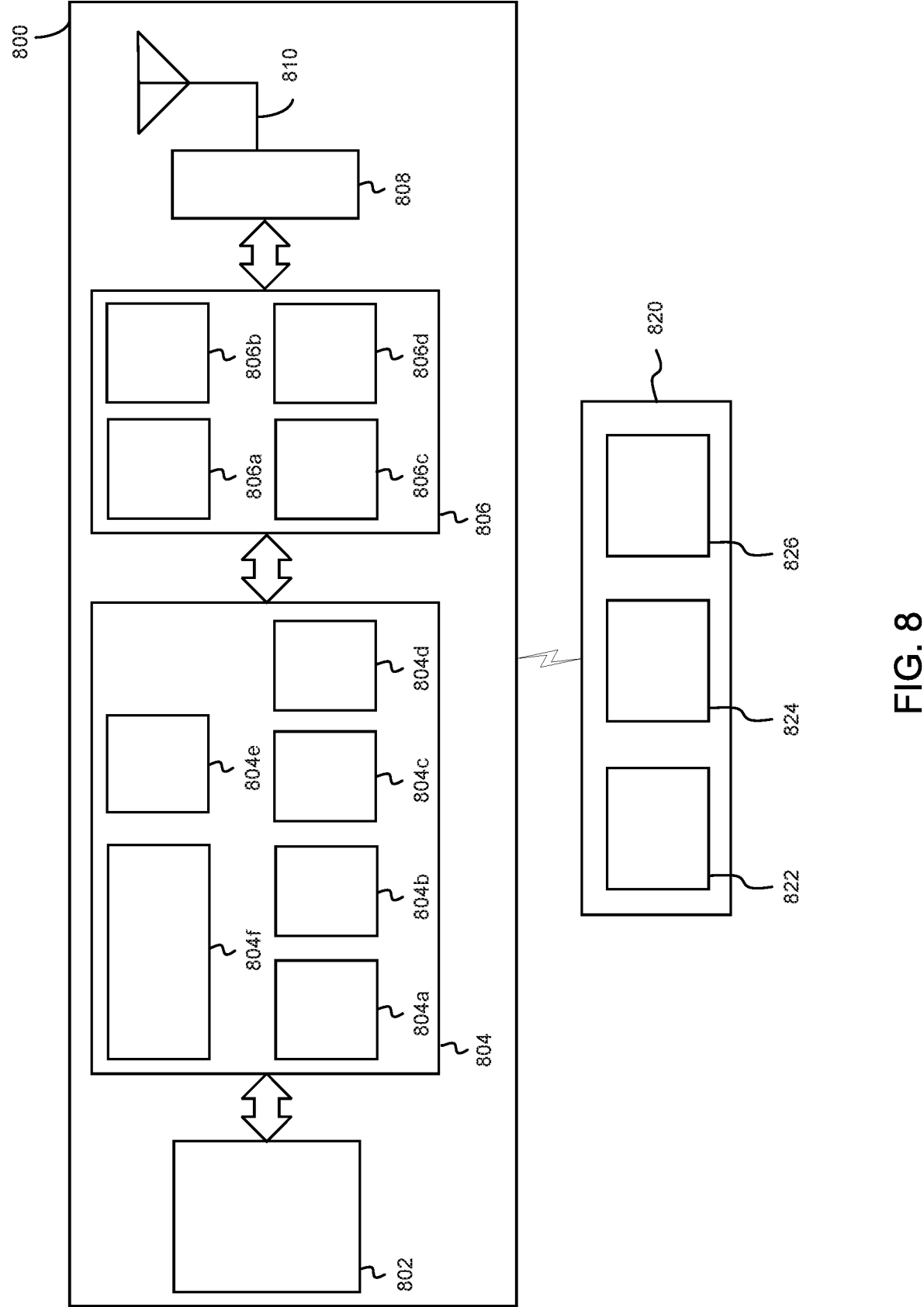


FIG. 8

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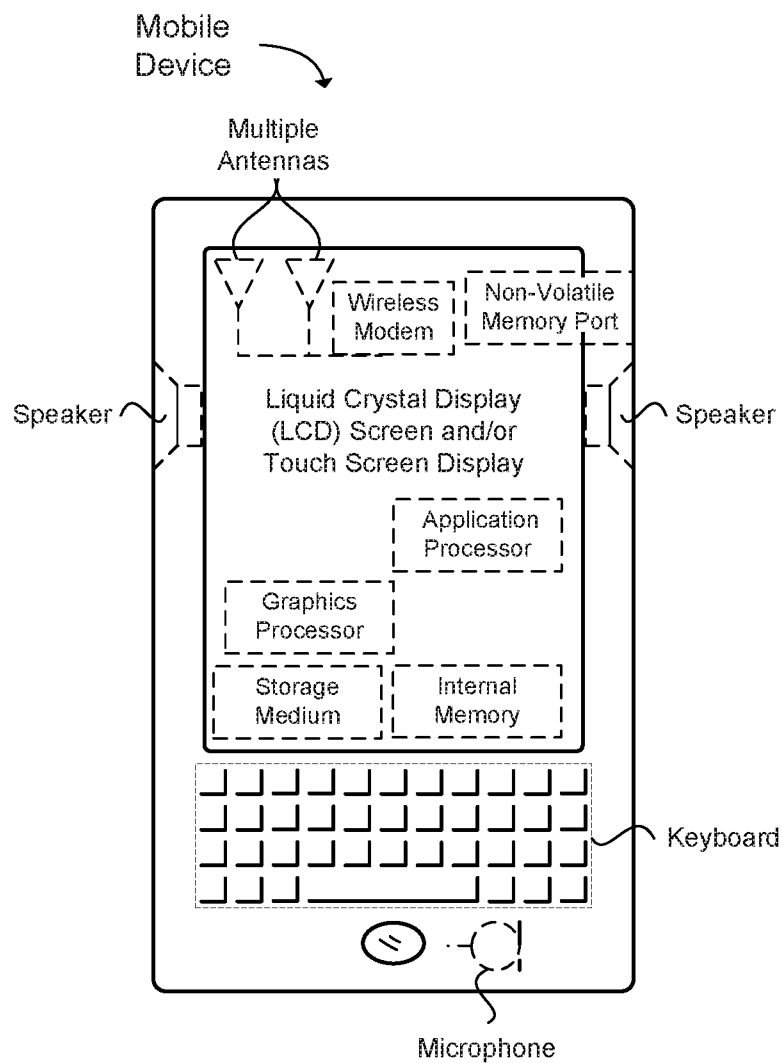


FIG. 9