



(51) International Patent Classification:

H04W 72/14 (2009.01) H04W 16/14 (2009.01)  
H04W 72/12 (2009.01) H04L 5/00 (2006.01)  
H04W 74/08 (2009.01)

(21) International Application Number:

PCT/US2016/050655

(22) International Filing Date:

8 September 2016 (08.09.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/323,102 15 April 2016 (15.04.2016) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available):

AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available):

ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

— with international search report (Art. 21(3))

(54) Title: SYSTEMS, METHODS AND DEVICES FOR OPTIMIZED UPLINK GRANT TRANSMISSION TO ENABLE MULTI-SUBFRAME SCHEDULING

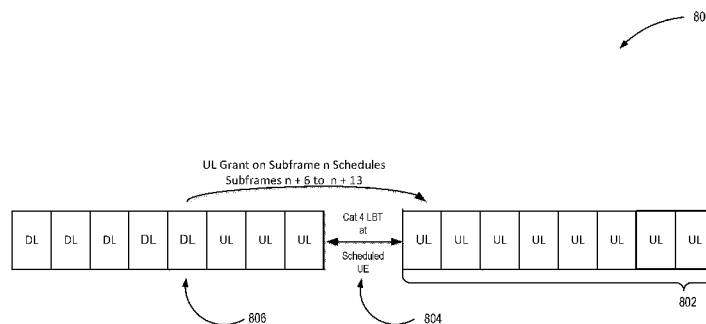


FIG. 8

(57) Abstract: Design of uplink (UL) grants can include scheduling multi-frame UL Licensed-Assisted Access (LAA) transmissions. These UL LAA transmissions can include a single UL grant in a subframe for a UE to schedule multiple physical uplink shared channel (PUSCH) transmissions and/or a single UL grant to schedule interlace allocations. The design can include (1) multi-subframe scheduling, (2) uplink LBT indication and/or (3) multi-clustered transmission using block interleaved frequency division multiple access (B-IFDMA) design.

WO 2017/180179 A1

SYSTEMS, METHODS AND DEVICES FOR OPTIMIZED UPLINK GRANT  
TRANSMISSION TO ENABLE MULTI-SUBFRAME SCHEDULING

Related Application

**[0001]** This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 62/323,102 filed April 15, 2016, which is incorporated by reference herein in its entirety.

Technical Field

**[0002]** The present disclosure relates to uplink transmissions in cellular devices and more specifically to optimized uplink grant transmission to enable multi-subframe scheduling in a shared wireless medium.

Background

**[0003]** Wireless mobile communication technology uses various standards and protocols to transmit data between a base station and a wireless mobile device. Wireless communication system standards and protocols can include the 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE); the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard, which is commonly known to industry groups as worldwide interoperability for microwave access (WiMAX); and the IEEE 802.11 standard for wireless local area networks (WLAN), which is commonly known to industry groups as Wi-Fi. In 3GPP radio access networks (RANs) in LTE systems, the base station can include a RAN Node such as a Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node B (also commonly denoted as evolved Node B, enhanced Node B, eNodeB, or eNB) and/or Radio Network Controller (RNC) in an E-UTRAN, which communicate with a wireless communication device, known as user equipment (UE).

**[0004]** RANs use a radio access technology (RAT) to communicate between the RAN Node and UE. RANs can include global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE) RAN (GERAN), Universal Terrestrial Radio Access Network (UTRAN), and/or E-UTRAN, which provide access to communication services through a core network. Each of the RANs operates according to a specific 3GPP RAT. For

example, the GERAN 104 implements GSM and/or EDGE RAT, the UTRAN 106 implements universal mobile telecommunication system (UMTS) RAT or other 3GPP RAT, and the E-UTRAN 108 implements LTE RAT.

[0005] A core network can be connected to the UE through the RAN Node. The core network can include a serving gateway (SGW), a packet data network (PDN) gateway (PGW), an access network detection and selection function (ANDSF) server, an enhanced packet data gateway (ePDG) and/or a mobility management entity (MME).

#### Brief Description of the Drawings

[0006] FIG. 1 is a diagram illustrating a radio access network (RAN) system using Long-Term Evolution (LTE) and License Assisted Access (LAA) consistent with embodiments disclosed herein.

[0007] FIG. 2 is a table illustrating downlink control format (DCI) 0 fields consistent with embodiments disclosed herein.

[0008] FIG. 3 is a table illustrating available interlace index assignments based on a starting interlace index consistent with embodiments disclosed herein.

[0009] FIG. 4 is a table illustrating fields for single subframe scheduling including interlace allocation consistent with embodiments disclosed herein.

[0010] FIG. 5 is a table illustrating fields for multi-subframe scheduling using scheme 1 consistent with embodiments disclosed herein.

[0011] FIG. 6 is a table illustrating schemes and bit length for multi-subframe scheduling consistent with embodiments disclosed herein.

[0012] FIG. 7 is a table illustrating fields for multi-subframe scheduling using scheme 8 consistent with embodiments disclosed herein.

[0013] FIG. 8 is diagram illustrating an indication of cross-transmission opportunity (TxOP) with explicit timing relationship consistent with embodiments disclosed herein.

[0014] FIG. 9 is a schematic diagram illustrating the structure of a Long-Term Evolution (LTE) communication frame consistent with embodiments disclosed herein.

[0015] FIG. 10 is a block diagram illustrating electronic device circuitry that may be radio access node (RAN) circuitry (such as an eNB circuitry), UE circuitry, network node circuitry, or some other type of circuitry consistent with embodiments disclosed herein.

[0016] FIG. 11 is a block diagram illustrating example components of a user equipment (UE) or mobile station (MS) device consistent with embodiments disclosed herein.

[0017] FIG. 12 is block diagram of a method for \_\_\_ consistent with embodiments disclosed herein.

[0018] FIG. 13 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) consistent with embodiments disclosed herein.

#### Detailed Description

[0019] A detailed description of systems and methods consistent with embodiments of the present disclosure is provided below. While several embodiments are described, it should be understood that the disclosure is not limited to any one embodiment, but instead encompasses numerous alternatives, modifications, and equivalents. In addition, while numerous specific details are set forth in the following description in order to provide a thorough understanding of the embodiments disclosed herein, some embodiments can be practiced without some or all of these details. Moreover, for the purpose of clarity, certain technical material that is known in the related art has not been described in detail in order to avoid unnecessarily obscuring the disclosure.

[0020] Techniques, apparatus and methods are disclosed that enable design of uplink (UL) grants to schedule multi-frame UL Licensed-Assisted Access (LAA) transmissions. These UL LAA transmissions can include a single UL grant in a subframe for a UE to schedule multiple physical uplink shared channel (PUSCH) transmissions and/or a single UL grant to schedule interlace allocations. The design can include (1) multi-subframe scheduling, (2) uplink LBT indication and/or (3) multi-clustered transmission using block interleaved frequency division multiple access (B-IFDMA) design.

[0021] Wireless mobile communication technology uses various standards and protocols to transmit data between a base station and a wireless mobile device. Wireless communication system standards and protocols can include the 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE); the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard, which is commonly known to industry groups as worldwide interoperability for microwave access (WiMAX); and the IEEE 802.11 standard, which is commonly known to industry groups as Wi-Fi. In 3GPP radio access networks (RANs) in LTE systems, the base station can include Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node Bs (also commonly denoted as evolved Node Bs, enhanced Node Bs, eNodeBs, or eNBs) and/or Radio Network Controllers (RNCs) in an E-UTRAN, which communicate with a wireless communication device, known as user equipment (UE).

[0022] The explosive wireless traffic growth leads to a need of rate improvement. With mature physical layer techniques, further improvement in spectral efficiency is anticipated to

be marginal. Scarcity of licensed spectrum in low frequency band results in a deficit in a data rate boost. Thus, there are emerging interests in the operation of Long-Term Evolution (LTE) systems in unlicensed spectrum. As a result, one major enhancement for LTE in 3GPP Release 13 has been to enable its operation in the unlicensed spectrum via Licensed-Assisted Access (LAA), which expands the system bandwidth by utilizing the flexible carrier aggregation (CA) framework introduced by the LTE-Advanced system. Enhanced operation of LTE systems in the unlicensed spectrum is expected in future releases and fifth generation (5G) systems. Potential LTE operation in the unlicensed spectrum includes but is not limited to (1) LTE operation in the unlicensed spectrum via dual connectivity (DC) – called DC based LAA herein, and (2) standalone LTE system in the unlicensed spectrum (or shared spectrum, shared medium or unlicensed medium), where LTE-based technology solely operates in the unlicensed spectrum without an “anchor” in the licensed spectrum – called MuLTFire. MuLTFire, combining the performance benefits of LTE technology with the simplicity of Wi-Fi-like deployments, is envisioned as a technology component to help meet increasing wireless traffic.

**[0023]** An unlicensed frequency band of interest in 3GPP is the 5 GHz band, which has wide spectrum with global common availability. The 5 GHz band in the U.S. is governed by Unlicensed National Information Infrastructure (U-NII) rules by the Federal Communications Commission (FCC). An 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. Since WLAN systems are widely deployed by both individuals and operators for carrier-grade access service and data offloading, sufficient care must be taken before the deployment. This incumbent use implies that Listen-Before-Talk (LBT) be considered as a mandatory feature of Rel-13 LAA system for fair coexistence with the incumbent system. LBT is a procedure whereby radio transmitters first sense a wireless medium for signals (which can include recognized signals, unrecognized signals or noise above a threshold) and transmit only if the wireless medium is sensed to be idle.

**[0024]** In Rel-14 LAA and MuLTFire, UL LAA design is being considered. The UL LAA design is inherently different from the legacy LTE design in that the UE is required to perform LBT before transmission. Additionally there are additional restrictions for UL LAA transmissions to obey the regulations (e.g., ETSI).

**[0025]** In this description, we describe the design of UL grant to schedule UL LAA transmissions. Below we describe three configurations for the UL grant design for UL scheduling. These include (1) multi-subframe scheduling, (2) uplink LBT indication and (3)

multi-clustered transmission using block interleaved frequency division multiple access (B-IFDMA) design.

**[0026]** With respect to (1) multi-subframe scheduling, (A) flexible timing and (B) cross-TxOP scheduling can be supported. With respect to (A) flexible timing, in Rel-14 eLAA WI/MF, flexible timing between UL grant and UL transmission can be supported. For example, in an Option (1), a single UL grant in a subframe for a UE can schedule  $N$  ( $N \geq 1$ ) physical uplink shared channel (PUSCH) transmissions for the UE in  $N$  subframes with a single PUSCH per subframe. This is referred to as multi-subframe scheduling herein. In another example or Option (2), a single UL grant in a subframe for a UE can schedule a single PUSCH transmission in a single subframe while a UE can receive multiple UL grants in a subframe for PUSCH transmissions in different subframes. This is referred to as single subframe scheduling herein.

**[0027]** With respect to (B) cross-TxOP UL scheduling, Rel-14 LAA and MF support cross-TxOP UL scheduling. Cross-TxOP UL scheduling aims to address poor LAA UL performance and increase UL transmission opportunities, by allowing the UL subframes in one transmission burst (TxOP) to be scheduled in the preceding transmission bursts. In the examples presented herein for cross-TxOP, two options can be considered (but are not limited to only these two examples). In a type 1, an eNB schedules the UE with a fixed time relationship between grant and transmission. In a type 2, an eNB schedules the UE without a fixed time relationship between grant and transmission, and the UE transmits after receiving a trigger sent by eNB on C-PDCCH.

**[0028]** The UL grant can also include relevant information to schedule multiple subframes that may be present within a maximum channel occupancy time (MCOT) or outside MCOT or a combination of the two.

**[0029]** With respect to (2) the uplink LBT, indication Rel-13 LAA design restricts the MCOT or transmission opportunity (TxOP) after completion of LBT at the eNB to be 8 ms (if LAA co-exists with Wi-Fi) or 10 ms (otherwise). UEs that are scheduled within a TxOP perform a single interval LBT or a short cat 4 LBT, for example, by puncturing the first symbol of PUSCH transmission. It is also possible that the UE performs no LBT (e.g., if UE has already completed UL LBT in the previous subframe within the MCOT). If UL transmission occurs outside the MCOT and the UL grant schedules transmission with an explicit timing relationship, then the UE performs a cat 4 LBT. A UL grant can indicate a type of LBT to be performed including no LBT, single interval LBT, and cat 4 LBT, which can use a total of 2 bits for such indication.

**[0030]** With respect to (3) multi-clustered transmission using block interleaved frequency division multiple access (B-IFDMA) design, MF and eLAA can use a multi-clustered UL transmission and an interlaced design based on a B-IFDMA waveform. This design is considered to satisfy regulatory requirements, including the ETSI specification that defines a maximum Power Spectral Density (PSD) of 10 dBm/MHz for 5150-5350 MHz. In addition, regulations can impose a band-specific total maximum transmission power of the transmitter constraint indicated by Effective Isotropic Radiated Power (EIRP).

**[0031]** In B-IFDMA, a UL assignment occurs in units of interlaces. An interlace consists of equidistance physical resource blocks (PRBs) spread across the system bandwidth (which can also satisfy regulations, such as the PSD described above). The number of interlaces is dependent on the inter-PRB distance and the system bandwidth. For example, 10 interlaces are supported for 20 MHz bandwidth in MF. It is possible that the distance between PRBs is randomized keeping the number of interlaces fixed according to the fixed PRB distance and simultaneously satisfy the regulations. Such randomizations can be useful for inter-cell interference randomization and intermodulation distortion. A UE can be assigned multiple such interlaces. The Resource Indication Value (RIV) UL grant may be optimized to indicate assigned interlaces rather than PRBs.

**[0032]** FIG. 1 is a diagram illustrating a radio access network (RAN) system using Long-Term Evolution (LTE) and licensed assisted access (LTE) consistent with embodiments disclosed herein. Turning to Figure 1, an example of a portion of a RAN system 100 that includes a single cellular air interface (such as an LTE/LTE-Advanced access link) being provided between the LTE RAN Node 104 and the UE 102 (i.e., on Access Link A), and an air interface (a supplemental network interface such as a wireless licensed assisted access (LAA) based interface) being provided between the LAA RAN Node 106 and the UE 102 (i.e., on Access Link B). UE 102 is located in macro cell coverage 108. The UE 102 determines that connection with a LAA RAN Node 106 will be beneficial to a user of the UE 102. In some embodiments, the UE 102 retains Access Link A to LTE RAN Node 104. The UE 102 can offload some, part or all of wireless services onto Access Link B. In other embodiments, the UE 102 disconnects from Access Link A and moves all wireless services to Access Link B. In some embodiments Access Link A uses a licensed medium (e.g., a licensed spectrum or bands) and Access Link B uses an unlicensed medium (e.g., an unlicensed spectrum or bands). In other embodiments, Access Link A and Access Link B use different frequencies (e.g., LTE licensed frequencies and unlicensed frequencies) and different link technology (e.g., LTE and LAA). For example, a UE can use DC based LAA

by using Access Link A and Access Link B. In another example, the UE can use access link B with MuLTEfire, as a standalone LTE system in the unlicensed spectrum, where LTE-based technology solely operates in unlicensed spectrum without an “anchor” in the licensed spectrum.

**[0033]** FIG. 2 is a table illustrating downlink control information (DCI) format 0 fields consistent with embodiments disclosed herein. Legacy LTE design uses DCI format 0 and DCI format 4 for scheduling PUSCH transmission. The bit assignment for DCI format 0 is described in table 200. This DCI format 0 can be further extended to support enhanced LAA (eLAA) and multi-subframe (MF) design. The uplink (UL) grant design is extended to support eLAA and multi-subframe design. Examples of such extensions can be seen in FIGs. 3 and 6.

**[0034]** Additional fields can be used with DCI format 0 to support eLAA and multi-subframe design. For example, a listen before talk (LBT) indication field can be used to indicate UE behavior before transmitting on the UL (e.g., no LBT, single interval LBT, category 4 LBT (a.k.a. cat 4 or cat 4 LBT)).

**[0035]** A transmission opportunity (TxOP) field can use one bit to indicate whether the UL transmission will be within TxOP or outside TxOP. A transmission opportunity is a set of contiguous transmissions that can occur after the UE or LAA RAN Node accesses the medium. For example, a TxOP can be defined as 4 ms after the LAA RAN Node transmits a UL grant (other durations can be used, such as values between 4ms and 20ms).

**[0036]** An outside TxOP indicator can indicate a type of transmission outside of TxOP (e.g., a fixed time relationship to a UL grant or without a fixed time relationship to UL grant) using one bit (type 1 or type 2).

**[0037]** A 4 bit timing relationship field can be added. If a UL subframe is within TxOP, the UL grant indicates the offset between the UL grant that scheduled UL subframes and the first scheduled UL subframe. If a UL grant schedules via cross-TxOP, the UE indicates if UE is scheduled within TxOP or outside TxOP. The UE infers the valid subframe with respect to the first scheduled UL subframe outside TxOP.

**[0038]** The set of scheduled UL subframes can also be indicated by a field. For a consecutive embodiment, a number of the scheduled UL subframes, where  $\lceil \log_2 N_{max} \rceil$  bits can be used for  $N_{max}$  ( $N_{max}$  being a maximum number of subframes that can be consecutively scheduled). Up to 4 bits can be used for this purpose. For a distributed embodiment, a bitmap-based approach can be used. In the distributed embodiment, 10 bits can be used when a maximum channel occupancy time (MCOT) is 10 ms.

**[0039]** A number of UL hybrid automatic repeat request (HARQ) processes can be increased to 16 HARQ processes and up to 4 bits can be used. Note that in DCI 0 a HARQ ID (is not explicitly indicated).

**[0040]** In addition to the above additional indicator, UL grant design for an eLAA MF design can include other modifications. An RIV field can be reused for indicating the assigned interlaces (such as with 10 bits or optimized 6 bits for indication). A Format0-1A-Flag is not used. It is expected that the LAA UL grant will use a different DCI format. A frequency hopping flag is not used for eLAA if the frequency hopping across slots is not used within an interlace. As eLAA/MF supports asynchronous UL, an additional two bits can be used to indicate redundancy version (RV). Information bits of a physical downlink control channel (PDCCH) can be appended with 16 bits before channel coding/rate matching. The channel coding can be performed with the tail biting convolutional code (TBCC) as per legacy PDCCH.

**[0041]** FIG. 3 is a table 300 illustrating available interlace index assignments based on a starting interlace index consistent with embodiments disclosed herein. A UE may be assigned multiple logical interlaces. Two design options can include an interlace ordering method and a bitmap method. For an interlace ordering method, the interlace assignment is indicated by the starting interlace index and the number of interlaces to be assigned to the UE. For example, in the case of 10 interlaces, the possible interlace assignments (up to 55 possible assignments in the case of single-user resource allocation) are shown in table 300. For 20 MHz, with 10 interlaces, 6 bits can be used. As the starting interlace index increases, an interlace assignment of a lower interlace is not possible (as the starting interlace would be the lower interlace index).

**[0042]** For example, at a starting interlace index of 0, any of the 10 interlaces are possible for selection. At a starting interlace index of 1, only the 9 highest interlaces are possible for selection. This continues until there is a starting interlace index of 9, where only the highest interlace is possible for selection.

**[0043]** For a bitmap method, the indication of interlace assignment is performed via a bitmap. Note that the number of bits in the bitmap for each UE equals the number of interlaces, and each bit in the bitmap shows whether that interlace is assigned or not. For example, in the case of 10 interlaces, a 10-bit bitmap can be used, wherein each bit corresponds to an interlace. Each UE would be indicated by a specific 10-bit bitmap, to indicate the interlaces that are assigned to it. For example, “0110010001” indicates that

interlaces {1, 2, 5, 9} are assigned to the UE. For 20 MHz, with 10 interlaces, 10 bits are required.

**[0044]** FIG. 4 is a table 400 illustrating fields for single subframe scheduling including interlace allocation consistent with embodiments disclosed herein. In this design, the UL grant indicates the required field for the operation of UL LBT. Additionally RIV is modified to indicate the interlace allocation. In one embodiment 6 bits are used to indicate interlace assignment. In another embodiment 10 bits are used for interlace assignment. In the above design, the UL grant for scheduling a single subframe for eLAA/MF can use up to 36 bits (with 6 bit interlace mapping). In comparison, DCI 0 uses 32 bits. Further description of these fields can be found in conjunction with FIG. 2.

**[0045]** FIG. 5 is a table illustrating fields for multi-subframe scheduling using a scheme 1 (as shown in FIG. 6) consistent with embodiments disclosed herein. Multi-subframe scheduling may schedule multiple UL subframes in a flexible way, wherein different UL resources, MCS, HARQ ID, NDI, and RV are indicated via DCI separately for each scheduled subframe. Such a design can impose linear increase in physical downlink control channel (PDCCH) overhead as a number of scheduled subframes is increased. Additionally, a UE may need to blindly detect the PDCCH based on a number of scheduled UL transmissions based on scheduled UL subframes. This can increase UE complexity. Thus, various design options can be considered that reduce the PDCCH overhead and blind detection at the UE.

**[0046]** Depending on an embodiment, the number of bits used for UL grant can be predesigned based on a maximum number of possible scheduled subframes ( $N_{max}$ ). Otherwise, a UE may need to perform blind decoding over possible choices of  $N_{max}$  to the number of scheduled subframes.

**[0047]** In table 500, an embodiment for a scheme of DCI fields is shown. In this option, for each scheduled subframe, RIV, MCS, HARQ ID, NDI, RV, LBT information, and cross-TxOP info are separately indicated for each subframe. In this option, a number of bits are  $16 + 22 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$  the number of bits required can be as large as 195 bits. This option is the most flexible option for multi-subframe scheduling.

**[0048]** FIG. 6 is a table illustrating schemes and bit length for multi-subframe scheduling in addition to the scheme 1 described in conjunction with FIG. 5. The schemes illustrate different embodiments of DCI fields that can be used in multi-subframe scheduling.

**[0049]** In Scheme 2, for each scheduled subframe, MCS, HARQ ID, NDI, RV, LBT information, and cross-TxOP info are separately indicated for each subframe. RIV value is

fixed for each scheduled subframe. In this option, the number of bits required are  $22 + 16 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 153 bits.

**[0050]** Scheme 3: In this option, for each scheduled subframe, HARQ ID, NDI, LBT information, and type of cross-TxOP are separately indicated for each subframe. MCS, RV and RIV are fixed for each scheduled subframe. In this option, the number of bits required are  $29 + 9 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 104 bits.

**[0051]** Scheme 4: In this option, for each scheduled subframe, HARQ ID, NDI, and LBT information are separately indicated for each subframe. MCS/RV, RIV, and cross-TxOP info are fixed for each scheduled subframe. This option limits the scheduled subframes to be within TxOP or outside TxOP. If it is scheduled outside TxOP, then either type 1 or type 2 cross-TxOP scheduling is also fixed for all scheduled subframes. In this option, the number of bits required are  $31 + 7 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 89 bits.

**[0052]** Scheme 5: Scheme 5 is a slight variation of scheme 3. In this option, UL LBT is not separately indicated for each subframe. Depending on the information specified in cross-TxOP, the first subframe of the UL burst can perform single interval LBT or cat 4 LBT. This information is implicitly obtained based on cross-TxOP info. Thus, the two bits needed for LBT type indication are not needed. All subframes following the first subframe perform single interval LBT. In this option, the number of bits required are  $31 + 5 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 74 bits.

**[0053]** Scheme 6: In this option, for each scheduled subframe, NDI information is separately indicated for each subframe. MCS/RV, RIV, and cross-TxOP info are fixed for each scheduled subframe. HARQ ID for the first subframe is indicated. The HARQ ID for the remaining subframes is obtained by sequentially incrementing the HARQ ID (and starting from 0 if incremented HARQ ID is greater than the maximum number of HARQ processes supported). In this option, the number of bits required are  $32 + 1 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 47 bits.

**[0054]** Scheme 7: In this option, for each scheduled subframe, RV and NDI information is separately indicated for each subframe. MCS, RIV, and cross-TxOP info are fixed for each scheduled subframe. HARQ ID is implicitly indicated. In DCI 0, MCS + RV uses 5 bits. If RV information is encoded, then MCS still needs 5 bits, while RV needs an additional 2 bits.

In this option, the number of bits required are  $32 + 3 \times N_{max} + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 59 bits.

**[0055]** Scheme 8: In this option, all variables such as MCS/RV, RIV, NDI, and type of cross-TxOP are fixed for each scheduled subframe. HARQ ID is indicated implicitly based on the first scheduled subframe. In this option, the number of bits required are  $35 + \lceil \log_2 N_{max} \rceil$ . For  $N_{max} = 8$ , the number of bits required can be as large as 38 bits. An example of DCI fields used with this scheme can be found in FIG. 7, and descriptions of the fields can be found in conjunction with the description of FIG. 2.

**[0056]** FIG. 8 is a diagram 800 illustrating an indication of cross-transmission opportunity (TxOP) with an explicit timing relationship consistent with embodiments disclosed herein. For example, the presence of potential PUSCH transmission outside TxOP is indicated by the UL grant 806 in the previous TxOP with an explicit timing relationship. UL grant 806 transmitted in subframe  $n$  explicitly indicates the subframes  $n + \alpha$  to  $n + \beta$ , where  $\alpha, \beta > 0$  (shown as  $\alpha=6, \beta=13$  here), that can be used for UL transmission by the UE. Before the start of the UL burst 802 from the scheduled UE, the scheduled UE performs a cat 4 LBT 804 if it is scheduled outside TxOP. The parameters for the cat 4 LBT 804 to be used can be based on the priority class associated with the traffic scheduled for the UE. The UE is indicated if the subframe scheduled by UL grant 806 is within TxOP or outside TxOP. This indication is used to determine the LBT to be performed by the UE. A scheduled UE in the next TxOP performs cat 4 LBT 804 with self-defer. The scheduled UE can start the PUSCH transmission at the subframe boundary or after the second symbol of the subframe containing PUSCH transmission depending on the time of the cat 4 LBT 804 completion. The eNB performs blind detection to determine the start of the PUSCH transmission.

**[0057]** If a scheduled UE is not able to complete LBT before the scheduled subframe, UE may continue to perform LBT until it can successfully complete LBT before any of the scheduled UL subframes. The behavior of the UE, if the UE cannot complete LBT for the scheduled subframes outside TxOP, can include two options. For Option 1, the UE restarts the LBT for any future cross-TxOP scheduling if the UE cannot complete LBT before all scheduled UL subframes within the next TxOP. For Option 2, the UE may resume the LBT for any future cross-TxOP unless otherwise indicated by the eNB. The UE can restart the LBT procedure if no scheduled UL subframe within Cross-TxOP is indicated by the eNB for a configured duration of time. In some embodiments, Option 2 is preferred due to its similarity with WLAN operation. After completion of the LBT, the UE can transmit on the

scheduled UL subframe, as indicated by the UL grant and if the scheduled subframe occurs after the completion of the LBT.

**[0058]** FIG. 9 is a schematic diagram 900 illustrating the structure of a Long-Term Evolution (LTE) communication frame 905. A frame 905 has a duration of 10 milliseconds (ms). The frame 905 includes ten subframes 910, each having a duration of 1 ms. Each subframe 910 includes two slots 915, each having a duration of 0.5 ms. Therefore, the frame 905 includes 20 slots 915.

**[0059]** Each slot 915 includes six or seven orthogonal frequency-division multiplexing (OFDM) symbols 920. The number of OFDM symbols 920 in each slot 915 is based on the size of the cyclic prefixes (CP) 925. For example, the number of OFDM symbols 920 in the slot 915 is seven while in normal mode CP and six in extended mode CP.

**[0060]** The smallest allocable unit for transmission is a resource block 930 (i.e., physical resource block (PRB) 930). Transmissions are scheduled by PRB 930. A PRB 930 consists of 12 consecutive subcarriers 935, or 180 kHz, for the duration of one slot 915 (0.5 ms). A resource element 940, which is the smallest defined unit, consists of one OFDM subcarrier during one OFDM symbol interval. In the case of normal mode CP, each PRB 930 consists of  $12 \times 7 = 84$  resource elements 940. Each PRB 930 consists of 72 resource elements 940 in the case of extended mode CP.

**[0061]** FIG. 10 is a block diagram illustrating electronic device circuitry 1000 that may be radio access node (RAN) node circuitry (such as an eNB circuitry), UE circuitry, network node circuitry, or some other type of circuitry in accordance with various embodiments. In embodiments, the electronic device circuitry 1000 may be, or may be incorporated into or otherwise a part of, a RAN Node (e.g., an eNB), a UE, a mobile station (MS), a BTS, a network node, or some other type of electronic device. In embodiments, the electronic device circuitry 1000 may include radio transmit circuitry 1010 and receive circuitry 1012 coupled to control circuitry 1014 (e.g., baseband processor(s), etc.). In embodiments, the transmit circuitry 1010 and/or receive circuitry 1012 may be elements or modules of transceiver circuitry, as shown. In some embodiments, some or all of the control circuitry 1015 can be in a device separate or external from the transmit circuitry 1010 and the receive circuitry 1012 (baseband processors shared by multiple antenna devices, as in cloud-RAN (C-RAN) implementations, for example).

**[0062]** The electronic device circuitry 1010 may be coupled with one or more plurality of antenna elements 1016 of one or more antennas. The electronic device circuitry 1000 and/or

the components of the electronic device circuitry 1000 may be configured to perform operations similar to those described elsewhere in this disclosure.

**[0063]** In embodiments where the electronic device circuitry 1000 is or is incorporated into or otherwise part of a UE, the transmit circuitry 1010 can transmit UL data as shown in FIGs. 1 and 8. The receive circuitry 1012 can receive downlink (DL) data, DCI data and/or an uplink grant as shown in FIGs. 1 and 8.

**[0064]** In embodiments where the electronic device circuitry 1000 is an eNB, BTS and/or a network node, or is incorporated into or is otherwise part of an eNB, BTS and/or a network node, the transmit circuitry 1010 can transmit downlink (DL) data, DCI data and/or an uplink grant as shown in FIGs. 1 and 8. The receive circuitry 1012 can receive UL data as shown in FIGs. 1 and 8.

**[0065]** In certain embodiments, the electronic device circuitry 1000 shown in FIG. 10 is operable to perform one or more methods, such as the methods shown in FIG. 12.

**[0066]** 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.

**[0067]** Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 11 is a block diagram illustrating, for one embodiment, example components of a user equipment (UE) or mobile station (MS) device 1100. In some embodiments, the UE device 1100 may include application circuitry 1102, baseband circuitry 1104, Radio Frequency (RF) circuitry 1106, front-end module (FEM) circuitry 1108, and one or more antennas 1110, coupled together at least as shown in FIG. 11.

**[0068]** The application circuitry 1102 may include one or more application processors. By way of non-limiting example, the application circuitry 1102 may include 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 processor(s) may be operably coupled and/or 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.

**[0069]** By way of non-limiting example, the baseband circuitry 1104 may include one or more single-core or multi-core processors. The baseband circuitry 1104 may include one or more baseband processors and/or control logic. The baseband circuitry 1104 may be configured to process baseband signals received from a receive signal path of the RF circuitry 1106. The baseband 1104 may also be configured to generate baseband signals for a transmit signal path of the RF circuitry 1106. The baseband processing circuitry 1104 may interface with the application circuitry 1102 for generation and processing of the baseband signals, and for controlling operations of the RF circuitry 1106.

**[0070]** By way of non-limiting example, the baseband circuitry 1104 may include at least one of a second generation (2G) baseband processor 1104A, a third generation (3G) baseband processor 1104B, a fourth generation (4G) baseband processor 1104C, other baseband processor(s) 1104D for other existing generations, and generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1104 (e.g., at least one of baseband processors 1104A-1104D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1106. By way of non-limiting example, the radio control functions may include signal modulation/demodulation, encoding/decoding, radio frequency shifting, other functions, and combinations thereof. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1104 may be programmed to perform Fast-Fourier Transform (FFT), precoding, constellation mapping/demapping functions, other functions, and combinations thereof. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1104 may be programmed to perform convolutions, tail-biting convolutions, turbo, Viterbi, Low Density Parity Check (LDPC) encoder/decoder functions, other functions, and combinations thereof. Embodiments of modulation/demodulation and encoder/decoder functions are not limited to these examples, and may include other suitable functions.

**[0071]** In some embodiments, the baseband circuitry 1104 may include elements of a protocol stack. By way of non-limiting 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) 1104E of the baseband circuitry 1104 may be programmed 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 1104 may include one or more audio digital signal processor(s) (DSP) 1104F. The audio DSP(s) 1104F may include elements for compression/decompression and echo cancellation. The audio DSP(s) 1104F may also include other suitable processing elements.

**[0072]** The baseband circuitry 1104 may further include memory/storage 1104G. The memory/storage 1104G may include data and/or instructions for operations performed by the processors of the baseband circuitry 1104 stored thereon. In some embodiments, the memory/storage 1104G may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 1104G may also include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. In some embodiments, the memory/storage 1104G may be shared among the various processors or dedicated to particular processors.

**[0073]** Components of the baseband circuitry 1104 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 1104 and the application circuitry 1102 may be implemented together, such as, for example, on a system on a chip (SOC).

**[0074]** In some embodiments, the baseband circuitry 1104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1104 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 1104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[0075]** The RF circuitry 1106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. The RF circuitry 1106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1108, and provide baseband signals to the baseband circuitry 1104. The RF circuitry 1106 may also include a transmit signal path which may include circuitry to up-

convert baseband signals provided by the baseband circuitry 1104, and provide RF output signals to the FEM circuitry 1108 for transmission.

**[0076]** In some embodiments, the RF circuitry 1106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1106 may include mixer circuitry 1106A, amplifier circuitry 1106B, and filter circuitry 1106C. The transmit signal path of the RF circuitry 1106 may include filter circuitry 1106C and mixer circuitry 1106A. The RF circuitry 1106 may further include synthesizer circuitry 1106D configured to synthesize a frequency for use by the mixer circuitry 1106A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1106A of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1108 based on the synthesized frequency provided by synthesizer circuitry 1106D. The amplifier circuitry 1106B may be configured to amplify the down-converted signals.

**[0077]** The filter circuitry 1106C may include 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 1104 for further processing. In some embodiments, the output baseband signals may include zero-frequency baseband signals, although this is not a requirement. In some embodiments, the mixer circuitry 1106A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

**[0078]** In some embodiments, the mixer circuitry 1106A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1106D to generate RF output signals for the FEM circuitry 1108. The baseband signals may be provided by the baseband circuitry 1104 and may be filtered by filter circuitry 1106C. The filter circuitry 1106C may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 1106A of the receive signal path and the mixer circuitry 1106A 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 1106A of the receive signal path and the mixer circuitry 1106A of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1106A of the receive signal path and the mixer circuitry 1106A may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 1106A of the

receive signal path and the mixer circuitry 1106A of the transmit signal path may be configured for super-heterodyne operation.

**[0079]** 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 such embodiments, the RF circuitry 1106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry, and the baseband circuitry 1104 may include a digital baseband interface to communicate with the RF circuitry 1106.

**[0080]** In some dual-mode embodiments, 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.

**[0081]** In some embodiments, the synthesizer circuitry 1106D may include one or more of a fractional-N synthesizer and 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 1106D may include a delta-sigma synthesizer, a frequency multiplier, a synthesizer comprising a phase-locked loop with a frequency divider, other synthesizers and combinations thereof.

**[0082]** The synthesizer circuitry 1106D may be configured to synthesize an output frequency for use by the mixer circuitry 1106A of the RF circuitry 1106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1106D may be a fractional  $N/N+1$  synthesizer.

**[0083]** 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 1104 or the applications processor 1102 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 1102.

**[0084]** The synthesizer circuitry 1106D of the RF circuitry 1106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may include a dual modulus divider (DMD), and the phase accumulator may include 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 such 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 may provide negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

**[0085]** In some embodiments, the synthesizer circuitry 1106D may be configured to generate a carrier frequency as the output frequency. In some embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency, etc.) and used in conjunction with a 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 1106 may include an IQ/polar converter.

**[0086]** The FEM circuitry 1108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1110, amplify the received signals, and provide the amplified versions of the received signals to the RF circuitry 1106 for further processing. The FEM circuitry 1108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1106 for transmission by at least one of the one or more antennas 1110.

**[0087]** In some embodiments, the FEM circuitry 1108 may include a TX/RX switch configured to switch between a transmit mode and a receive mode operation. The FEM circuitry 1108 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 1108 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 1106). The transmit signal path of the FEM circuitry 1108 may include a power amplifier (PA) configured to amplify input RF signals (e.g., provided by RF circuitry 1106), and one or more filters configured to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1110).

**[0088]** In some embodiments, the MS device 1100 may include additional elements such as, for example, memory/storage, a display, a camera, one of more sensors, an input/output (I/O) interface, other elements, and combinations thereof.

**[0089]** In some embodiments, the MS device 1100 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof.

**[0090]** FIG. 12 is block diagram of a method for multiple physical uplink transmissions using an unlicensed wireless medium. The method can be accomplished using systems such as those shown in FIG. 1 including LTE RAN Node 104, LAA RAN Node 106 and UE 102. In block 1202, a UE processes an uplink grant from an eNB, the uplink grant comprising an interlace allocation assignment schedule for PUSCH transmissions using the unlicensed wireless medium. In block 1204, the UE senses the unlicensed medium to determine if the unlicensed medium is idle at an physical resource block at an interlace allocation assignment. In block 1206, the system uses the sensing to determine if the unlicensed medium is idle. In block 1208, when the unlicensed medium is determined to be idle, the UE generates a PUSCH transmission based at least in part on the schedule. In block 1210, when the unlicensed medium is determined to be busy, the UE prevents the PUSCH transmission during the schedule.

**[0091]** FIG. 13 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. 13 shows a diagrammatic representation of hardware resources 1300 including one or more processors (or processor cores) 1310, one or more memory/storage devices 1320, and one or more communication resources 1330, each of which are communicatively coupled via a bus 1340.

**[0092]** The processors 1310 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 1312 and a processor 1314. The memory/storage devices 1320 may include main memory, disk storage, or any suitable combination thereof.

**[0093]** The communication resources 1330 may include interconnection and/or network interface components or other suitable devices to communicate with one or more peripheral devices 1304 and/or one or more databases 1306 via a network 1308. For example, the communication resources 1330 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

**[0094]** Instructions 1350 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1310 to perform any one or more of the methodologies discussed herein. The instructions 1350 may reside, completely or partially, within at least one of the processors 1310 (e.g., within the processor's cache memory), the memory/storage devices 1320, or any suitable combination thereof. Furthermore, any portion of the instructions 1350 may be transferred to the hardware resources 1300 from any combination of the peripheral devices 1304 and/or the databases 1306. Accordingly, the memory of processors 1310, the memory/storage devices 1320, the peripheral devices 1304, and the databases 1306 are examples of computer-readable and machine-readable media.

#### Examples

**[0095]** The following examples pertain to further embodiments.

**[0096]** Example 1 is an apparatus of a user equipment (UE). The apparatus contains storage designed to store an uplink grant configuration. The apparatus contains a processor designed to process an uplink grant from radio access network node (RAN node), the uplink grant including the uplink grant configuration and a schedule for multiple physical uplink transmissions using an unlicensed wireless medium. The apparatus further contains a processor designed to sense the unlicensed medium for signals or noise to determine if the unlicensed medium is idle when the unlicensed medium is determined to be idle, generate the multiple physical uplink transmissions during the schedule and when the unlicensed medium is determined to be busy, preventing the multiple physical uplink transmissions during the schedule.

**[0097]** Example 2 is the apparatus of Example 1, where the multiple physical uplink transmissions include physical uplink shared channel (PUSCH) transmissions or physical uplink control channel (PUCCH) transmissions.

**[0098]** Example 3 is the apparatus of Example 1, where each of the multiple physical uplink transmissions include a subframe.

**[0099]** Example 4 is the apparatus of Example 1, where the uplink grant schedules one or more uplink subframes.

**[0100]** Example 5 is the apparatus of Example 1, where the uplink grant includes an indicator that the uplink grant is within maximum channel occupancy time (MCOT), allowing the UE to use a shorter listen before talk (LBT) protocol.

**[0101]** Example 6 is the apparatus of Example 5, where the shorter listen before talk (LBT) protocol is a single interval LBT.

[0102] Example 7 is the apparatus of Example 5, where the shorter listen before talk (LBT) protocol is a short category 4 LBT including puncturing a first symbol of a physical uplink transmission shared channel (PUSCH) transmission.

[0103] Example 8 is the apparatus of Example 1, where the uplink grant includes an indicator that the uplink grant is outside a maximum channel occupancy time (MCOT).

[0104] Example 9 is the apparatus of Example 8, where the uplink grant being outside the MCOT causes the UE to use a category 4 listen before talk (LBT) protocol.

[0105] Example 10 is the apparatus of Example 1, where no listen before talk (LBT) protocol is performed for sequential uplink transmissions after a LBT protocol was performed before a first transmission.

[0106] Example 11 is the apparatus of Example 1, where the uplink grant indicates a type of uplink listen before talk (LBT) protocol.

[0107] Example 12 is the apparatus of Example 1, where the uplink grant indicates that a scheduled transmission scheduled via a cross-transmission opportunity (TxOP) includes an explicit timing relationship between the uplink grant and a physical uplink transmission shared channel (PUSCH) transmission.

[0108] Example 13 is the apparatus of Example 1, where the uplink grant indicates resource indication value (RIV), modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) information separately for each subframe.

[0109] Example 14 is the apparatus of Example 1, where the uplink grant indicates modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each scheduled subframe via a single uplink grant; and where resource indication value (RIV) is fixed for scheduled uplink subframes.

[0110] Example 15 is the apparatus of Example 1, where the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each subframe via a single UL grant; and where resource indication value (RIV), modulation and coding scheme (MCS), and redundancy version (RV) are fixed for scheduled uplink subframes.

**[0111]** Example 16 is the apparatus of Example 1, where the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID) and new data indicator (NDI) information separately for each subframe via a single UL grant; and where resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes.

**[0112]** Example 17 is the apparatus of Example 1, where the uplink grant indicates new data indicator (NDI) information separately for each subframe and where resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0113]** Example 18 is the apparatus of Example 1, where the uplink grant indicates redundancy version (RV) and new data indicator (NDI) information separately for each subframe, and where resource indication value (RIV), modulation and coding scheme (MCS), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0114]** Example 19 is the apparatus of Example 18, where the subsequent HARQ IDs for remaining subframes are implicitly computed by sequentially incrementing a subframe offset with respect to the first HARQ ID.

**[0115]** Example 20 is the apparatus of Example 1, where the uplink grant indicates the new data indicator (NDI) information, resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0116]** Example 21 is an apparatus of enhanced node B (eNB). The apparatus includes storage designed to store an uplink grant configuration. The apparatus also includes a processor designed to generate an uplink grant, the uplink grant includes a schedule for multiple PUSCH transmissions using an unlicensed wireless medium and an indication of a

type of listen before talk (LBT) sensing to use with the unlicensed medium to determine if the unlicensed medium is idle, when the unlicensed medium is determined to be idle, process the multiple PUSCH transmissions during the schedule.

[0117] Example 22 is the apparatus of Example 21, where the uplink grant for multiple physical uplink transmissions is for physical uplink shared channel (PUSCH) transmissions or physical uplink control channel (PUCCH) transmissions.

[0118] Example 23 is the apparatus of Example 1, where the uplink grant indicates if a scheduled subframe transmission is within a maximum channel occupancy time (MCOT) or outside the MCOT.

[0119] Example 24 is a computer program product including a computer-readable storage medium that stores instructions for execution by a processor to perform operations of a user equipment (UE). The operations, when executed by the processor, to perform a method. The method contains processing an uplink grant from an eNB, the uplink grant including an interlace allocation assignment schedule for PUSCH transmissions using the unlicensed wireless medium. The method further contains sensing the unlicensed medium to determine if the unlicensed medium is idle at a physical resource block at an interlace allocation assignment, when the unlicensed medium is determined to be idle, generate a PUSCH transmission based at least in part on the schedule. The method further contains sensing the unlicensed medium to determine if the unlicensed medium is idle at a physical resource block at an interlace allocation assignment when the unlicensed medium is determined to be busy, preventing the PUSCH transmission during the schedule.

[0120] Example 25 is the computer program product of Example 24, where the uplink grant uses resource indication value (RIV) to indicate the interlace allocation.

[0121] Example 26 is the computer program product of Example 24, where the uplink grant for a physical uplink transmission includes a grant for a physical uplink shared channel (PUSCH) transmission or a physical uplink control channel (PUCCH) transmission.

[0122] Example 27 is the computer program product of Example 24, where each of the PUSCH transmissions includes a subframe.

[0123] Example 28 is the computer program product of Example 24, where the uplink grant includes an indicator that the uplink grant is within maximum channel occupancy time (MCOT), allowing the UE to use a shorter listen before talk (LBT) protocol.

[0124] Example 29 is the computer program product of Example 28, where the shorter listen before talk (LBT) protocol is a single interval LBT.

[0125] Example 30 is the computer program product of Example 28, where the shorter listen before talk (LBT) protocol is a short category 4 LBT including puncturing a first symbol of a physical uplink transmission shared channel (PUSCH) transmission.

[0126] Example 31 is the computer program product of Example 24, where the uplink grant includes an indicator that the uplink grant is outside a maximum channel occupancy time (MCOT).

[0127] Example 32 is the computer program product of Example 31, where the uplink grant being outside the MCOT causes the UE to use a category 4 listen before talk (LBT) protocol.

[0128] Example 33 is the computer program product of Example 24, where no listen before talk (LBT) protocol is performed for sequential uplink transmissions after a LBT protocol was performed before a first transmission.

[0129] Example 34 is the computer program product of Example 24, where the uplink grant indicates a type of uplink listen before talk (LBT) protocol.

[0130] Example 35 is the computer program product of Example 24, where the uplink grant indicates that a scheduled transmission scheduled via a cross-transmission opportunity (TxOP) includes an explicit timing relationship between the uplink grant and a physical uplink transmission shared channel (PUSCH) transmission.

[0131] Example 36 is the computer program product of Example 24, where the uplink grant uses a field present in a DCI 0 format.

[0132] Example 37 is the computer program product of Example 24, where the uplink grant indicates resource indication value (RIV), modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) information separately for each subframe.

[0133] Example 38 is the computer program product of Example 24, where the uplink grant indicates modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each subframe; and where resource indication value (RIV) is fixed for scheduled uplink subframes.

[0134] Example 39 is the computer program product of Example 24, where the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each subframe; and where resource indication value

(RIV), modulation and coding scheme (MCS), and redundancy version (RV) are fixed for scheduled uplink subframes.

**[0135]** Example 40 is the computer program product of Example 24, where the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI) information separately for each subframe; and where resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes.

**[0136]** Example 41 is the computer program product of Example 24, where the uplink grant indicates new data indicator (NDI) information separately for each subframe, where resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0137]** Example 42 is the computer program product of Example 24, where the uplink grant indicates redundancy version (RV) and new data indicator (NDI) information separately for each subframe, where resource indication value (RIV), modulation and coding scheme (MCS), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0138]** Example 43 is the computer program product of Example 24, where the uplink grant indicates the new data indicator (NDI) information, resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes, and where the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

**[0139]** Example 44 is a method for providing an uplink grant with an interlace allocation assignment. The method includes generating an uplink grant from a RAN Node, the uplink grant including an interlace allocation assignment schedule for physical uplink transmission shared channel (PUSCH) transmissions using an unlicensed wireless medium and an indication of a type of listen before talk (LBT) sensing to use with the unlicensed medium to

determine if the unlicensed medium is idle when the unlicensed medium is determined to be idle, process a PUSCH transmission during the allocation assignment schedule.

[0140] Example 45 is the method of Example 44, where the uplink grant includes a grant for a physical uplink control channel (PUCCH) transmission.

[0141] Example 46 is the method of Example 44, where the uplink grant uses resource indication value (RIV) to indicate the interlace allocation assignment.

[0142] Example 47 is the method of Example 46, where the RIV indicates assigned interlaces.

[0143] Example 48 is the method of Example 46, where the RIV indicates assigned physical resource blocks.

[0144] Example 49 is the method of Example 46, where the RIV indicates a randomized distance between physical resource blocks while keeping a number of interlaces fixed using a fixed physical resource distance.

[0145] Example 50 is the method of Example 44, where the interlace allocation assignment is based on inter-physical resource block distance and system bandwidth.

[0146] Example 51 is the method of Example 50, where the interlace allocation assignment supports 10 interlaces when the system bandwidth is 20 MHz.

[0147] Example 52 is the method of Example 44, where the uplink grant uses a starting interlace index and a number of interlaces to be assigned to the UE to indicate the interlace allocation assignment.

[0148] Example 53 is the method of Example 44, where the uplink grant uses a bitmap to indicate the interlace allocation assignment.

[0149] Example 54 is an apparatus including method to perform a method as exemplified in any of Examples 44-53.

[0150] Example 55 is a machine-readable storage including machine-readable instructions, when executed, to implement a method or realize an apparatus as exemplified in any of Examples 44-53.

[0151] Example 56 is a machine readable medium including code, when executed, to cause a machine to perform the method of any one of Examples 44-53.

[0152] Embodiments and implementations of the systems and methods described herein may include various operations, which may be embodied in machine-executable instructions to be executed by a computer system. A computer system may include one or more general-purpose or special-purpose computers (or other electronic devices). The computer system

may include hardware components that include specific logic for performing the operations or may include a combination of hardware, software, and/or firmware.

**[0153]** Computer systems and the computers in a computer system may be connected via a network. Suitable networks for configuration and/or use as described herein include one or more local area networks, wide area networks, metropolitan area networks, and/or Internet or IP networks, such as the World Wide Web, a private Internet, a secure Internet, a value-added network, a virtual private network, an extranet, an intranet, or even stand-alone machines which communicate with other machines by physical transport of media. In particular, a suitable network may be formed from parts or entirety of two or more other networks, including networks using disparate hardware and network communication technologies.

**[0154]** One suitable network includes a server and one or more clients; other suitable networks may contain other combinations of servers, clients, and/or peer-to-peer nodes, and a given computer system may function both as a client and as a server. Each network includes at least two computers or computer systems, such as the server and/or clients. A computer system may include a workstation, laptop computer, disconnectable mobile computer, server, mainframe, cluster, so-called “network computer” or “thin client,” tablet, smart phone, personal digital assistant or other hand-held computing device, “smart” consumer electronics device or appliance, medical device, or a combination thereof.

**[0155]** Suitable networks may include communications or networking software, such as the software available from Novell®, Microsoft®, and other vendors, and may operate using TCP/IP, SPX, IPX, and other protocols over twisted pair, coaxial, or optical fiber cables, telephone lines, radio waves, satellites, microwave relays, modulated AC power lines, physical media transfer, and/or other data transmission “wires” known to those of skill in the art. The network may encompass smaller networks and/or be connectable to other networks through a gateway or similar mechanism.

**[0156]** 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, CD-ROMs, hard drives, magnetic or optical cards, solid-state memory devices, a nontransitory 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 nonvolatile memory and/or storage elements), at least one input device, and at least one output device. The

volatile and nonvolatile memory and/or storage elements may be a RAM, an EPROM, a flash drive, an optical drive, a magnetic hard drive, or other medium for storing electronic data. The eNB (or other base station) and UE (or other mobile station) may also include a transceiver component, a counter component, a processing component, and/or a clock component or timer component. 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 an 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.

**[0157]** Each computer system includes one or more processors and/or memory; computer systems may also include various input devices and/or output devices. The processor may include a general purpose device, such as an Intel®, AMD®, or other “off-the-shelf” microprocessor. The processor may include a special purpose processing device, such as ASIC, SoC, SiP, FPGA, PAL, PLA, FPLA, PLD, or other customized or programmable device. The memory may include static RAM, dynamic RAM, flash memory, one or more flip-flops, ROM, CD-ROM, DVD, disk, tape, or magnetic, optical, or other computer storage medium. The input device(s) may include a keyboard, mouse, touch screen, light pen, tablet, microphone, sensor, or other hardware with accompanying firmware and/or software. The output device(s) may include a monitor or other display, printer, speech or text synthesizer, switch, signal line, or other hardware with accompanying firmware and/or software.

**[0158]** It should be understood that many of the functional units described in this specification may be implemented as one or more components, which is a term used to more particularly emphasize their implementation independence. For example, a component may be implemented as a hardware circuit comprising custom very large scale integration (VLSI) circuits or gate arrays, or off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A component may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices, or the like.

**[0159]** Components may also be implemented in software for execution by various types of processors. An identified component 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, a procedure, or a function. Nevertheless, the executables of an

identified component need not be physically located together, but may comprise disparate instructions stored in different locations that, when joined logically together, comprise the component and achieve the stated purpose for the component.

**[0160]** Indeed, a component 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 components, 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 components may be passive or active, including agents operable to perform desired functions.

**[0161]** Several aspects of the embodiments described will be illustrated as software modules or components. As used herein, a software module or component may include any type of computer instruction or computer-executable code located within a memory device. A software module may, for instance, include one or more physical or logical blocks of computer instructions, which may be organized as a routine, program, object, component, data structure, etc., that perform one or more tasks or implement particular data types. It is appreciated that a software module may be implemented in hardware and/or firmware instead of or in addition to software. One or more of the functional modules described herein may be separated into sub-modules and/or combined into a single or smaller number of modules.

**[0162]** In certain embodiments, a particular software module may include disparate instructions stored in different locations of a memory device, different memory devices, or different computers, which together implement the described functionality of the module. Indeed, a module may include a single instruction or many instructions, and may be distributed over several different code segments, among different programs, and across several memory devices. Some embodiments may be practiced in a distributed computing environment where tasks are performed by a remote processing device linked through a communications network. In a distributed computing environment, software modules may be located in local and/or remote memory storage devices. In addition, data being tied or rendered together in a database record may be resident in the same memory device, or across several memory devices, and may be linked together in fields of a record in a database across a network.

**[0163]** Reference throughout this specification to “an example” means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment of the present invention. Thus, appearances of the phrase “in an example” in various places throughout this specification are not necessarily all referring to the same embodiment.

**[0164]** 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 its presentation in a common group without indications to the contrary. In addition, various embodiments and examples of the present invention 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 de facto equivalents of one another, but are to be considered as separate and autonomous representations of the present invention.

**[0165]** 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 materials, frequencies, sizes, lengths, widths, shapes, etc., to provide a thorough understanding of embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention may be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

**[0166]** It should be recognized that the systems described herein include descriptions of specific embodiments. These embodiments can be combined into single systems, partially combined into other systems, split into multiple systems or divided or combined in other ways. In addition, it is contemplated that parameters/attributes/aspects/etc. of one embodiment can be used in another embodiment. The parameters/attributes/aspects /etc. are merely described in one or more embodiments for clarity, and it is recognized that the parameters/attributes/aspects /etc. can be combined with or substituted for parameters/attributes/etc. of another embodiment unless specifically disclaimed herein.

**[0167]** Although the foregoing has been described in some detail for purposes of clarity, it will be apparent that certain changes and modifications may be made without departing from the principles thereof. It should be noted that there are many alternative ways of

implementing both the processes and apparatuses described herein. Accordingly, the present embodiments are to be considered illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

**[0168]** Those having skill in the art will appreciate that many changes may be made to the details of the above-described embodiments without departing from the underlying principles of the invention. The scope of the present invention should, therefore, be determined only by the following claims.

**Claims:**

1. An apparatus of a user equipment (UE), comprising storage configured to store an uplink grant configuration; a processor configured to:
  - process an uplink grant from radio access network node, the uplink grant comprising the uplink grant configuration and a schedule for multiple physical uplink transmissions using an unlicensed wireless spectrum;
  - sense the unlicensed wireless spectrum for signals or noise to determine whether the unlicensed wireless spectrum is idle or busy;
  - when the unlicensed wireless spectrum is determined to be idle, generate the multiple physical uplink transmissions during the schedule; and
  - when the unlicensed wireless spectrum is determined to be busy, prevent the multiple physical uplink transmissions during the schedule.
2. The apparatus of claim 1, wherein the multiple physical uplink transmissions comprise physical uplink shared channel (PUSCH) transmissions or physical uplink control channel (PUCCH) transmissions.
3. The apparatus of claim 1, wherein each of the multiple physical uplink transmissions comprises a subframe.
4. The apparatus of claim 1, wherein the uplink grant schedules one or more uplink subframes.
5. The apparatus of claim 1, wherein the uplink grant includes an indicator that the uplink grant is within maximum channel occupancy time (MCOT), to allow the UE to use a shorter listen before talk (LBT) protocol.
6. The apparatus of any of claims 1-5, wherein the uplink grant indicates resource indication value (RIV), modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) information separately for each subframe.
7. The apparatus of any of claims 1-5, wherein the uplink grant indicates modulation and coding scheme (MCS), hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each scheduled subframe via a single uplink grant; and wherein resource indication value (RIV) is fixed for scheduled uplink subframes.

8. The apparatus of any of claims 1-5, wherein the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID), new data indicator (NDI), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) separately for each subframe via a single UL grant; and wherein resource indication value (RIV), modulation and coding scheme (MCS), and redundancy version (RV) are fixed for scheduled uplink subframes.

9. The apparatus of any of claims 1-5, wherein the uplink grant indicates hybrid automatic repeat request identifier (HARQ ID) and new data indicator (NDI) information separately for each subframe via a single UL grant; and wherein resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes.

10. The apparatus of any of claims 1-5, wherein the uplink grant indicates new data indicator (NDI) information separately for each subframe; and

wherein resource indication value (RIV), modulation and coding scheme (MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes; and

wherein the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

11. The apparatus of any of claims 1-5, wherein the uplink grant indicates redundancy version (RV) and new data indicator (NDI) information separately for each subframe;

wherein resource indication value (RIV), modulation and coding scheme (MCS), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes; and

wherein the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

12. The apparatus of claim 11, wherein the subsequent HARQ IDs for remaining subframes are implicitly computed by sequentially incrementing a subframe offset with respect to the first HARQ ID.

13. The apparatus of any of claims 1-5, wherein the uplink grant indicates new data indicator (NDI) information, resource indication value (RIV), modulation and coding scheme

(MCS), redundancy version (RV), listen before talk (LBT) information and cross-transmission opportunity (cross-TxOP) are fixed for scheduled uplink subframes; and

wherein the uplink grant indicates a first hybrid automatic repeat request identifier (HARQ ID) for a first uplink subframe and subsequent HARQ IDs for remaining subframes are implicitly computed.

14. An apparatus of enhanced node B (eNB), comprising:  
storage configured to store an uplink grant configuration;  
a processor configured to:

generate an uplink grant, the uplink grant comprising a schedule for multiple physical uplink shared channel (PUSCH) transmissions using an unlicensed wireless medium and an indication of a type of listen before talk (LBT) sensing to use with the unlicensed wireless medium to determine if the unlicensed wireless medium is idle;

when the unlicensed wireless medium is determined to be idle, process the multiple PUSCH transmissions during the schedule.

15. The apparatus of claim 14, wherein the uplink grant for multiple physical uplink transmissions is for physical uplink shared channel (PUSCH) transmissions or physical uplink control channel (PUCCH) transmissions.

16. The apparatus of claim 14, wherein the uplink grant indicates if a scheduled subframe transmission is within a maximum channel occupancy time (MCOT) or outside the MCOT.

17. A computer program product comprising a computer-readable storage medium that stores instructions for execution by a processor to perform operations of a user equipment (UE), the operations, when executed by the processor, to perform a method, the method comprising:

process an uplink grant from an enhanced node B (eNB), the uplink grant comprising an interlace allocation assignment schedule for physical uplink shared channel (PUSCH) transmissions using an unlicensed wireless medium;

sense the unlicensed wireless medium for signals or noise to determine if the unlicensed wireless medium is idle at a physical resource block at an interlace allocation assignment;

when the unlicensed wireless medium is determined to be idle, generate a PUSCH transmission based at least in part on the schedule; and

when the unlicensed wireless medium is determined to be busy, prevent the PUSCH transmission during the schedule.

18. The computer program product of claim 17, wherein the uplink grant uses resource indication value (RIV) to indicate an interlace allocation.

19. The computer program product of claim 17, wherein the uplink grant includes an indicator that the uplink grant is within maximum channel occupancy time (MCOT), allowing the UE to use a shorter listen before talk (LBT) protocol.

20. The computer program product of claim 19, wherein the shorter listen before talk (LBT) protocol is a single interval LBT.

21. The computer program product of claim 19, wherein the shorter listen before talk (LBT) protocol is a short category 4 LBT including puncturing a first symbol of a physical uplink transmission shared channel (PUSCH) transmission.

22. The computer program product of claim 17, wherein no listen before talk (LBT) protocol is performed for sequential uplink transmissions after a LBT protocol was performed before a first transmission.

23. A method for providing an uplink grant with an interlace allocation assignment, the method comprising:

generate an uplink grant from a radio access network node, the uplink grant comprising an interlace allocation assignment schedule for physical uplink transmission shared channel (PUSCH) transmissions using a shared spectrum and an indication of a type of listen before talk (LBT) sensing to use with the shared spectrum to determine if the shared spectrum is idle; and

when the shared spectrum is determined to be idle, process a PUSCH transmission during the allocation assignment schedule.

24. The method of claim 23, wherein the uplink grant uses resource indication value (RIV) to indicate the interlace allocation assignment.

25. The method of claim 23, wherein the interlace allocation assignment is based on inter-physical resource block distance and system bandwidth.

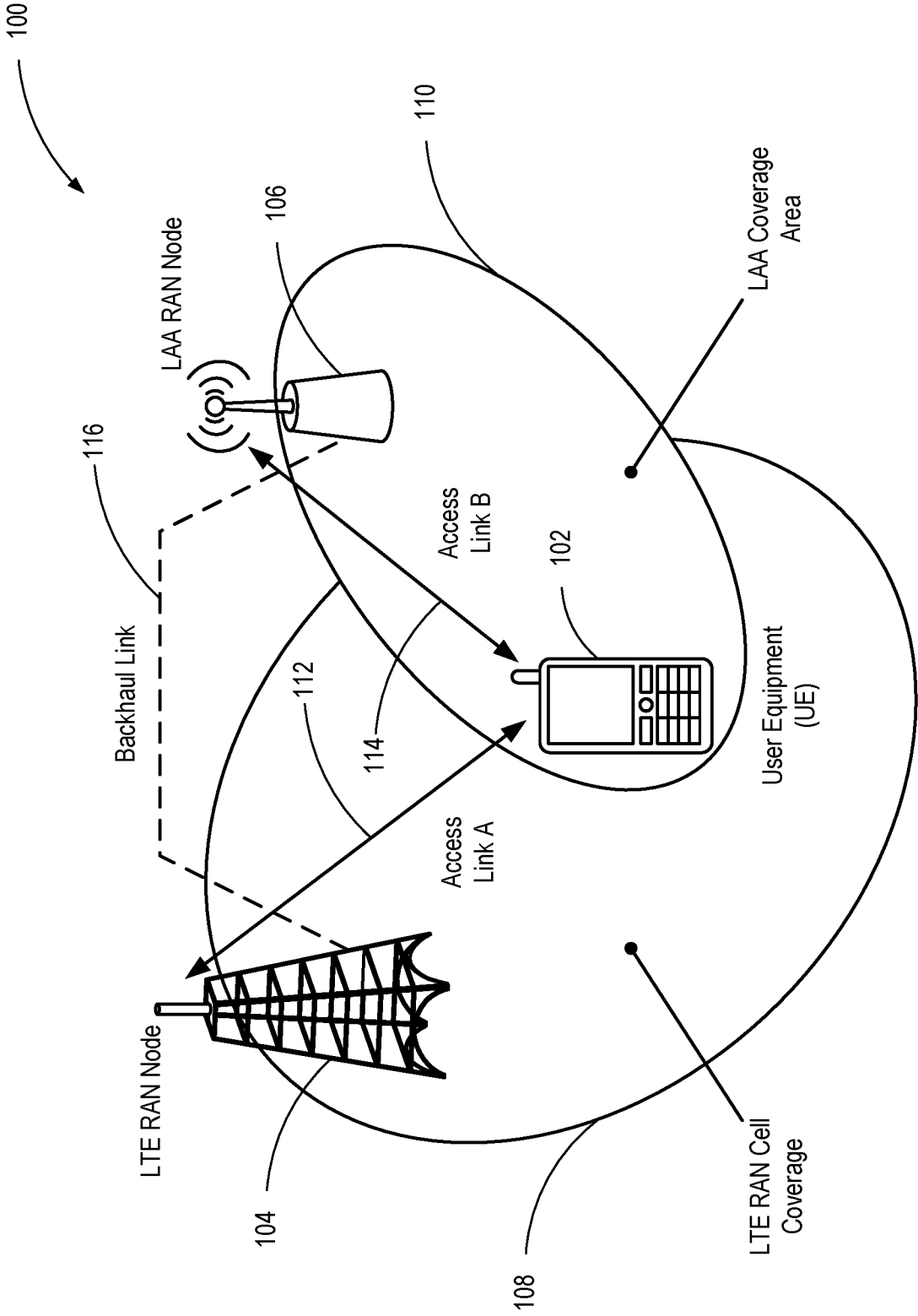
26. The method of claim 23, wherein the uplink grant uses a starting interlace index and a number of interlaces to be assigned to the UE to indicate the interlace allocation assignment.

27. The method of claim 23, wherein the uplink grant uses a bitmap to indicate the interlace allocation assignment.

28. An apparatus comprising means to perform a method as claimed in any of claims 23-27.

29. A machine readable medium including code, when executed, to cause a machine to perform the method of any one of claims 23-27.

FIG. 1



200



Field	Bit Length
Carrier Indicator	3
Format0-A-Flag	1
Frequency Hopping	1
RIV	13 (for 20 MHz)
MCS	5
RV	2
NDI	1
TPC	2
Cyclic Shift	3
CQI Request	1 or 2 bits
SRS Request	1

FIG. 2

300

Starting Interface Index	0	1	2	3	4	5	6	7	8	9
# of Interfaces That Can Be Assigned in Case of Single-User	{1, 2, 3, 4, 5, 6, 7, 8, 9, 10}	{1, 2, 3, 4, 5, 6, 7, 8, 9}	{1, 2, 3, 4, 5, 6, 7, 8}	{1, 2, 3, 4, 5, 6, 7}	{1, 2, 3, 4, 5, 6}	{1, 2, 3, 4, 5}	{1, 2, 3, 4}	{1, 2, 3}	{1, 2}	{1}

FIG. 3

400

Field	Bit Length
Carrier Indicator	3
Format0-A-Flag	0
Frequency Hopping	0
RIV	6 or 10
MCS	5
RV	2
NDI	1
TPC	2
Cyclic Shift	3
CQI Request	1 or 2
SRS Request	1
HARQ ID	4
LBT Information	2 bits (LBT Type)
Within/Outside MCOT	1
Indication of Scheduled UL SF Location	4 bit Timing Relationship (w.r.t. First UL Subframe)

FIG. 4

500

Field	Bit Length
Carrier Indicator	3
Format0-A-Flag	0
Frequency Hopping	0
RIV	6*Nmax
MCS/RV	5* Nmax
RV	2*Nmax
NDI	1* Nmax
TPC	2
Cyclic Shift	3
CQI Request	1 or 2
SRS request	1
HARQ ID	4*Nmax
LBT information	2 (LBT type)* Nmax
Within/Outside MCOT	1 *Nmax
Indication of Scheduled UL SF Location	4 bit Timing Relationship (w.r.t. First UL Subframe)
Cross-TxOP Option 1 or 2	1* Nmax
Set of Scheduled UL Subframe	Consecutive: log(Nmax) bits, Distributed Bitmap = Nmax bits

FIG. 5

600

Scheme	Comments	Max Bit Length for N = 8
Scheme 1	RIV, MCS, HARQID, NDI, RV, LBT Information, Cross-TxOP Info are Indicated for Each SF.	195
Scheme 2	MCS, HARQID, NDI, RV, LBT Information, Cross-TxOP Info are Indicated for Each SF. RIV are Fixed.	153
Scheme 3	HARQID, NDI, LBT, Cross-TxOP info Indicated for Each Subframe. MCS, RV, RIV, is Fixed	104
Scheme 4	HARQID, NDI, LBT Indicated for Each Subframe. MCS, RV, RIV, Type of Cross-TxOP are Fixed.	89
Scheme 5	HARQID, NDI for Each Subframe. MCS/RV, RIV, Type of Cross-TxOP are Fixed.	74
Scheme 6	MCS, RIV, Cross-TxOP Option, Within/Outside TxOP Indication are Fixed. HARQ is Implicitly Indicated. RV, NDI separately Indicated for Each Subframe.	59
Scheme 7	MCS, RV, RIV, Cross-TxOP Option, Within/Outside TxOP Indication are Fixed. HARQ is Implicitly Indicated. NDI is separately Indicated for Each Subframe.	44
Scheme 8	MCS, RV, NDI, RIV, Cross-TxOP Option, Within/Outside TxOP Indication are Fixed. HARQ is Implicitly Indicated.	38

FIG. 6

700

Field	Bit Length
Carrier Indicator	3
Format0-A-Flag	0
Frequency Hopping	0
RIV	6
MCS	5
RV	2
NDI	1
TPC	2
Cyclic Shift	3
CQI Request	1 or 2
SRS Request	1
HARQ ID	4
LBT Information	0
Within/Outside MCOT	1
Indication of Scheduled UL SF Location	4 bit Timing Relationship (w.r.t. First UL Subframe)
Cross-TxOP Option 1 or 2	1
Set of Scheduled UL Subframe	Consecutive: $\log(N_{max})$ bits, Distributed Bitmap = $N_{max}$ bits

FIG. 7

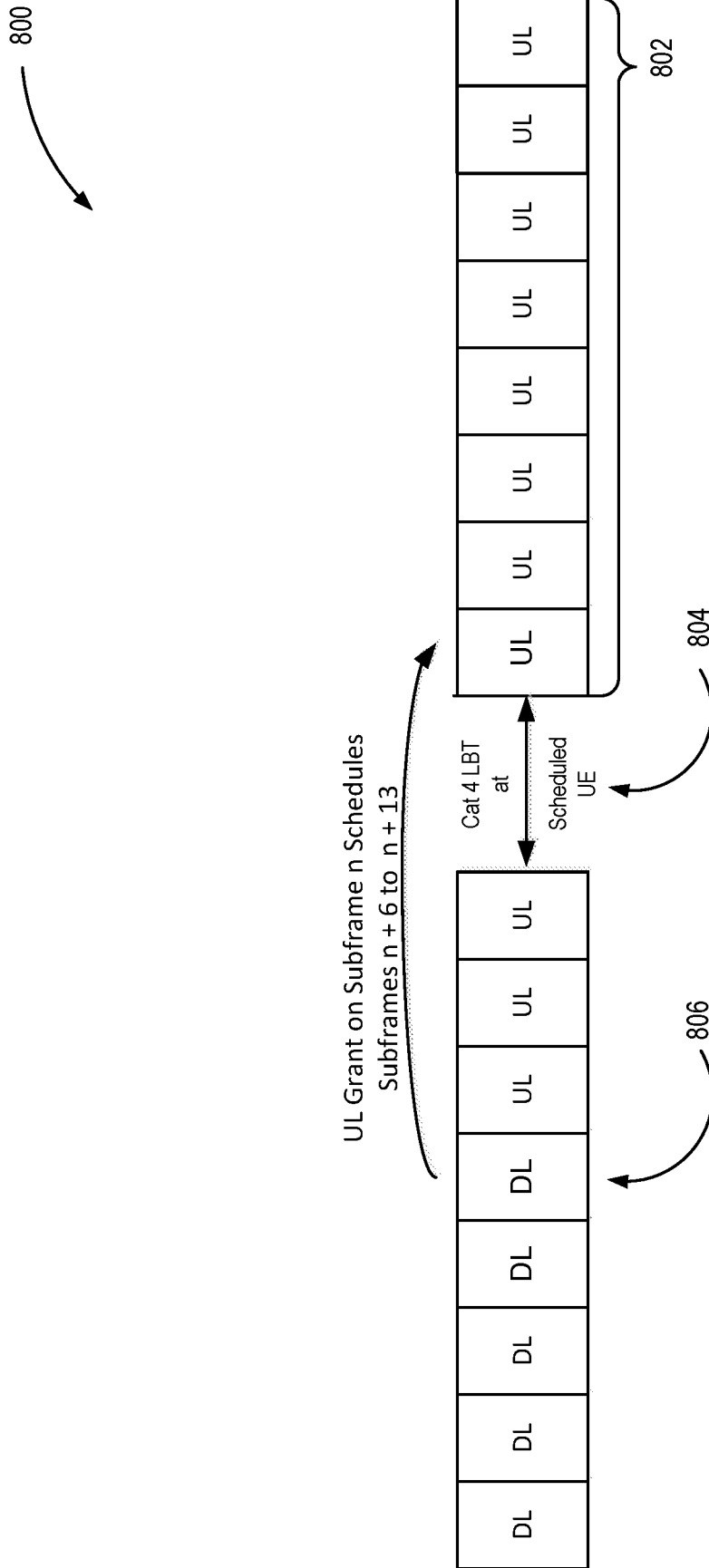


FIG. 8

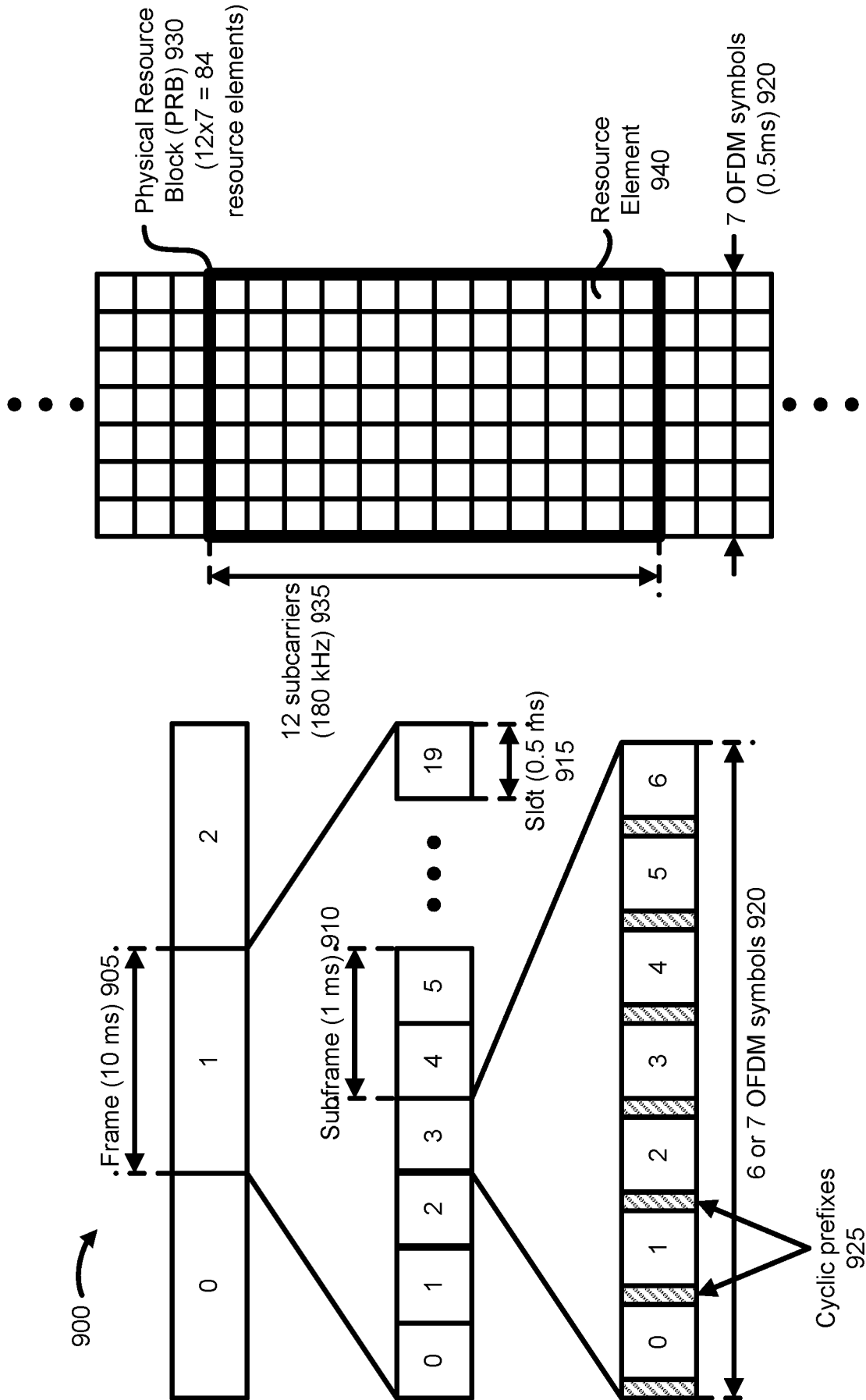


FIG. 9

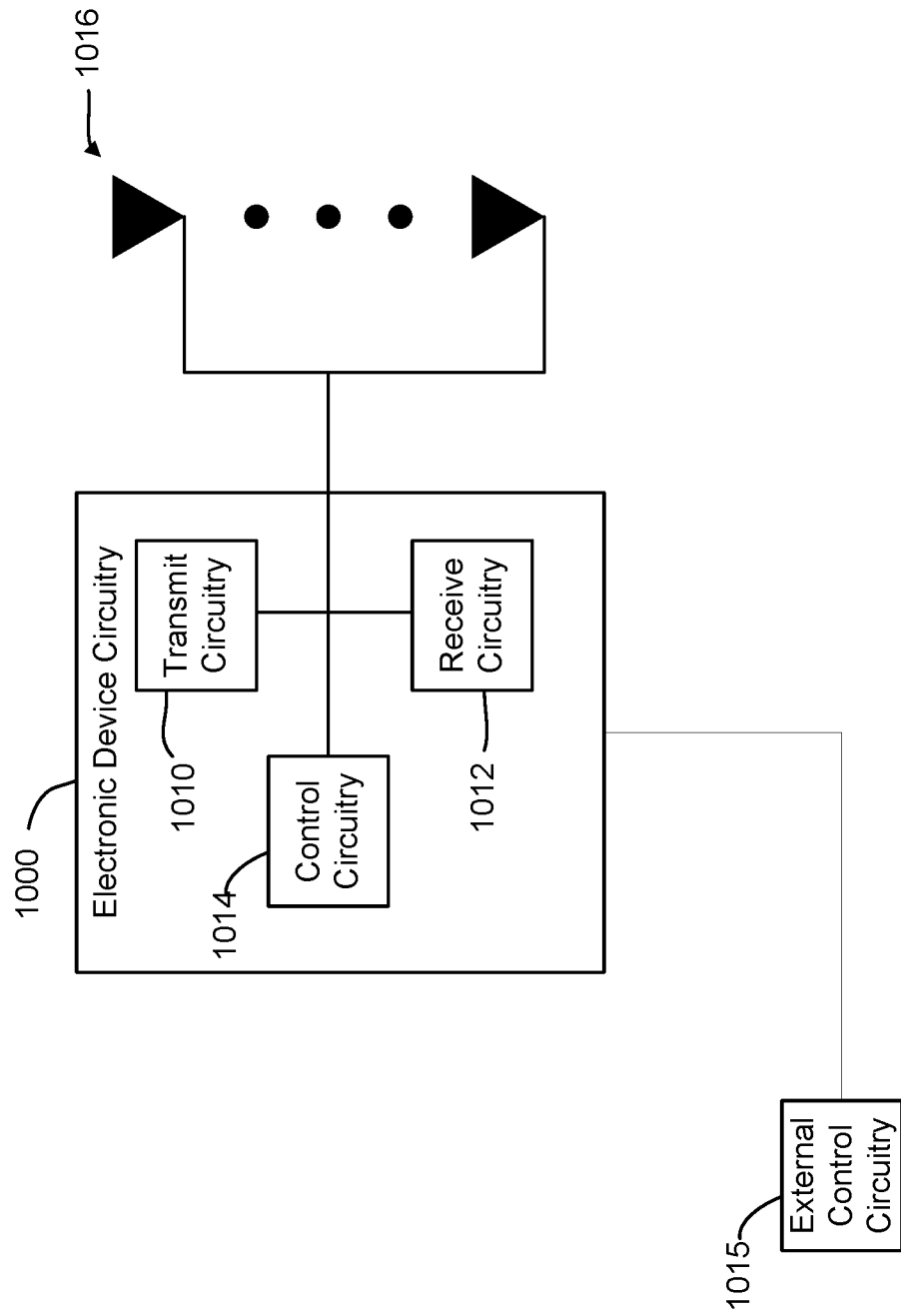


FIG. 10

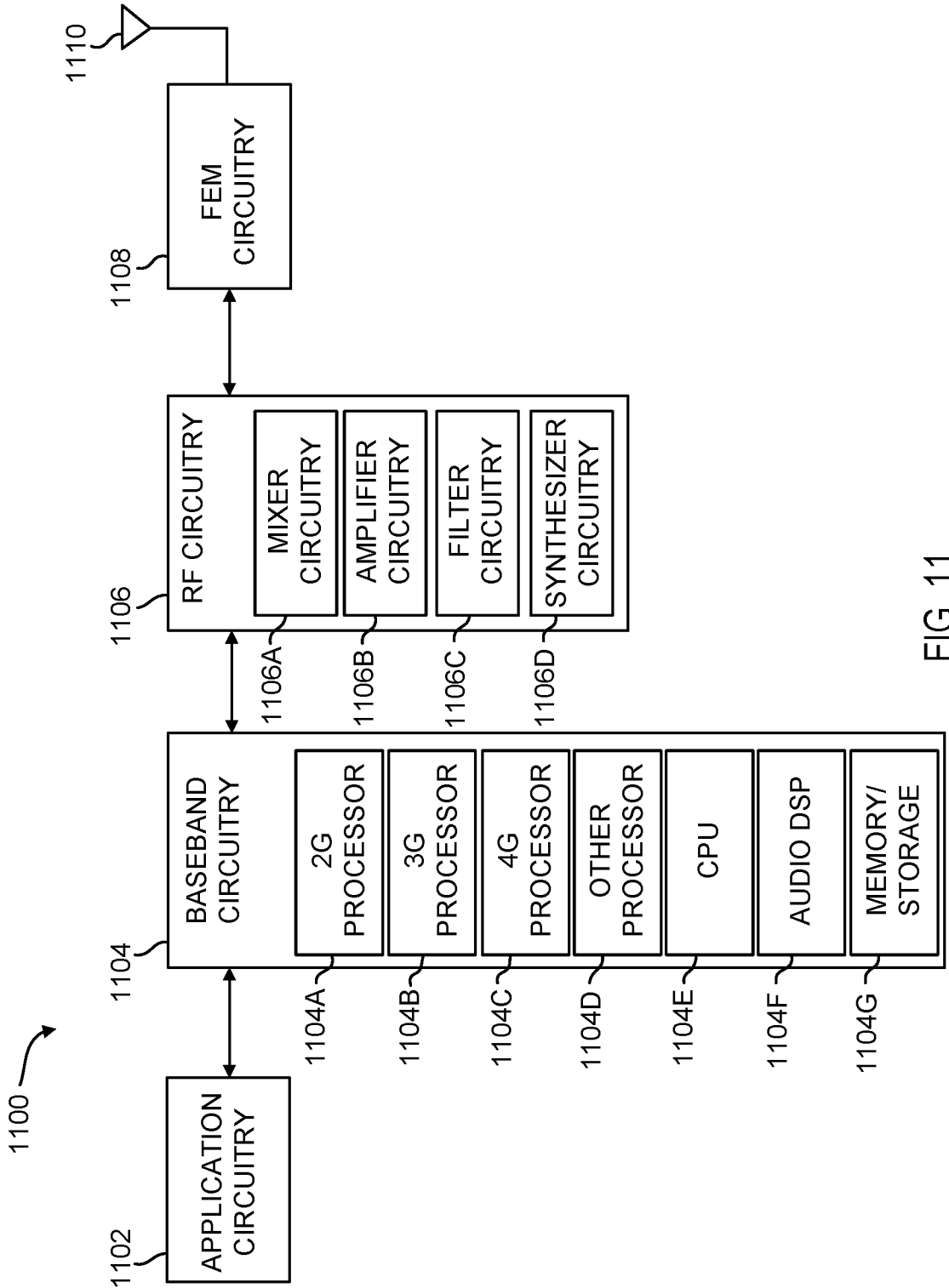


FIG. 11

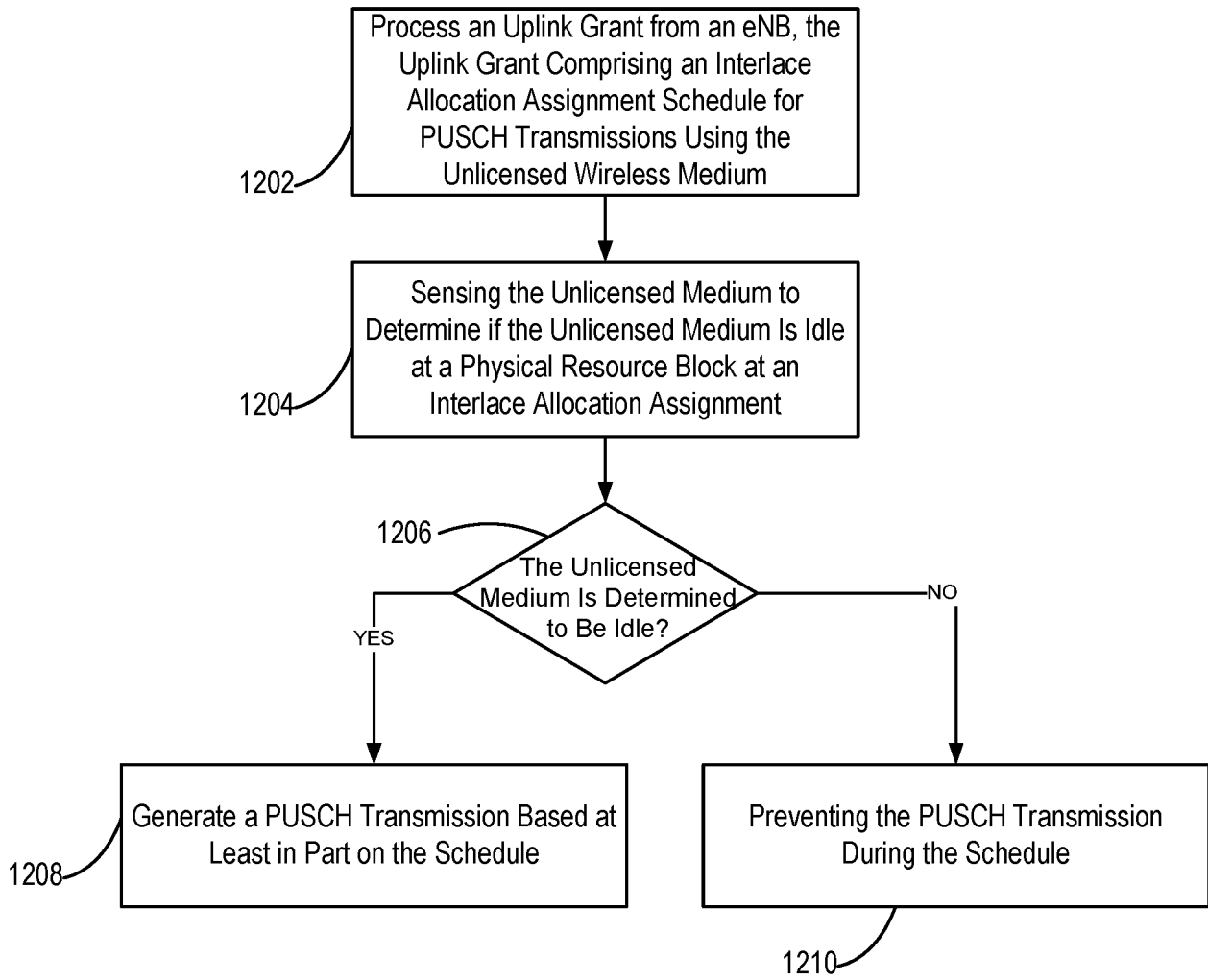


FIG. 12

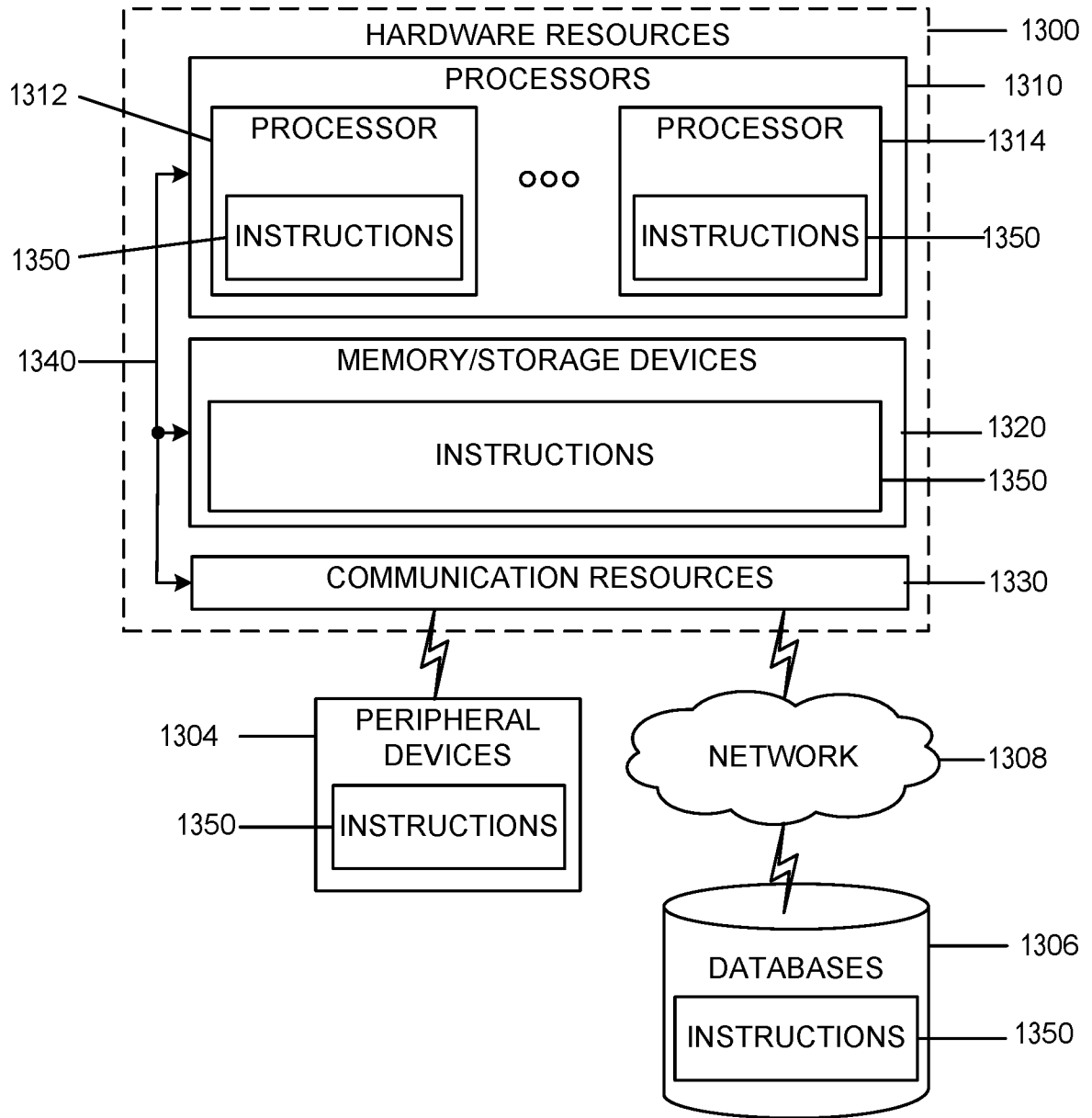


FIG. 13

# INTERNATIONAL SEARCH REPORT

International application No PCT/US2016/050655
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<b>A. CLASSIFICATION OF SUBJECT MATTER</b> INV. H04W72/14 ADD. H04W72/12      H04W74/08      H04W16/14      H04L5/00				
According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b>				
Minimum documentation searched (classification system followed by classification symbols) H04W H04L				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  EPO-Internal				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
X	ERICSSON: "On UL Channel Access Procedures for PUSCH", 3GPP DRAFT; R1-163150, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE  vol. RAN WG1, no. Busan, Korea; 20160411 - 20160415 2 April 2016 (2016-04-02), XP051080566, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-02]	1-5, 14-16		
A	page 1, line 20 - line 21 page 2, line 18 - line 20 page 3, line 2 - line 5  -----  -/--	6-13, 17-29		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.				
* Special categories of cited documents : <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none; vertical-align: top;">                     "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                 </td> <td style="width: 50%; border: none; vertical-align: top;">                     "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                      "&amp;" document member of the same patent family                 </td> </tr> </table>			"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
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Date of the actual completion of the international search  22 December 2016		Date of mailing of the international search report  10/01/2017		
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer  Andrés Muñoz, E		

INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2016/050655

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ZTE: "UL framework for LAA", 3GPP DRAFT; R1-156994 UL FRAMEWORK FOR LAA, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE  , vol. RAN WG1, no. Anaheim, USA; 20151115 - 20151122 15 November 2015 (2015-11-15), XP051003305, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_ SYNC/RAN1/Docs/ [retrieved on 2015-11-15]	1, 14, 17-25, 27-29
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INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2016/050655

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>LG ELECTRONICS: "Multi-subframe scheduling in LAA", 3GPP DRAFT; R1-162466 LAA MULTI-SF SCHEDULING, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>, vol. RAN WG1, no. Busan, Korea; 20160411 - 20160415 2 April 2016 (2016-04-02), XP051080204, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-02]</p>	1,7-14
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X	<p>INTERDIGITAL COMMUNICATIONS: "On UL data transmission for eLAA", 3GPP DRAFT; R1-162910 IDCC ELAA UL DATA, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>, vol. RAN WG1, no. Busan, Korea; 20160411 - 20160415 1 April 2016 (2016-04-01), XP051079743, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-01]</p>	1,17
Y A	<p>page 1, line 26 - line 27 page 2, line 17 - line 29 page 3, line 18 - line 19 -----</p>	26 2-16, 18-25, 27-29