



(51) International Patent Classification:

H04W 74/08 (2009.01) *H04L 27/00* (2006.01)

(21) International Application Number:

PCT/US2017/049770

(22) International Filing Date:

31 August 2017 (31.08.2017)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/383,103	02 September 2016 (02.09.2016)	US
62/414,470	28 October 2016 (28.10.2016)	US
62/415,215	31 October 2016 (31.10.2016)	US

(71) Applicant: **INTEL CORPORATION** [US/US]; 2200 Mission College Blvd., Santa Clara, California 95054 (US).(72) Inventors: **BHORKAR, Abhijeet**; 3300 Darwin Drive, Fremont, California 94555 (US). **NIU, Huaning**; 6806 Bluffwood Court, San Jose, California 95120 (US). **YE, Qiaoyang**; 4536 Piper Street, Fremont, California 94538 (US). **JEON, Jeongho**; 5621 Bluegrass Lane, San Jose, California 95118 (US). **CHANG, Wenting**; 8F, Raycom Infotech Park A, No2, Kexueyuan South Road, Beijing, Heilongjiang 100190 (CN).(74) Agent: **HAYMOND, Alex W.**; P.O. Box 1219, Sandy, Utah 84091 (US).(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, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,

(54) Title: PHYSICAL RANDOM ACCESS CHANNEL (PRACH) DESIGN FOR UNLICENSED CARRIERS IN LTE

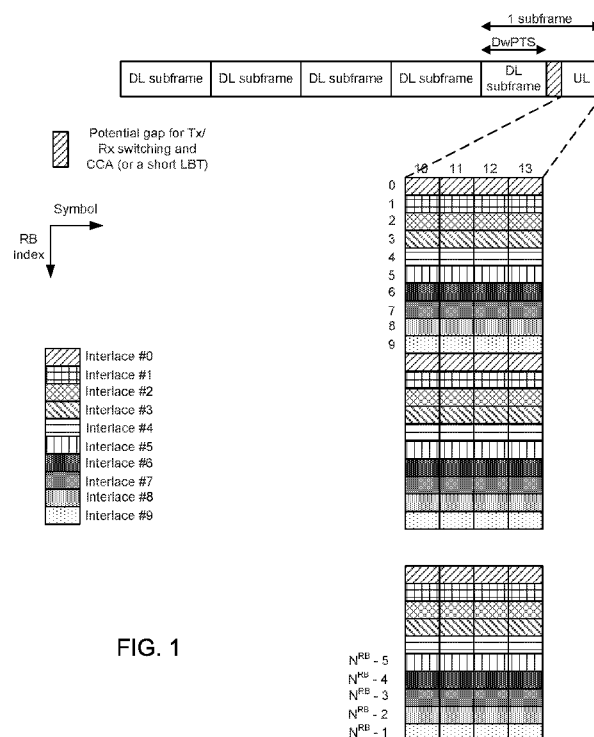


FIG. 1

(57) **Abstract:** Technology for an eNodeB operable to perform physical random access channel (PRACH) transmissions in an unlicensed frequency band, in the context of 3GPP LTE eLAA, i.e. MuLTEfire, is disclosed. The eNodeB can identify a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum. The PRACH configuration can define a number of continuous physical resource blocks (PRBs) in the unlicensed spectrum to be used for PRACH transmissions. The eNodeB can decode a PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration. The PRACH transmission can include a PRACH preamble that is transmitted using the number of continuous PRBs defined in the PRACH configuration. The eNB configures the performance of Clear Channel Assessment, CCA, before preamble transmission by the UE. In case the uplink transmission frame is configured with short PUCCH, sPUCCH, only a short CCA is configured. Otherwise, for example when the frame

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 the identity of the inventor (Rule 4.17(i))*

Published:

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

PHYSICAL RANDOM ACCESS CHANNEL (PRACH) DESIGN FOR UNLICENSED CARRIERS IN LTE

BACKGROUND

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

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

[0004] FIG. 1 illustrates a physical random access channel (PRACH) transmission in a special subframe in accordance with an example;

[0005] FIG. 2 illustrates a random access channel (RACH) transmission that is blocked

by an ongoing data transmission due to a timing advance (TA) in accordance with an example;

[0006] FIG. 3 illustrates an uplink (UL) timing advance (TA) setting for a random access channel (RACH) transmission in a small cell in accordance with an example;

5 [0007] FIG. 4 illustrates an uplink (UL) timing advance (TA) setting issue for a random access channel (RACH) transmission in accordance with an example;

[0008] FIG. 5 illustrates a channel access technique and timing advance (TA) setting for a random access channel (RACH) transmission in accordance with an example;

10 [0009] FIG. 6 illustrates a physical random access channel (PRACH) symbol structure in accordance with an example;

[0010] FIG. 7 illustrates another physical random access channel (PRACH) symbol structure in accordance with an example;

[0011] FIG. 8 illustrates yet another physical random access channel (PRACH) symbol structure in accordance with an example;

15 [0012] FIG. 9 illustrates a further physical random access channel (PRACH) symbol structure in accordance with an example;

[0013] FIG. 10 depicts functionality of an eNodeB operable to set an uplink timing advance (TA) value for random access channel (RACH) transmissions in a MuLTEfire system in accordance with an example;

20 [0014] FIG. 11 depicts functionality of an eNodeB operable to perform physical random access channel (PRACH) transmissions in accordance with an example;

[0015] FIG. 12 depicts a flowchart of a machine readable storage medium having instructions embodied thereon for performing physical random access channel (PRACH) transmissions in accordance with an example;

25 [0016] FIG. 13 illustrates an architecture of a wireless network in accordance with an example;

[0017] FIG. 14 illustrates a diagram of a wireless device (e.g., UE) in accordance with an example;

[0018] FIG. 15 illustrates interfaces of baseband circuitry in accordance with an example; and

[0019] FIG. 16 illustrates a diagram of a wireless device (e.g., UE) in accordance with an example.

5 [0020] Reference will now be made to the exemplary embodiments illustrated, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the technology is thereby intended.

DETAILED DESCRIPTION

10 [0021] Before the present technology is disclosed and described, it is to be understood that this technology is not limited to the particular structures, process actions, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular examples only and is not
15 intended to be limiting. The same reference numerals in different drawings represent the same element. Numbers provided in flow charts and processes are provided for clarity in illustrating actions and operations and do not necessarily indicate a particular order or sequence.

20 EXAMPLE EMBODIMENTS

[0022] An initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail later. This initial summary is intended to aid readers in understanding the technology more quickly but is not intended to identify key features or essential features of the technology nor is it
25 intended to limit the scope of the claimed subject matter.

[0023] The explosive growth in wireless traffic has led to a demand for rate improvement. However, with mature physical layer techniques, further improvement in spectral efficiency has been marginal. In addition, the scarcity of licensed spectrum in the low frequency band results in a deficit in the data rate boost. There are emerging interests
30 in the operation of LTE systems in unlicensed spectrum. In 3GPP LTE Release 13, one

enhancement has been to enable operation in the unlicensed spectrum via licensed-assisted access (LAA). LAA can expand the system bandwidth by utilizing a flexible carrier aggregation (CA) framework, as introduced in the LTE-Advanced system (3GPP LTE Release 10 system). Release 13 LAA focuses on the downlink (DL) design, while
5 3GPP Release 14 enhanced LAA (or eLAA) focuses on the uplink (UL) design. Enhanced operation of LTE systems in the unlicensed spectrum is expected in Fifth Generation (5G) wireless communication systems. In one example, LTE operation in the unlicensed spectrum can be achieved using dual connectivity (DC) based LAA. In DC based LAA, an anchor deployed in the licensed spectrum can be utilized.

10 [0024] In another example, 3GPP Release 14 describes that LTE operation in the unlicensed system can be achieved using a MuLTEfire system, which does not utilize an anchor in the licensed spectrum. The MuLTEfire system is a standalone LTE system that operates in the unlicensed spectrum, and does not necessitate assistance from the licensed spectrum and combines the performance benefits of LTE technology with the simplicity
15 of WiFi-like deployments. Therefore, Release 14 eLAA and MuLTEfire systems can potentially be significant evolutions in future wireless networks.

[0025] In one example, the unlicensed frequency band of current interest for 3GPP systems is the 5 gigahertz (GHz) band, which has wide spectrum with global common availability. The 5 GHz band in the United States is governed using Unlicensed National
20 Information Infrastructure (U-NII) rules by the Federal Communications Commission (FCC). The main incumbent system in the 5 GHz band is the wireless local area networks (WLAN), specifically those based on the IEEE 802.11 a/n/ac technologies. WLAN systems are widely deployed both by individuals and operators for carrier-grade access service and data offloading. Therefore, listen-before-talk (LBT) in the unlicensed
25 spectrum is a mandatory feature in the 3GPP Release 13 LAA system, which can enable fair coexistence with the incumbent system. LBT is a procedure in which radio transmitters first sense the medium, and transmit only if the medium is sensed to be idle.

[0026] The regulations for usage of the unlicensed spectrum can vary based on region. For example, the European Telecommunications Standards Institute (ETSI) in the
30 European Union specifies that an occupied channel bandwidth (OCB) is to be between 80% and 100% of a declared nominal channel bandwidth. In other words, a transmitter is

to transmit a signal by occupying between 80% and 100% of the system bandwidth. For example, when the system operates with a total bandwidth of 10 MHz, each transmission is to occupy at least 8 MHz. The regulations on the maximum power spectral density are typically stated with a resolution bandwidth of 1 megahertz (MHz). The ETSI

5 specification defines a maximum power spectral density (PSD) of 10 decibel-milliwatts (dBm)/MHz for 5150-5350 MHz. The FCC has a maximum PSD of 11 dBm/MHz for 5150-5350 MHz. A 10 kilohertz (KHz) resolution can be utilized for testing the 1 MHz PSD constraint and, therefore, the maximum PSD constraint can be satisfied in an occupied 1MHz bandwidth. In addition, the regulations impose a band specific total
10 maximum transmission power in terms of equivalent isotropically radiated power (EIRP), e.g., ETSI has an EIRP limit of 23 dBm for 5150 – 5350 MHz.

[0027] FIG. 1 illustrates an exemplary physical random access channel (PRACH) transmission in a special subframe. The PRACH can utilize a block interleaved frequency division multiple access (B-IFDMA) waveform, in part, to satisfy an occupied channel
15 bandwidth (OCB) regulation (e.g., the OCB is to be between 80% and 100% system bandwidth). In eLAA and MuLTEfire systems, an UL portion of the special subframe can be used for the PRACH transmission. In a specific example, an uplink pilot time slot (UpPTS) region or an extended UpPTS region occupying a last four OFDM symbols of the special subframe can be used for the PRACH transmission. Alternatively, the PRACH
20 can be transmitted over a regular UL subframe, which can be beneficial for large cells.

[0028] As shown in FIG. 1, the special subframe can include a DL portion and an UL portion. The first N symbols in the special subframe can be used for DL transmissions, wherein N is an integer. There can be a gap between the DL portion and the UL portion, which enables a transmitter to switch between a DL reception and an UL transmission. As
25 shown, the PRACH can be transmitted during the UL portion of the special subframe. In the example shown, the PRACH can utilize 4 symbols, but a different number of symbols can be used for the PRACH as well.

[0029] The PRACH can be transmitted using an interlaced subframe structure, such as a B-IFDMA subframe structure, to satisfy the OCB regulation. A total system bandwidth
30 can be separated into multiple interlaces. For example, a 20 MHz system can be separated into 10 interlaces. One interlace can include 10 resource blocks (RBs). Interlace #0 can

occupy RB 0, 10, 20 and so on. Interlace #1 can occupy RB 1, 11, 21 and so on. Here, the total occupied bandwidth can be from 0 to 90 RBs, which is more than 80% of the total system bandwidth (which satisfies the OCB regulation). By interlacing, the bandwidth usage can be increased to at least 80%.

5

RACH Channel Access Procedure and Timing Advance

[0030] In one example, other than the 5GHz band, there are regional unlicensed bands or shared licensed bands, such as the 3.5GHz band in the United States, or the 1.9GHz band in Japan, which are of great interest to extend coverage and data rates. These bands can allow for an increased cell size without WiFi.

10

[0031] In one example, in 3GPP Release 14 LAA and MuLTEfire systems, UL LAA design is being considered. The UL LAA design can be inherently different from a legacy LTE design, as the UE has to perform LBT before transmission. In addition, there can be further restrictions for UL LAA transmissions to obey various regulations, such as ETSI.

15

[0032] In one configuration, a random access channel (RACH) is defined in MulteFire systems, such that a RACH transmission is periodically allocated in a location, which can be signaled through a system information block MulteFire (SIB-MF). The RACH can use a shortened physical uplink control channel (sPUCCH) format for a short cell size, and an enhanced physical uplink control channel (ePUCCH) format for a large cell size. Before each RACH transmission opportunity, the UE can perform one shot clear channel assessment (CCA) sensing. If successful, the UE can send a RACH preamble. Otherwise, the UE can wait until a next RACH transmission opportunity.

20

[0033] In one example, a technique is described for setting a timing advance (TA), as well as a random access procedure for RACH transmissions in a MulteFire system. For example, when RACH is configured with the sPUCCH format, a TA can be set to a TA offset (TA_offset), and the random access procedure can follow the one shot CCA process defined in the 5GHz band. When the RACH is configured with the ePUCCH format, the TA can be set to the TA offset (TA_offset), while the random access procedure can perform an earlier sensing and a self-defer, where a defer value can be signaled through the SIB-MF. Since the MuLTEfire system operates in the unlicensed spectrum, the UE

25

30

can perform listen before talk (LBT) before a transmission, and if the UE does not perform the self-defer in conjunction with LBT, the UE can potentially block other UEs from performing transmissions.

[0034] In one example, in LTE systems, RACH transmissions do not apply the TA. A RACH sequence can typically have a longer cyclic prefix (CP), which can be longer than a round trip delay plus a channel delay spread. Thus, the TA can be applied to following data and control information after a radio resource control (RRC) connection is established. On the other hand, in MulteFire systems, due to the listen before talk procedure, the TA that is applied to data transmission through a different frequency interlace can block a RACH transmission.

[0035] FIG. 2 illustrates an example of a random access channel (RACH) transmission that is blocked by an ongoing data transmission due to a timing advance (TA). In MulteFire systems, due to a listen before talk procedure, the TA applied to the data transmission can block the RACH transmission. For example, a subframe can include a downlink radio frame, an uplink radio frame for a PUSCH or e/sPUCCH for a first UE (UE1) and an uplink radio frame for RACH for a second UE (UE2). In some cases, a UE2 RACH transmission can be blocked by the ongoing data transmission due to the TA.

[0036] In one example, in LTE systems, a TA setting can be specified as a TA value = $(N_{TA} + N_{TA\ offset})T_s$, where T_s is a sampling time, N_{TA} is an individual TA value per UE to handle a different round trip time (RTT), and $N_{TA\ offset}$ is a common offset applied to all UEs. In one example, $N_{TA\ offset}$ can be 0 in frame structure type 1, $N_{TA\ offset}$ can be 624 in frame structure type 2, and $N_{TA\ offset}$ can be 0 in frame structure type 3. As described in further detail below, an $N_{TA\ offset}$ can be applied to RACH transmissions.

[0037] In one configuration, with respect to TA settings for small cells, the RACH can be configured using the sPUCCH transmission format, and the RTT can be smaller than 5 micro seconds (us) (cell size is less than 750 meters). A CCA mechanism or procedure in the 5GHz band can necessitate a CCA sensing time of 4us out of a slot of 9us, while the last 5us can be used for medium access control (MAC) processing, receive (Rx) to transmit (Tx) switching, etc. When the N_{TA} is smaller than 5us, a normal UL transmission may not block the CCA sensing of the RACH, and the TA for the RACH can be set to $N_{TA\ offset} T_s$.

[0038] FIG. 3 illustrates an example of an uplink (UL) timing advance (TA) setting for a random access channel (RACH) transmission in a small cell. A subframe can include a downlink (DL) radio frame, an UL radio frame for a PUSCH or e/sPUCCH and an UL radio frame for a RACH transmission. When a N_{TA} is smaller than 5us, a normal UL transmission may not block a CCA sensing of the RACH transmission, and the UL TA for the RACH transmission can be set to $N_{TA\ offset} T_s$.

[0039] In one configuration, with respect to TA settings for large cells (e.g., RTT is greater than 5us and a cell size is greater than 750 meters), there can be several issues in the 3.5GHz band. For example, a RACH transmission can block a PUSCH/PUCCH transmission, or a PUSCH/PUCCH transmission can block the RACH transmission. For example, when the $N_{TA\ offset} T_s$ is applied to the RACH transmission, the RACH transmission can be blocked by the other UE's UL transmission. In another example, when $(N_{TA\ offset} + \max(N_{TA})) T_s$ is applied to the RACH transmission, the RACH transmission can be blocked by the other UE's UL transmission, wherein $\max(N_{TA})$ indicates a maximum individual TA value per UE.

[0040] FIG. 4 illustrates an example of an uplink (UL) timing advance (TA) setting issue for a random access channel (RACH) transmission. A subframe can include a downlink (DL) radio frame, an uplink (UL) radio frame for a first user equipment (UE) (UE1) with a $\max(N_{TA})$, an UL radio frame for the UE1 with N_{TA0} , and an UL radio frame for RACH. When a cell is large (e.g., RTT is greater than 5 us and a cell size is greater than 750 meters), the RACH transmission can block a PUSCH/PUCCH transmission, or a PUSCH/PUCCH transmission can block a RACH transmission. More specifically, as shown, when the $N_{TA\ offset} T_s$ is applied to the RACH transmission, the RACH transmission can be blocked by the other UE's UL transmission. In another example, when $(N_{TA\ offset} + \max(N_{TA})) T_s$ is applied to the RACH transmission, the RACH transmission can be blocked by the other UE's UL transmission.

[0041] In one configuration, in order to resolve the above issue regarding the UL TA setting for the RACH transmission, a UE CCA sensing period can be moved by $\max(N_{TA})$. When the UE senses that a channel is clear, the UE can self-defer to a common TA setting of $N_{TA\ offset} T_s$ or $\max(N_{TA})$, and start the RACH transmission. In this configuration, a RACH CCA time can end by $(N_{TA\ offset} + \max(N_{TA})) T_s$. The UE self-

defer for the RACH transmission may not be applicable to the 5GHz band due to regulation. In addition, the RACH transmission can apply the TA offset $N_{TA\ offset} T_s$, and a self-defer value for the UE can be signaled in the SIB-MF.

[0042] FIG. 5 illustrates an example of a channel access technique and timing advance

5 (TA) setting for a random access channel (RACH) transmission. A subframe can include a downlink (DL) radio frame, an uplink (UL) radio frame for a first user equipment (UE) (UE1) with a $\max(N_{TA})$, an UL radio frame for the UE1 with N_{TA0} , and an UL radio frame for RACH. The UL radio frame for RACH can be preceded by CCA and a self-defer period. For example, a UE CCA sensing period can be moved by $\max(N_{TA})$. When
10 the UE senses that a channel is clear, the UE can self-defer to a common TA setting of $N_{TA\ offset} T_s$ and start the RACH transmission. In this configuration, a RACH CCA time can end by $(N_{TA\ offset} + \max(N_{TA})) T_s$.

[0043] In one configuration, a technique for channel access and setting a TA value for a RACH transmission in MulteFire systems is described. In one example, when the RACH
15 transmission is performed using the sPUCCH format, the TA can be set using $N_{TA\ offset} T_s$ for the RACH transmission. A 4 micro second (us) CCA sensing can be performed at a beginning of a CCA slot. In another example, when the RACH transmission is performed using ePUCCH resources, the TA can be set using $N_{TA\ offset} T_s$ for the RACH transmission. In this example, the CCA for the RACH transmission can be performed $\max(N_{TA}) T_s$
20 earlier. In addition, the UE can self-defer the RACH transmission by $\max(N_{TA}) T_s$, and the $\max(N_{TA})$ can be signaled in the SIB-MF.

Design of PRACH on 3.5 GHz Unlicensed Spectrum

[0044] In one configuration, MulteFire systems can consider the 3.5 GHz unlicensed
25 spectrum as a potential unlicensed deployment. In future releases (3GPP LTE Release 15), 3GPP may also consider the operation of new radio (NR) or (e)LAA systems on a 3.5 GHz Citizens Broadband Radio Service (CBRS) spectrum. The 3.5 GHz band was previously locked up by the United States Department of Defense (DoD), but was recently allowed to be used for commercial purposes. The Federal Communications
30 Commission (FCC) has adopted a three-tiered access model for the 3.5 GHz CBRS band as follows: (1) incumbent (federal user, fixed satellite service), (2) priority access

licensees (PALs), which can involve 100 MHz and an auction for short-term licensing, and (3) general authorized access (GAA), which can involve 150 MHz open for anyone with an FCC-certified device.

[0045] According to the above order of priority, a channel access by higher priority is protected from lower priorities. For instance, a channel access by PAL can be protected from GAA, whereas PAL should not hinder a channel access by an Incumbent. However, no particular coexistence rule, such as LBT is mandated by the FCC among GAAs. The FCC has defined a spectrum access system (SAS) that authorizes and manages the use of the CBRS (PAL, GAA) spectrum. The SAS is responsible for maintaining the prioritized channel access. As a frequency coordinator, the SAS can optimize frequency use to facilitate coexistence. In addition, the SAS can have limited coexistence provisioning between GAAs by means of spectrum coordination.

[0046] In one example, as opposed to the 5 GHz bandwidth, there is no regulation on a minimal channel bandwidth constraint, or the PSD limitation for transmission on the 3.5 GHz band. Thus, the motivation for interlaced structure in MulteFire systems and 3GPP LTE Release 13 eLAA systems no longer exists, and it is possible to have transmissions over continuous PRBs.

[0047] In one configuration, a novel PRACH design can be defined for the 3.5 GHz band. With respect to the PRACH in MulteFire 1.0 systems, the PRACH can be used for scheduling requests (SR), uplink (UL) synchronization and power control for an initial UL transmission. As agreed in MulteFire 1.0, an sPUCCH waveform can be used for the PRACH, which has an interlaced structure with 4 symbols (as shown in FIG. 1). The sPUCCH waveform can have 4 symbols in 20MHz systems, and there can be 10 interlaces with 10 PRBs per interlace in MulteFire systems with 20MHz bandwidth.

[0048] In one configuration, as large cell deployments should be considered in the MulteFire 1.1 design, the PRACH is to be used for timing advance. However, in the MulteFire 1.0 and 3GPP LTE Release 13 eLAA design, the PRACH with the interlaced structure cannot provide a favorable timing estimation performance. There is no minimal channel bandwidth and PSD regulation on the 3.5 GHz band, which weakens the motivation for interlaced structure. Therefore, it is possible to have the PRACH design over continuous PRBs in the 3.5 GHz unlicensed spectrum.

[0049] As described herein, the novel PRACH design can involve a PRACH preamble transmitted over continuous PRBs, which can have various benefits. For example, the PRACH over the continuous PRB can have better timing estimation accuracy as compared to the interlaced structure. As another example, there is no regulation on a minimal channel bandwidth and PSD limitation, and thus there is no penalty to transmit the PRACH over continuous PRBs. As yet another example, the resource granularity for the PRACH transmission can be smaller, and thus the overhead for the PRACH transmission can be reduced. In other words, a number of PRBs less than 10 can be used for the PRACH transmission (as the interlaced structure has 10 PRBs per interlace). In addition, an impact on other channels with the interlaced structure can be limited. Thus, the novel PRACH design with continuous PRBs for operation on the 3.5 GHz spectrum can reduce the PRACH overhead and improve the timing estimation accuracy, as compared to the interlaced structure.

[0050] In one configuration, with respect to the PRACH waveform design, the PRACH transmission can occupy continuous N PRBs, where N can be 5 or 6 PRBs. The motivation for N=5 is that there are 10 PRBs per interlace, and by allocating 1 out of 10 PRBs from 5 interlaces (corresponding to a 10MHz system bandwidth for systems operating in the 3.5 GHz band), 5 PRBs are available for the PRACH transmission, while remaining resources can be used for other UL channels with the interlaced structure. The motivation for N=6 is to align with the LTE design, which can minimize changes to the 3GPP LTE specification.

[0051] In one example, a PRACH preamble from the legacy LTE system can be extended. Similar to the PRACH design in the legacy LTE system, a subcarrier spacing can be reduced. For example, a PRACH format similar to PRACH preamble format 0 in the legacy LTE system can be transmitted over a regular UL subframe. The subcarrier spacing of PRACH preamble format 0 is 1.25 kHz, and a CP duration is 103.13 μ s, which can be applied to cells with a radius of about 14km (e.g., with a maximal delay spread of 6.25 μ s). A cell size to be supported on the 3.5 GHz band can be smaller than a cell size to be supported with a CP of 103.13 μ s (i.e., the cell radius may be smaller than 14km). Thus, in one example, a shorter CP can be adopted, and a remaining time (103.13 μ s minus the reduced CP duration) can be used for LBT.

[0052] In one example, the PRACH format 4 in legacy LTE systems can be used as a baseline. A subcarrier spacing of the PRACH can be 7.5 kHz, and the CP duration is 14.6 μ s, which can be applied to cells with a radius of at least 1km. Given that the duration of the PRACH format 4 is about 2 OFDM symbols, the PRACH preamble symbol in this option can be repeated over the time domain when transmitted over a regular UL subframe. In one example, a guard band can be utilized for the PRACH transmission when frequency multiplexed with other transmissions (e.g., a PUSCH transmission from another UE using the 15 kHz subcarrier spacing). Similar to the LTE PRACH design, a guard band at two ends of a “large resource chunk” consisting of N continuous PRBs can be applied. The number of subcarriers to leave blank as a guard band can depend on the cell size, as well as operation preferences on a tradeoff of performance loss due to overhead caused by the guard band. In another example, 15 kHz at one end and 22.5 kHz at another end can be left blank.

[0053] In one configuration, the PRACH waveform can have the same subcarrier spacing as the PUSCH (i.e., 15 kHz). Within every 2 symbols, a preceding symbol within these 2 symbols can be performed as a ‘long CP’ for the following symbol.

[0054] FIG. 6 illustrates an example of a physical random access channel (PRACH) symbol structure. As shown, the PRACH symbol structure can include symbol k and symbol (k+1). Symbol (k+1) can be a cyclic shifted version (in the time domain) of symbol k, where $k \in \{0, 2, 4, 6, 8, 10, 12\}$ when the PRACH is transmitted over a regular UL subframe and $k \in \{0, 2\}$ or $k=0$ when the PRACH is transmitted over a special subframe. In this example, the symbol k can be used as a CP. For instance, by truncating with a length of an OFDM symbol without prefix, the obtained part is a cyclic shifted version of the OFDM symbol without prefix. The OFDM symbol without prefix in symbol k+1 is a cyclic shifted version of OFDM symbol without prefix in symbol k. In this example, in addition to the regular CP overhead as in legacy LTE systems, every other symbol is also overhead. The symbol (k+1) can be a cyclic shifted version of symbol k in the time domain. At the receiver side, an eNodeB can obtain one Fast Fourier Transform (FFT) duration within every 2 FFT durations for detection.

[0055] FIG. 7 illustrates an example of a physical random access channel (PRACH) symbol structure. As shown, the OFDM symbol without prefix in symbol k+1 can be the

same as the OFDM symbol without prefix in symbol k , where $k \in \{0, 2, 4, 6, 8, 10, 12\}$ when the PRACH is transmitted over a regular UL subframe and $k \in \{0, 2\}$ or $k=0$ when the PRACH is transmitted over a special subframe. In this case, the first symbol duration can be used as a CP, and thus can help overcome the inter-interlace interference. In one example, the CP duration in the first symbol can be the same as the CP duration in the PUSCH, or can be twice of the CP duration in the PUSCH to align a symbol boundary of every two symbols. In another example, if the CP duration in symbol k is the same as in legacy LTE systems, the symbol boundary may not be aligned with other channels (e.g., PUSCH). Given that the total duration of n symbols in this option is shorter than the total duration of n symbols in legacy LTE systems, the additional time can be left blank (i.e., no transmission) and used as a guard period. Alternatively, the CP duration in symbol k can be set to be twice of the CP duration in legacy LTE systems. In this case, the symbol boundary of every 2 symbols can be aligned with other channels (e.g., PUSCH). The total duration of $2n$ with $n \in \{1, 2, \dots, 7\}$ symbols in this option is the same as the total duration of $2n$ symbols in legacy LTE systems.

[0056] FIG. 8 illustrates an example of a physical random access channel (PRACH) symbol structure. Similar to PRACH formats 2 and 3 in legacy LTE systems where the PRACH symbols are repeated, the PRACH in eLAA and MuLTEfire systems can also be repeated multiple times to enhance coverage. As shown, the PRACH transmission can include a CP and several repeated PRACH preamble symbols. The repeated PRACH preamble symbols (e.g., 3 symbols) can follow a CP duration, which can depend on a maximal delay spread, a maximal round trip delay and a cell size, or the repeated PRACH preamble symbols can have no CP. A number of preamble repetitions can depend on a specified coverage area. The CP duration can be predefined in the 3GPP LTE specification, or can be configured via RRC signaling. Alternatively, the PRACH preamble can include no CP, but only several repeated PRACH preamble symbols, and a preceding symbol can perform as a CP for a following symbol.

[0057] In one configuration, a first format can be supported having a subcarrier spacing of 7.5 kHz, which can be transmitted over a special subframe (e.g. an uplink pilot time slot (UpPTS) region). The first format can be transmitted without frequency multiplexing of other channels with different subcarrier spacing, which can reduce ICI and limit a

number of needed guard subcarriers. In another configuration, a second format can be supported having a subcarrier spacing of 1.25 kHz, which can be transmitted over a regular UL subframe.

[0058] FIG. 9 illustrates an example of a physical random access channel (PRACH) symbol structure. Similar to PRACH formats 2 and 3 in legacy LTE systems where the PRACH symbols are repeated, the PRACH in eLAA and MuLTEfire systems can also be repeated multiple times to enhance coverage. As shown, the PRACH transmission can include several repeated PRACH preamble symbols, but no CP. The repeated PRACH preamble symbols (e.g., 3 symbols) can depend on a maximal delay spread, a maximal round trip delay and a cell size.

[0059] In one configuration, with respect to a PRACH preamble sequence design, a sequence designed in legacy LTE systems can be reused, which can involve repeating or truncating the sequence to fit into a number of REs that are allocated for the PRACH transmission. In one example, the PRACH can be transmitted over continuous 5 PRBs, and a legacy LTE PRACH sequence which is designed to map to 6 PRBs can be truncated to fit into 5 PRBs. In another example, the PRACH can be transmitted over 6 continuous PRBs, and the legacy LTE PRACH sequence can be reused directly.

[0060] In one configuration, a new sequence can be designed with a desirable length. Specifically, a new set of Zadoff-Chu (ZC) sequences with a desirable length can be designed. Denoting a subcarrier spacing of the PRACH by f_{RACH} , a set of ZC sequences with a length being a largest prime number that is smaller than $N * 15 / f_{\text{RACH}} * 12 - N_{\text{guard}}$ can be defined for the PRACH, where N is a number of continuous RBs allocated to the PRACH (e.g., $N = 5$ or 6) and N_{guard} is a number of specified guard subcarriers (e.g., $N_{\text{guard}} = 30$ and 5 for 1.25 kHz and 7.5 kHz subcarrier spacing, respectively, and $N_{\text{guard}} = 0$ for 15 kHz subcarrier spacing).

[0061] In one example, for a PRACH transmission over 5 continuous PRBs, a set of ZC sequences with a length being a largest prime number that is smaller than $5 * 15 / 1.25 * 12 = 720 - N_{\text{guard}}$ and $5 * 15 / 7.5 * 12 = 120 - N_{\text{guard}}$ can be defined for 1.25 kHz and 7.5 kHz SC spacing, respectively, where N_{guard} is reserved for guard bands. For example, when $N=5$ and there are 15 kHz and 22.5 kHz left blank at the two ends of the allocated resources, respectively, the PRACH sequence can be one belonging to the set of ZC

sequences with length of 683 for 1.25kHz SC spacing and with a length of 113 for 7.5kHz SC spacing. In another example, a ZC sequence with a length of 59 can be used for $N=5$ and a ZC sequence with a length of 71 can be used for $N=6$.

[0062] In one example, UE multiplexing among the PRACH on same resources can be based on cyclic shifts (CS), orthogonal cover codes (OCC) and/or different base sequences. With respect to CS, not all possible CSs can be used. For example, a CS value should be at least larger than a maximal delay spread plus a maximal round-trip delay. With respect to OCC, an OCC length can be the same as the number of PRACH preamble symbols with CP, e.g., an OCC with length of N can be applied for PRACH format 4 when the format 4 preamble is repeated N times. In addition, if the number of transmitted PRACH preambles is N , an OCC with length of $N/2$ can be applied instead of N . The OCC for the symbol k and $k+1$ with $k \in \{0, 2, 4, 6, 8, 10, 12\}$ can be the same.

[0063] In one configuration, for multiplexing of the PRACH and other UL channels, e.g., PUSCH and PUCCH, which use interlaced structure, various techniques can be applied. For example, frequency division multiplexing (FDM) among PRACH and other UL channels using interlaced structure may not be supported. Rather, the PRACH and the other UL channels can be multiplexed via time division multiplexing (TDM). In another example, the PRACH and other UL channels, e.g., PUSCH and PUCCH, which use interlaced structure, can be multiplexed via FDM and/or TDM.

[0064] In one example, the UL transmissions with the interlaced structure can be rate matched around the RBs allocated for the PRACH transmission. Specifically, when there are 5 PRBs allocated for the PRACH transmission in a subframe, the UL transmissions with the interlaced structure can be mapped to 9 RBs per interlace in the subframe, with 1 RB in each interlaced left empty for the PRACH transmission. In another example, when there are 6 PRBs allocated for the PRACH transmission in a subframe, there can be 4 interlaces with 9 PRBs per interlace and 1 interlace with 8 PRBs per interlace available for the UL transmission with the interlaced structure. Alternatively, the RBs allocated for the PRACH transmission can be punctured. In other words, the UL transmissions with the interlaced structure can be mapped to 10 PRBs per interlace. Then the RBs allocated for PRACH transmissions can be used to carry a PRACH preamble, with symbols for other UL transmissions being punctured on these PRBs.

[0065] In one configuration, with respect to resource allocation and an indication of the resource allocation, the PRACH can be transmitted over a remaining part following a downlink pilot time slot (DwPTS) of a special subframe or a regular UL subframe, which is similar to MulteFire 1.0 systems. For a time resource indication, various techniques can be considered. For example, for contention-free PRACH, a PDCCH order can be used to indicate the PRACH preamble sequence, and a time resource to transmit PRACH, which can be explicit or implicit. For an implicit indication, a fixed timing relationship between a reception of the PDCCH order and the transmission of the PRACH can be predefined (e.g., 4 or 6 subframes between the PDCCH order and the PRACH transmission).

Alternatively, the timing resource can be semi-statically configured via RRC signaling for contention-free and/or contention-based PRACH. Specifically, the periodicity and offset can be indicated by the RRC signaling. In addition, frequency resources for the PRACH transmission can be semi-statically configured via RRC signaling, or can be dynamically indicated via the PDCCH order for contention-free PRACH. For example, indication information can include a starting RB index. UEs can know a whole “resource chunk” available for the PRACH, given that N is predefined. Alternatively, N can also be configured via RRC signaling.

[0066] In one configuration, a user equipment (UE) operating on an unlicensed spectrum can be capable of listen before talk (LBT). The UE can communicate with an enhanced node B (eNodeB) using a licensed medium and/or an unlicensed medium. The UE can be capable of sensing the unlicensed medium before an UL transmission, and when the unlicensed medium is determined to be idle, the UE can perform the UL transmission. When the unlicensed medium is determined as being busy, the UE can prevent the UL transmission. The eNodeB can receive the UL transmission from the UE. Furthermore, the UE and the eNodeB can operate using a 3.5 GHz unlicensed spectrum.

[0067] In one configuration, a technique is described for physical random access channel (PRACH) design for systems operating on a 3.5 GHz unlicensed spectrum, e.g., MulteFire systems. In one example, as part of the PRACH design, a PRACH preamble can be transmitted over continuous N physical resource blocks (PRBs), e.g., N=5 or N=6. In another example, similar to the PRACH design in legacy LTE systems (e.g., PRACH preamble format 0/4), a subcarrier spacing can be reduced and a longer sequence can be designed. A cyclic prefix (CP) duration can follow a LTE PRACH design (e.g., 103.13us

for PRACH format 0). Alternatively, the CP duration can be shorter than the LTE PRACH design, with remaining time available for transmitters to perform LBT. In yet another example, the PRACH can have a same subcarrier spacing as a PUSCH (i.e., 15 kHz).

[0068] In one configuration, every other symbol can be used to carry the PRACH preamble, and remaining symbols can be cyclic shifted versions of other symbols that can use a "long CP". For example, a symbol (k+1) can be a cyclic shifted version of symbol k, where $k \in \{0, 2, 4, 6, 8, 10, 12\}$, when the PRACH can be transmitted over a regular UL subframe, and $k \in \{0, 2\}$ or $k=0$ when PRACH is transmitted over a special subframe. In another example, every other symbol can repeat a previous symbol without the CP, i.e., symbol (k+1) is the same as symbol k without the CP, for $k \in \{0, 2, 4, 6, 8, 10, 12\}$ when the PRACH is transmitted over a regular UL subframe, and $k \in \{0, 2\}$ or $k=0$ when the PRACH is transmitted over a special subframe. In yet another example, the CP duration of symbol $k \in \{0, 2, 4, 6, 8, 10, 12\}$ can be the same as in legacy LTE systems (e.g., 4.7 μ s), or can be twice of the CP duration as in legacy LTE systems, where a symbol boundary of every 2 symbols can be aligned with other channels (e.g., PUSCH) in the latter case.

[0069] In one example, similar to PRACH formats 2 and 3 in legacy LTE systems where the PRACH symbols are repeated, the PRACH in eLAA and MulteFire systems can also be repeated multiple times. In another example, the PRACH transmission can include a CP and several repeated PRACH preamble symbols, where the CP duration can depend on a maximal delay spread and a maximal round trip delay, and a number of preamble repetition can depend on a specified coverage area. In addition, the CP duration can be predefined in a 3GPP LTE specification, or can be configured via RRC signaling.

[0070] In one example, the PRACH transmission can include no CP, but only several repeated PRACH preamble symbols. In another example, a guard band can be introduced at two ends of whole allocated resource blocks (RBs). In another example, a number of subcarriers left to the guard band can depend on a cell size and operation preference (e.g., a tolerable performance loss due to overhead caused by the guard band). For example, 15 kHz and 22.5 kHz can be left blank at the two ends, respectively, to reduce inter-cell interference (ICI).

[0071] In one example, a PRACH preamble sequence can be based on a sequence

designed in legacy LTE systems, where the PRACH preamble sequence can be repeated/truncated to fit into a number of resource elements (REs) that are allocated for a PRACH transmission, e.g., a PRACH preamble sequence after puncturing/repeating can be a length of $(720-N_{\text{guard}})$ for a 1.25kHz subcarrier spacing and $(120-N_{\text{guard}})$ for 7.5kHz, where N_{guard} is a number of guard subcarriers (e.g., $N_{\text{guard}} = 30$ and 5 for 1.25 kHz and 7.5 kHz subcarrier spacing, respectively, and $N_{\text{guard}} = 0$ for 15 kHz subcarrier spacing).

[0072] In one example, a novel sequence with a desirable length can be designed. For example, a set of Zadoff–Chu (ZC) sequences with a length being a largest prime number that is smaller than $N * 15 / f_{\text{RACH}} * 12 - N_{\text{guard}}$ can be defined for the PRACH, where f_{RACH} is a subcarrier spacing of the PRACH, N is a number of continuous RBs allocated to the PRACH (e.g., $N = 5$ or 6) and N_{guard} is a number of guard subcarriers (e.g., $N_{\text{guard}} = 30$ and 5 for 1.25 kHz and 7.5 kHz subcarrier spacing, respectively, and $N_{\text{guard}} = 0$ for 15 kHz subcarrier spacing).

[0073] In one configuration, a PRACH from different UEs can be multiplexed in a frequency domain, via cyclic shifts (CS) and/or orthogonal cover codes (OCC) and/or base sequences. In one example, an OCC length can be the same as a number of PRACH preamble symbols with a CP, e.g., an OCC with a length of N can be applied for PRACH format 4 when a PRACH format 4 preamble is repeated N times. In another example, an OCC length can be half of a number of PRACH symbols, where the OCC can be applied to symbol k and $k+1$ with $k \in \{0, 2, 4, 6, 8, 10, 12\}$ being the same.

[0074] In one example, the PRACH and other UL channels, e.g., PUSCH and PUCCH, which use an interlaced structure can be multiplexed via time division multiplexing (TDM) but not frequency division multiplexing (FDM). In another example, the PRACH and other UL channels, e.g., PUSCH and PUCCH, which use an interlaced structure can be multiplexed via TDM and/or FDM. In yet another example, when the PRACH and other UL channels with interlaced structure are multiplexed via FDM, the UL transmissions with the interlaced structure can be rate matched around the RBs allocated for the PRACH transmission.

[0075] In one example, when 5 PRBs are allocated for the PRACH transmission in a subframe, the UL transmissions with interlaced structure can be mapped to 9 RBs per

interlace in the subframe, with 1 RB in each interlaced left empty for the PRACH transmission. In another example, when 6 PRBs are allocated for the PRACH transmission in a subframe, there can be 4 interlaces with 9 PRBs per interlace and 1 interlace with 8 PRBs per interlace available for UL transmission with the interlaced structure. In yet another example, when the PRACH and other UL channels with interlaced structure are multiplexed via FDM, the RBs allocated for the PRACH transmission can be punctured, i.e., the UL transmissions with interlaced structure can be mapped to 10 PRBs per interlace, and RBs allocated for the PRACH transmissions can be used to carry the PRACH preamble, with the symbols for other UL transmissions being punctured on these PRBs.

[0076] In one example, the PRACH can be transmitted over a remaining part following a downlink pilot time slot (DwPTS) of a special subframe or a regular UL subframe. In another example, for contention-free PRACH, a PDCCH order can be used to indicate a PRACH preamble sequence, and a time resource to transmit the PRACH, which can be either explicit or implicit. For implicit indication, a fixed timing relationship between the reception of the PDCCH order and the transmission of the PRACH can be predefined (e.g., 4 or 6 subframes between the PDCCH order and PRACH transmission). In yet another example, the timing resource for the PRACH can be semi-statically configured via RRC signaling for contention-free and/or contention-based PRACH.

[0077] In one example, frequency resources for the PRACH transmission can be semi-statically configured via RRC, or dynamically indicated via the PDCCH order for contention-free PRACH. For example, indication information can include a starting RB index. In another example, a number of PRBs available for the PRACH transmission (denoted by N) can be predefined, or can be configured via RRC signaling.

Design of PRACH with Interlaced Structure in MulteFire Systems

[0078] In one configuration, the UL design for MulteFire systems is to abide by regulatory specifications. For example, to satisfy the occupied channel bandwidth (OCB) regulation, traditional subband-based UL scheduling is to be updated, unless one UE is always assigned for the entire bandwidth. To this end, multi-cluster transmissions are to be supported in eLAA and MulteFire systems, where user data is placed over interlaced

RBs and are frequency multiplexed. Specifically, one interlace can include 10 RBs for systems with 20MHz. A cluster can include 1 RB, and thus one interlace can have 10 clusters for 20MHz, e.g., a B-IFDMA waveform.

[0079] In one example, a novel PRACH design is described for the unlicensed spectrum.

5 The PRACH can be used for scheduling requests (SR), uplink synchronization and power control for initial UL transmissions in legacy LTE systems. Due to the OCB regulation, the PRACH can use the B-IFDMA waveform (as shown in FIG. 1). In MulteFire systems, an UL portion in a special subframe can be used for the PRACH transmission, where the PRACH can occupy a last 4 symbols, which can be referred to as a shortened PRACH
10 (sPRACH). The sPRACH can utilize a 15 kHz subcarrier spacing, and a cyclic prefix (CP) duration of 4.7 us, which is the same as other UL channels. The targeted use case of the sPRACH is for small cell deployments with a cell radius within 200-300m. The transmissions from different UEs in a small cell can arrive at an eNodeB within a CP duration. Thus, transmissions on different interlaces can be orthogonal, and there is no
15 inter-interlace interference.

[0080] However, for large cell deployments, a transmission arrival time at the eNodeB from different UEs can have larger disparities, e.g., larger than the CP duration in LTE systems. This may break the orthogonality among transmissions on different interlaces, which can result in inter-interlace interference. As described in further detail below, a
20 novel PRACH design can overcome the inter-interlace interference in large cell deployments. In this design, the PRACH can be transmitted over a regular UL subframe, which can be referred to as an enhanced PRACH (ePRACH). The PRACH can include an interlaced structure and is useful for MulteFire systems. In addition, the novel PRACH design can incorporate various novel design aspects, such as a combination of specific UE
25 multiplexing techniques, LBT techniques, a novel PRACH waveform and resource allocation (or interlace allocation) techniques to improve a timing estimation accuracy (or timing estimation ambiguity issues). .

[0081] In one configuration, with respect to the novel PRACH waveform design, a PRACH waveform can have a same subcarrier spacing as a PUSCH (i.e., 15 kHz).

30 Similar to PRACH formats 2 in legacy LTE systems where the PRACH symbols are repeated, the PRACH in MulteFire systems can also be repeated multiple times. In one

example, a PRACH transmission can include a CP and several repeated PRACH preamble symbols, where a CP duration can depend on a maximal delay spread and a maximal round trip delay. The CP duration can be predefined in a 3GPP LTE specification, or can be configured via RRC signaling. Alternatively, the PRACH preamble can have no CP. A preceding symbol can be used as a CP for a following symbol, and a number of preamble repetitions can depend on a specified coverage area. In one example, a PRACH symbol structure can include repeated PRACH preamble symbols (e.g., 3 repeated preambles) that follow a CP duration, which can depend on the maximal delay spread and a cell size, or have no CP.

[0082] In one configuration, UE multiplexing techniques can be based on a cyclic shift (CS), an orthogonal cover code (OCC) or different root sequences. With respect to the CS, not all possible CS can be used. A CS value is to be at least larger than a maximal delay spread plus a maximal round-trip delay. With respect to the OCC, when a number of transmitted PRACH preambles is N , an OCC with a length of $N/2$ can be applied instead of N . In addition, an OCC for a symbol k and $k+1$ with $k \in \{0, 2, 4, 6, 8, 10, 12\}$ can be the same.

[0083] In one configuration, a timing estimation ambiguity issue caused by an equidistant B-IFDMA waveform can be resolved. The equidistant B-IFDMA can result in multiple peaks in a correlation profile of the PRACH, which can lead to ambiguity in timing estimation and impact TA functionality. To solve this issue, an interlace can be shared among multiple UEs. For example, one interlace can be frequency multiplexed with M set of UEs (e.g., $M=2$), where 10 PRBs within one interlace can be randomly separated into M parts and allocated to these M set of UEs, so as to create a non-equidistant RB pattern. In addition, L interlaces (e.g., $L=2$) can be shared with M sets of UEs (e.g., $M=2$) for the PRACH transmission, where RBs in each interlace can be randomly separated into M parts and allocated to these M sets. Each UE can use $10L/M$ RBs for the PRACH transmission. Further, denoting the M sets of RBs by $R_1, R_2, \dots, R_M$, any separation satisfying $\bigcup \{R_i\} = \text{all RBs in the } L \text{ interlaces}$, and $R_i \cap R_j = \emptyset$ for $i \neq j$, can be considered.

[0084] In one example, a generated RB pattern for each UE can be irregular, which can help reduce the ambiguity in timing estimation. For example, two interlaces (e.g., interlaces $\{0, 5\}$, $\{1, 6\}$, $\{2, 7\}$, $\{3, 8\}$, or $\{4, 9\}$) can be allocated to two sets of users,

where 10 out of 20 RBs within the two interlaces can be allocated to each set of users with an irregular pattern. In addition, each set of resources among the M sets can be allocated with different sets of PRACH preamble sequences, or a common set of PRACH preamble sequences.

- 5 [0085] In one configuration, with respect to the novel PRACH design, the PRACH can have a subcarrier spacing of 15 kHz, which can include N repeated PRACH preamble symbols, which may or may not be preceded by a CP. The PRACH can be multiplexed via the CS, OCC and/or root sequences. The OCC can be applied with a length of N/2 instead of N, where N is the number of PRACH symbols. The OCC for the symbol k and
- 10 k+1 with $k \in \{0, 2, 4, 6, 8, 10, 12\}$ can be the same. In addition, L interlaces can be shared with M sets of UEs (e.g. M=2) for the PRACH transmission, where RBs in each interlace can be randomly separated into M parts and allocated to these M sets. Each UE can use 10L/M RBs for the PRACH transmission. The generated RB pattern for each UE can be irregular, which can help reduce the ambiguity in timing estimation.
- 15 [0086] As an example, two interlaces can be shared with two sets of UEs, and each set of preambles can be transmitted on 10 out of 20 PRBs within the two interlaces. In cases where interlaces {0, 5} are allocated for the PRACH, the resource can be separated into RBs {0, 5, 20, 25, 30, 50, 55, 70, 75, 95} and {10, 15, 35, 40, 45, 60, 65, 80, 85, 90}, where each set of PRBs can be associated with two different sets of PRACH preamble
- 20 sequences, or a common set of PRACH preamble sequences.

- [0087] In one configuration, a PRACH design is defined with an interlaced structure for MulteFire systems. The PRACH design can define a PRACH waveform, a format, and a resource allocation, and can be utilized to resolve a timing estimation ambiguity issue. In one example, the PRACH can have the same subcarrier spacing as a PUSCH (i.e., 15
- 25 kHz). In another example, similar to PRACH format 2 in legacy LTE systems where the PRACH symbols are repeated, the PRACH in MulteFire systems can also be repeated multiple times. A previous symbol can be used as a “long CP” for a following symbol. In yet another example, a PRACH transmission can include a CP and several repeated PRACH preamble symbols, where a CP duration can depend on a maximal delay spread
- 30 and a maximal round trip delay, and a number of preamble repetition can depend on a specified coverage area.

[0088] In one example, the CP duration can be predefined in a 3GPP LTE specification, or can be configured via RRC signaling. In another example, the PRACH transmission can include no CP, but only several repeated PRACH preamble symbols. In yet another example, UEs can be multiplexed in same resources, via a cyclic shift (CS), root sequence
 5 and/or OCC. In addition, an OCC length can be half of the number of PRACH symbols, where the OCC applied to symbol k and $k+1$ with $k \in \{0, 2, 4, 6, 8, 10, 12\}$ are the same.

[0089] In one configuration, to resolve an ambiguity in timing estimation of an equidistant B-IFDMA structure, an irregular RB pattern can be allocated. In one example, N interlaces (e.g. $N=2$) with equidistant RBs can be shared with M sets of UEs (e.g.,
 10 $M=2$), where RBs in each interlace can be randomly separated into M parts, allocated to these M sets of UEs, to generate irregular RB pattern for each UE. In another example, any separation satisfying $U\{R_i\} = \text{all RBs in the } L \text{ interlaces}$, and $R_i \cap R_j = \emptyset$ for $i \neq j$, can be considered, where R_i denotes a set of PRBs in i^{th} separation, with $i \in \{1, 2, \dots, M\}$. Each separate PRB can be associated with a different set of PRACH preambles, or a common
 15 set of PRACH preambles can be transmitted in any separation of PRBs. In addition, N can be 2 and M can be 2, i.e., two interlaces can be separated into two parts, with each part having 10 PRBs out of the 20 PRBs, and the two interlaces can belong to set $\{0, 5\}$, $\{1, 6\}$, $\{2, 7\}$, $\{3, 8\}$, or $\{4, 9\}$.

[0090] Another example provides functionality 1000 of an eNodeB operable to set an
 20 uplink timing advance (TA) value for random access channel (RACH) transmissions in a MuLTEfire system, as shown in FIG. 10. The eNodeB can comprise one or more processors. The one or more processors can be configured to determine, at the eNodeB, that a RACH transmission to be received from a user equipment (UE) in an uplink in the MuLTEfire system is associated with a shortened physical uplink control channel
 25 (sPUCCH) format or an enhanced physical uplink control channel (ePUCCH) format, as in block 1010. The one or more processors can be configured to configure, at the eNodeB, the UE to utilize the uplink TA value for the RACH transmission when the RACH transmission is associated with the sPUCCH format or the ePUCCH format, wherein the uplink TA value is a common TA offset value for a plurality of UEs, as in block 1020. The
 30 one or more processors can be configured to encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform clear channel access (CCA)

sensing prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the sPUCCH format, as in block 1030. The one or more processors can be configured to encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform CCA sensing and a self-defer mechanism prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the ePUCCH format, as in block 1040. In addition, the eNodeB can comprise a memory interface configured to send to a memory the uplink TA value.

[0091] Another example provides functionality 1100 of an eNodeB operable to perform physical random access channel (PRACH) transmissions, as shown in FIG. 11. The eNodeB can comprise one or more processors. The one or more processors can be configured to identify, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines a number of continuous physical resource blocks (PRBs) in the unlicensed spectrum to be used for PRACH transmissions, as in block 1110. The one or more processors can be configured to decode, at the eNodeB, a PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration, wherein the PRACH transmission includes a PRACH preamble that is transmitted using the number of continuous PRBs defined in the PRACH configuration, as in block 1120. In addition, the eNodeB can comprise a memory interface configured to send to a memory the PRACH configuration being utilized by the MuLTEfire system.

[0092] Another example provides at least one machine readable storage medium having instructions 1200 embodied thereon for performing physical random access channel (PRACH) transmissions, as shown in FIG. 12. The instructions can be executed on a machine, where the instructions are included on at least one computer readable medium or one non-transitory machine readable storage medium. The instructions when executed perform: identifying, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines an interlaced structure of physical resource blocks (PRBs) in a regular uplink subframe to be used for PRACH transmissions, as in block 1210. The instructions when executed perform: decoding, at the eNodeB, a PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration, wherein the PRACH transmission is transmitted using the interlaced structure of PRBs in

the regular subframe in accordance with the PRACH configuration, as in block 1220.

[0093] FIG. 13 illustrates an architecture of a system 1300 of a network in accordance with some embodiments. The system 1300 is shown to include a user equipment (UE) 1301 and a UE 1302. The UEs 1301 and 1302 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface.

[0094] In some embodiments, any of the UEs 1301 and 1302 can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[0095] The UEs 1301 and 1302 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 1310 — the RAN 1310 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs 1301 and 1302 utilize connections 1303 and 1304, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 1303 and 1304 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System

(UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

[0096] In this embodiment, the UEs 1301 and 1302 may further directly exchange communication data via a ProSe interface 1305. The ProSe interface 1305 may
5 alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[0097] The UE 1302 is shown to be configured to access an access point (AP) 1306 via
10 connection 1307. The connection 1307 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.15 protocol, wherein the AP 1306 would comprise a wireless fidelity (WiFi®) router. In this example, the AP 1306 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[0098] The RAN 1310 can include one or more access nodes that enable the connections
15 1303 and 1304. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). The RAN 1310 may include
20 one or more RAN nodes for providing macrocells, e.g., macro RAN node 1311, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 1312.

[0099] Any of the RAN nodes 1311 and 1312 can terminate the air interface protocol and
25 can be the first point of contact for the UEs 1301 and 1302. In some embodiments, any of the RAN nodes 1311 and 1312 can fulfill various logical functions for the RAN 1310 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[00100] In accordance with some embodiments, the UEs 1301 and 1302 can be configured
30 to communicate using Orthogonal Frequency-Division Multiplexing (OFDM)

communication signals with each other or with any of the RAN nodes 1311 and 1312 over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a
5 Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[00101] In some embodiments, a downlink resource grid can be used for downlink
10 transmissions from any of the RAN nodes 1311 and 1312 to the UEs 1301 and 1302, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for
15 radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical
20 channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[00102] The physical downlink shared channel (PDSCH) may carry user data and higher-
25 layer signaling to the UEs 1301 and 1302. The physical downlink control channel (PDCCH) may carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 1301 and 1302 about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink
30 scheduling (assigning control and shared channel resource blocks to the UE 1302 within a cell) may be performed at any of the RAN nodes 1311 and 1312 based on channel quality information fed back from any of the UEs 1301 and 1302. The downlink resource

assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1301 and 1302.

[00103] The PDCCH may use control channel elements (CCEs) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as resource element groups (REGs). Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the downlink control information (DCI) and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[00104] Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more enhanced the control channel elements (ECCEs). Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an enhanced resource element groups (EREGs). An ECCE may have other numbers of EREGs in some situations.

[00105] The RAN 1310 is shown to be communicatively coupled to a core network (CN) 1320 —via an S1 interface 1313. In embodiments, the CN 1320 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment the S1 interface 1313 is split into two parts: the S1-U interface 1314, which carries traffic data between the RAN nodes 1311 and 1312 and the serving gateway (S-GW) 1322, and the S1-mobility management entity (MME) interface 1315, which is a signaling interface between the RAN nodes 1311 and 1312 and MMEs 1321.

[00106] In this embodiment, the CN 1320 comprises the MMEs 1321, the S-GW 1322, the Packet Data Network (PDN) Gateway (P-GW) 1323, and a home subscriber server (HSS) 1324. The MMEs 1321 may be similar in function to the control plane of legacy Serving

General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 1321 may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS 1324 may comprise a database for network users, including subscription-related information to support the network entities' handling of

5 communication sessions. The CN 1320 may comprise one or several HSSs 1324, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1324 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

10 [00107] The S-GW 1322 may terminate the S1 interface 1313 towards the RAN 1310, and routes data packets between the RAN 1310 and the CN 1320. In addition, the S-GW 1322 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

15 [00108] The P-GW 1323 may terminate an SGI interface toward a PDN. The P-GW 1323 may route data packets between the EPC network 1323 and external networks such as a network including the application server 1330 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 1325. Generally, the application server 1330 may be an element offering applications that use IP bearer resources with the
20 core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW 1323 is shown to be communicatively coupled to an application server 1330 via an IP communications interface 1325. The application server 1330 can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions,
25 social networking services, etc.) for the UEs 1301 and 1302 via the CN 1320.

[00109] The P-GW 1323 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 1326 is the policy and charging control element of the CN 1320. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's
30 Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN

session: a Home PCRF (H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 1326 may be communicatively coupled to the application server 1330 via the P-GW 1323. The application server 1330 may signal the PCRF 1326 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 1326 may provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server 1330.

[00110] FIG. 14 illustrates example components of a device 1400 in accordance with some embodiments. In some embodiments, the device 1400 may include application circuitry 1402, baseband circuitry 1404, Radio Frequency (RF) circuitry 1406, front-end module (FEM) circuitry 1408, one or more antennas 1410, and power management circuitry (PMC) 1412 coupled together at least as shown. The components of the illustrated device 1400 may be included in a UE or a RAN node. In some embodiments, the device 1400 may include less elements (e.g., a RAN node may not utilize application circuitry 1402, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 1400 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

[00111] The application circuitry 1402 may include one or more application processors. For example, the application circuitry 1402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device 1400. In some embodiments, processors of application circuitry 1402 may process IP data packets received from an EPC.

[00112] The baseband circuitry 1404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1404 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 1406 and to generate baseband signals for a transmit signal path of the RF circuitry 1406. Baseband processing circuitry 1404 may interface with the application circuitry 1402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1406. For example, in some embodiments, the baseband circuitry 1404 may include a third generation (3G) baseband processor 1404a, a fourth generation (4G) baseband processor 1404b, a fifth generation (5G) baseband processor 1404c, or other baseband processor(s) 1404d for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry 1404 (e.g., one or more of baseband processors 1404a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1406. In other embodiments, some or all of the functionality of baseband processors 1404a-d may be included in modules stored in the memory 1404g and executed via a Central Processing Unit (CPU) 1404e. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1404 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1404 may include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[00113] In some embodiments, the baseband circuitry 1404 may include one or more audio digital signal processor(s) (DSP) 1404f. The audio DSP(s) 1404f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the

constituent components of the baseband circuitry 1404 and the application circuitry 1402 may be implemented together such as, for example, on a system on a chip (SOC).

[00114] In some embodiments, the baseband circuitry 1404 may provide for communication compatible with one or more radio technologies. For example, in some
5 embodiments, the baseband circuitry 1404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) 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 1404 is configured to support radio communications of more than one wireless protocol may be referred to as
10 multi-mode baseband circuitry.

[00115] RF circuitry 1406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1406 may include a
15 receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1408 and provide baseband signals to the baseband circuitry 1404. RF circuitry 1406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1404 and provide RF output signals to the FEM circuitry 1408 for transmission.

[00116] In some embodiments, the receive signal path of the RF circuitry 1406 may include mixer circuitry 1406a, amplifier circuitry 1406b and filter circuitry 1406c. In some embodiments, the transmit signal path of the RF circuitry 1406 may include filter circuitry 1406c and mixer circuitry 1406a. RF circuitry 1406 may also include synthesizer circuitry 1406d for synthesizing a frequency for use by the mixer circuitry
25 1406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1406a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1408 based on the synthesized frequency provided by synthesizer circuitry 1406d. The amplifier circuitry 1406b may be configured to amplify the down-converted signals and the filter circuitry 1406c may be a
30 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 1404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a necessity. In some embodiments, mixer circuitry 1406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00117] In some embodiments, the mixer circuitry 1406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1406d to generate RF output signals for the FEM circuitry 1408. The baseband signals may be provided by the baseband circuitry 1404 and may be filtered by filter circuitry 1406c.

[00118] In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a 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 1406a of the receive signal path and the mixer circuitry 1406a may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a of the transmit signal path may be configured for super-heterodyne operation.

[00119] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1404 may include a digital baseband interface to communicate with the RF circuitry 1406.

[00120] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[00121] In some embodiments, the synthesizer circuitry 1406d may be a fractional-N

synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

5 [00122] The synthesizer circuitry 1406d may be configured to synthesize an output frequency for use by the mixer circuitry 1406a of the RF circuitry 1406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1406d may be a fractional $N/N+1$ synthesizer.

[00123] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a necessity. Divider control input may be provided
10 by either the baseband circuitry 1404 or the applications processor 1402 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 1402.

15 [00124] Synthesizer circuitry 1406d of the RF circuitry 1406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a
20 fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay
25 through the delay line is one VCO cycle.

[00125] In some embodiments, synthesizer circuitry 1406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and
30 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 1406 may include an IQ/polar converter.

[00126] FEM circuitry 1408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1410, amplify
5 the received signals and provide the amplified versions of the received signals to the RF circuitry 1406 for further processing. FEM circuitry 1408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1406 for transmission by one or more of the one or more
10 antennas 1410. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1406, solely in the FEM 1408, or in both the RF circuitry 1406 and the FEM 1408.

[00127] In some embodiments, the FEM circuitry 1408 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the
15 FEM circuitry may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1406). The transmit signal path of the FEM circuitry 1408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas
20 1410).

[00128] In some embodiments, the PMC 1412 may manage power provided to the baseband circuitry 1404. In particular, the PMC 1412 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 1412 may often be
25 included when the device 1400 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 1412 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[00129] While FIG. 14 shows the PMC 1412 coupled only with the baseband circuitry 1404. However, in other embodiments, the PMC 14 12 may be additionally or
30 alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 1402, RF circuitry 1406, or

FEM 1408.

[00130] In some embodiments, the PMC 1412 may control, or otherwise be part of, various power saving mechanisms of the device 1400. For example, if the device 1400 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device 1400 may power down for brief intervals of time and thus save power.

[00131] If there is no data traffic activity for an extended period of time, then the device 1400 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device 1400 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device 1400 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00132] An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[00133] Processors of the application circuitry 1402 and processors of the baseband circuitry 1404 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1404, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1404 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY) layer of a UE/RAN node, described in further detail below.

[00134] FIG. 15 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry 1404 of FIG. 14 may comprise processors 1404a-1404e and a memory 1404g utilized by said processors. Each of the processors 1404a-1404e may include a memory interface, 1504a-1504e, respectively, to send/receive data to/from the memory 1404g.

[00135] The baseband circuitry 1404 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 1512 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 1404), an application circuitry interface 1514 (e.g., an interface to send/receive data to/from the application circuitry 1402 of FIG. 14), an RF circuitry interface 1516 (e.g., an interface to send/receive data to/from RF circuitry 1406 of FIG. 14), a wireless hardware connectivity interface 1518 (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 1520 (e.g., an interface to send/receive power or control signals to/from the PMC 1412).

[00136] FIG. 16 provides an example illustration of the wireless device, such as a user equipment (UE), a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. The wireless device can include one or more antennas configured to communicate with a node, macro node, low power node (LPN), or, transmission station, such as a base station (BS), an evolved Node B (eNB), a baseband processing unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), or other type of wireless wide area network (WWAN) access point. The wireless device can be configured to communicate using at least one wireless communication standard such as, but not limited to, 3GPP LTE, WiMAX, High Speed Packet Access (HSPA), Bluetooth, and WiFi. The wireless device can communicate using separate antennas for each wireless communication standard or shared antennas for multiple wireless communication standards. The wireless device can communicate in a wireless local area network (WLAN), a wireless personal area network (WPAN), and/or a WWAN. The wireless device can also comprise a wireless modem. The wireless modem can comprise, for example, a wireless radio transceiver and baseband circuitry (e.g., a baseband processor).

The wireless modem can, in one example, modulate signals that the wireless device transmits via the one or more antennas and demodulate signals that the wireless device receives via the one or more antennas.

[00137] FIG. 16 also provides an illustration of a microphone and one or more speakers that can be used for audio input and output from the wireless device. The display screen can be a liquid crystal display (LCD) screen, or other type of display screen such as an organic light emitting diode (OLED) display. The display screen can be configured as a touch screen. The touch screen can use capacitive, resistive, or another type of touch screen technology. An application processor and a graphics processor can be coupled to internal memory to provide processing and display capabilities. A non-volatile memory port can also be used to provide data input/output options to a user. The non-volatile memory port can also be used to expand the memory capabilities of the wireless device. A keyboard can be integrated with the wireless device or wirelessly connected to the wireless device to provide additional user input. A virtual keyboard can also be provided using the touch screen.

Examples

[00138] The following examples pertain to specific technology embodiments and point out specific features, elements, or actions that can be used or otherwise combined in achieving such embodiments.

[00139] Example 1 includes an apparatus of an eNodeB operable to set an uplink timing advance (TA) value for random access channel (RACH) transmissions in a MuLTEfire system, the apparatus comprising: one or more processors configured to: determine, at the eNodeB, that a RACH transmission to be received from a user equipment (UE) in an uplink in the MuLTEfire system is associated with a shortened physical uplink control channel (sPUCCH) format or an enhanced physical uplink control channel (ePUCCH) format; configure, at the eNodeB, the UE to utilize the uplink TA value for the RACH transmission when the RACH transmission is associated with the sPUCCH format or the ePUCCH format, wherein the uplink TA value is a common TA offset value for a plurality of UEs; encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform clear channel access (CCA) sensing prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the sPUCCH

format; and encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform CCA sensing and a self-defer mechanism prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the ePUCCH format; and a memory interface configured to send to a memory the uplink TA value.

[00140] Example 2 includes the apparatus of Example 1, further comprising a transceiver configured to: transmit the uplink TA value to the UE; transmit an instruction to the UE to perform the CCA sensing when the RACH transmission is associated with the sPUCCH format; and transmit an instruction to the UE to perform the CCA sensing and the self-defer mechanism when the RACH transmission is associated with the ePUCCH format.

[00141] Example 3 includes the apparatus of any of Examples 1 to 2, wherein the one or more processors are further configured to encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing at a beginning of a CCA slot when the RACH transmission is associated with the sPUCCH format.

[00142] Example 4 includes the apparatus of any of Examples 1 to 3, wherein the one or more processors are further configured to: encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing at a maximum individual TA value for the UE earlier than the RACH transmission when the RACH transmission is associated with the ePUCCH format; and encode an instruction for transmission to the UE that instructs the UE to perform the self-defer mechanism for the RACH transmission by the maximum individual TA value for the UE when the RACH transmission is associated with the ePUCCH format.

[00143] Example 5 includes the apparatus of any of Examples 1 to 4, wherein the one or more processors are further configured to encode a system information block for MuLTEfire (SIB-MF) for transmission to the UE, wherein the SIB-MF includes the maximum individual TA value for the UE.

[00144] Example 6 includes the apparatus of any of Examples 1 to 5, wherein the one or more processors are further configured to encode a system information block for MuLTEfire (SIB-MF) for transmission to the UE, wherein the SIB-MF includes a periodically allocated region for the RACH transmission.

[00145] Example 7 includes the apparatus of any of Examples 1 to 6, wherein the sPUCCH format for the RACH transmission corresponds to a reduced cell size, and the ePUCCH format for the RACH transmission corresponds to an increased cell size.

5 [00146] Example 8 includes the apparatus of any of Examples 1 to 7, wherein the one or more processors are further configured to decode a RACH preamble received from the UE, wherein the PRACH preamble is received when the UE is successful in performing the CCA sensing.

[00147] Example 9 includes the apparatus of any of Examples 1 to 8, wherein the one or more processors are further configured to: encode an instruction for transmission to the
10 UE that instructs the UE to perform the CCA sensing as defined for a 5 gigahertz (GHz) band when the RACH transmission is associated with the sPUCCH format; and encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing as defined for a 3.5 GHz band when the RACH transmission is associated with the ePUCCH format.

15 [00148] Example 10 includes the apparatus of any of Examples 1 to 9, wherein the one or more processors are configured to encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing and the self-defer mechanism to mitigate the RACH transmission being blocked by a physical uplink shared channel (PUSCH) or a physical uplink control channel (PUCCH) transmission, or a PUSCH or PUCCH
20 transmission blocking the RACH transmission, wherein the self-defer mechanism is performed at the UE in conjunction with listen before talk (LBT) to prevent the UE from blocking transmissions from other UEs.

[00149] Example 11 includes an apparatus of an eNodeB operable to perform physical random access channel (PRACH) transmissions, the eNodeB comprising: one or more
25 processors configured to: identify, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines a number of continuous physical resource blocks (PRBs) in the unlicensed spectrum to be used for PRACH transmissions; and decode, at the eNodeB, a PRACH transmission received from a user equipment (UE) in accordance with the
30 PRACH configuration, wherein the PRACH transmission includes a PRACH preamble that is transmitted using the number of continuous PRBs defined in the PRACH

configuration; and a memory interface configured to send to a memory the PRACH configuration being utilized by the MuLTEfire system.

[00150] Example 12 includes the apparatus of Example 11, wherein the unlicensed spectrum is in a 3.5 gigahertz (GHz) band.

5 [00151] Example 13 includes the apparatus of any of Examples 11 to 12, wherein the number of continuous PRBs is 5 continuous PRBs or 6 continuous PRBs.

[00152] Example 14 includes the apparatus of any of Examples 11 to 13, wherein the number of continuous PRBs to be used for PRACH transmissions are separate from other PRBs being utilized for other uplink channels in accordance with an interlaced structure.

10 [00153] Example 15 includes the apparatus of any of Examples 11 to 14, wherein the PRACH configuration defines the number of continuous PRBs in the unlicensed spectrum to be used for PRACH transmissions in order to improve a timing estimation performance.

[00154] Example 16 includes the apparatus of any of Examples 11 to 15, wherein the
15 PRACH transmission includes a number of repeated PRACH preamble symbols that are preceded by a cyclic prefix or not preceded by a cyclic prefix.

[00155] Example 17 includes the apparatus of any of Examples 11 to 16, wherein the PRACH configuration enables a PRACH and other uplink channels that utilize an
interlaced structure to be multiplexed via one or more of time division multiplexing
20 (TDM) or frequency division multiplexing (FDM), wherein the other uplink channels include a physical uplink shared channel (PUSCH) or a physical uplink control channel (PUCCH).

[00156] Example 18 includes at least one machine readable storage medium having instructions embodied thereon for performing physical random access channel (PRACH)
25 transmissions, the instructions when executed by one or more processors at an eNodeB perform the following: identifying, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines an interlaced structure of physical resource blocks (PRBs) in a regular uplink subframe to be used for PRACH transmissions; and decoding, at the
30 eNodeB, an PRACH transmission received from a user equipment (UE) in accordance

with the PRACH configuration, wherein the PRACH transmission is transmitted using the interlaced structure of PRBs in the regular subframe in accordance with the PRACH configuration.

[00157] Example 19 includes the at least one machine readable storage medium of

5 Example 18, wherein the unlicensed spectrum is in a 5 gigahertz (GHz) band.

[00158] Example 20 includes the at least one machine readable storage medium of any of Examples 18 to 19, wherein the PRACH configuration defines the interlaced structure of PRBs in the regular uplink subframe to be used for PRACH transmissions in order to satisfy a specification defined by a regulatory body.

10 [00159] Example 21 includes the at least one machine readable storage medium of any of Examples 18 to 20, wherein the PRACH transmission includes a number of repeated PRACH preamble symbols that are preceded by a cyclic prefix or not preceded by a cyclic prefix, wherein a cyclic prefix duration depends on a maximal delay spread and a maximal round trip delay, wherein the cyclic prefix duration is configured via radio
15 resource control (RRC) signaling.

[00160] Example 22 includes the at least one machine readable storage medium of any of Examples 18 to 21, wherein the PRACH configuration enables a PRACH to be multiplexed via one or more of a cyclic shift, an orthogonal cover code (OCC) or a root sequence.

20 [00161] Example 23 includes the at least one machine readable storage medium of any of Examples 18 to 22, wherein the PRACH configuration defines a number of interlaces to be shared with a number of sets of UEs for the PRACH transmission, wherein PRBs in each interlace are randomly separated into a number of parts allocated to the number of sets, wherein a generated PRB pattern for each UE is irregular to reduce ambiguity in a
25 timing estimation.

[00162] Example 24 includes an eNodeB operable to perform physical random access channel (PRACH) transmissions, the eNodeB comprising: means for identifying, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines an interlaced structure
30 of physical resource blocks (PRBs) in a regular uplink subframe to be used for PRACH

transmissions; and means for decoding, at the eNodeB, an PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration, wherein the PRACH transmission is transmitted using the interlaced structure of PRBs in the regular subframe in accordance with the PRACH configuration.

- 5 [00163] Example 25 includes the eNodeB of Example 24, wherein the unlicensed spectrum is in a 5 gigahertz (GHz) band.

- [00164] Example 26 includes the eNodeB of any of Examples 24 to 25, wherein the PRACH configuration defines the interlaced structure of PRBs in the regular uplink subframe to be used for PRACH transmissions in order to satisfy a specification defined
10 by a regulatory body.

- [00165] Example 27 includes the eNodeB of any of Examples 24 to 26, wherein the PRACH transmission includes a number of repeated PRACH preamble symbols that are preceded by a cyclic prefix or not preceded by a cyclic prefix, wherein a cyclic prefix duration depends on a maximal delay spread and a maximal round trip delay, wherein the
15 cyclic prefix duration is configured via radio resource control (RRC) signaling.

[00166] Example 28 includes the eNodeB of any of Examples 24 to 27, wherein the PRACH configuration enables a PRACH to be multiplexed via one or more of a cyclic shift, an orthogonal cover code (OCC) or a root sequence.

- [00167] Example 29 includes the eNodeB of any of Examples 24 to 28, wherein the
20 PRACH configuration defines a number of interlaces to be shared with a number of sets of UEs for the PRACH transmission, wherein PRBs in each interlace are randomly separated into a number of parts allocated to the number of sets, wherein a generated PRB pattern for each UE is irregular to reduce ambiguity in a timing estimation.

- [00168] Various techniques, or certain aspects or portions thereof, may take the form of
25 program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, compact disc-read-only memory (CD-ROMs), hard drives, non-transitory computer readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the various techniques. In the case of
30 program code execution on programmable computers, the computing device may include

a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. The volatile and non-volatile memory and/or storage elements may be a random-access memory (RAM), erasable programmable read only memory (EPROM),
5 flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). In one example, selected components of the transceiver module can be located in a cloud radio
10 access network (C-RAN). One or more programs that may implement or utilize the various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language,
15 if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[00169] 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
20 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.

25 [00170] It should be understood that many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very-large-scale integration (VLSI) circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete
30 components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00171] Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module may not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

[00172] Indeed, a module of executable code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

[00173] Reference throughout this specification to "an example" or "exemplary" means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment of the present technology. Thus, appearances of the phrases "in an example" or the word "exemplary" in various places throughout this specification are not necessarily all referring to the same embodiment.

[00174] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and example of the present technology may be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as defacto equivalents of one another, but are to be considered as separate and autonomous representations of the

present technology.

[00175] Furthermore, the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments. In the following description, numerous specific details are provided, such as examples of layouts, distances, network examples, etc., to provide a thorough understanding of embodiments of the technology. One skilled in the relevant art will recognize, however, that the technology can be practiced without one or more of the specific details, or with other methods, components, layouts, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the technology.

[00176] While the forgoing examples are illustrative of the principles of the present technology in one or more particular applications, it will be apparent to those of ordinary skill in the art that numerous modifications in form, usage and details of implementation can be made without the exercise of inventive faculty, and without departing from the principles and concepts of the technology. Accordingly, it is not intended that the technology be limited, except as by the claims set forth below.

CLAIMS

What is claimed is:

1. An apparatus of an eNodeB operable to set an uplink timing advance (TA) value for random access channel (RACH) transmissions in a MuLTEfire system, the apparatus comprising:
 - 5 one or more processors configured to:
 - determine, at the eNodeB, that a RACH transmission to be received from a user equipment (UE) in an uplink in the MuLTEfire system is associated with a shortened physical uplink control channel (sPUCCH) format or an enhanced physical uplink control channel (ePUCCH) format;
 - 10 configure, at the eNodeB, the UE to utilize the uplink TA value for the RACH transmission when the RACH transmission is associated with the sPUCCH format or the ePUCCH format, wherein the uplink TA value is a common TA offset value for a plurality of UEs;
 - 15 encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform clear channel access (CCA) sensing prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the sPUCCH format; and
 - 20 encode, at the eNodeB, an instruction for transmission to the UE that instructs the UE to perform CCA sensing and a self-defer mechanism prior to performing the RACH transmission in the uplink when the RACH transmission is associated with the ePUCCH format; and
 - a memory interface configured to send to a memory the uplink TA value.
- 25 2. The apparatus of claim 1, further comprising a transceiver configured to:
 - transmit the uplink TA value to the UE;
 - transmit an instruction to the UE to perform the CCA sensing when the RACH transmission is associated with the sPUCCH format; and
 - 30 transmit an instruction to the UE to perform the CCA sensing and the self-defer mechanism when the RACH transmission is associated with the ePUCCH format.

3. The apparatus of claim 1, wherein the one or more processors are further configured to encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing at a beginning of a CCA slot when the RACH transmission is associated with the sPUCCH format.
- 5
4. The apparatus of any of claims 1 to 3, wherein the one or more processors are further configured to:
- 10
- encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing at a maximum individual TA value for the UE earlier than the RACH transmission when the RACH transmission is associated with the ePUCCH format; and
- 15
- encode an instruction for transmission to the UE that instructs the UE to perform the self-defer mechanism for the RACH transmission by the maximum individual TA value for the UE when the RACH transmission is associated with the ePUCCH format.
- 20
5. The apparatus of claim 1, wherein the one or more processors are further configured to encode a system information block for MuLTEfire (SIB-MF) for transmission to the UE, wherein the SIB-MF includes the maximum individual TA value for the UE.
- 25
6. The apparatus of claim 1, wherein the one or more processors are further configured to encode a system information block for MuLTEfire (SIB-MF) for transmission to the UE, wherein the SIB-MF includes a periodically allocated region for the RACH transmission.
- 30
7. The apparatus of claim 1, wherein the sPUCCH format for the RACH transmission corresponds to a reduced cell size, and the ePUCCH format for the RACH transmission corresponds to an increased cell size.
8. The apparatus of claim 1, wherein the one or more processors are further configured to decode a RACH preamble received from the UE, wherein the

PRACH preamble is received when the UE is successful in performing the CCA sensing.

9. The apparatus of any of claims 5 to 8, wherein the one or more processors are further configured to:

5 encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing as defined for a 5 gigahertz (GHz) band when the RACH transmission is associated with the sPUCCH format; and

10 encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing as defined for a 3.5 GHz band when the RACH transmission is associated with the ePUCCH format.

10. The apparatus of claim 1, wherein the one or more processors are configured to encode an instruction for transmission to the UE that instructs the UE to perform the CCA sensing and the self-defer mechanism to mitigate the RACH transmission being blocked by a physical uplink shared channel (PUSCH) or a physical uplink control channel (PUCCH) transmission, or a PUSCH or PUCCH transmission blocking the RACH transmission, wherein the self-defer mechanism is performed at the UE in conjunction with listen before talk (LBT) to prevent the UE from blocking transmissions from other UEs.

11. The apparatus of an eNodeB operable to perform physical random access channel (PRACH) transmissions, the eNodeB comprising:

one or more processors configured to:

25 identify, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines a number of continuous physical resource blocks (PRBs) in the unlicensed spectrum to be used for PRACH transmissions; and

30 decode, at the eNodeB, a PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration, wherein the

PRACH transmission includes a PRACH preamble that is transmitted using the number of continuous PRBs defined in the PRACH configuration; and a memory interface configured to send to a memory the PRACH configuration being utilized by the MuLTEfire system.

5

12. The apparatus of claim 11, wherein the unlicensed spectrum is in a 3.5 gigahertz (GHz) band.

10

13. The apparatus of claim 11, wherein the number of continuous PRBs is 5 continuous PRBs or 6 continuous PRBs.

15

14. The apparatus of any of claims 11 to 14, wherein the number of continuous PRBs to be used for PRACH transmissions are separate from other PRBs being utilized for other uplink channels in accordance with an interlaced structure.

20

15. The apparatus of any of claims 11 to 14, wherein the PRACH configuration defines the number of continuous PRBs in the unlicensed spectrum to be used for PRACH transmissions in order to improve a timing estimation performance.

25

16. The apparatus of claim 11, wherein the PRACH transmission includes a number of repeated PRACH preamble symbols that are preceded by a cyclic prefix or not preceded by a cyclic prefix.

30

17. The apparatus of claim 11, wherein the PRACH configuration enables a PRACH and other uplink channels that utilize an interlaced structure to be multiplexed via one or more of time division multiplexing (TDM) or frequency division multiplexing (FDM), wherein the other uplink channels include a physical uplink shared channel (PUSCH) or a physical uplink control channel (PUCCH).

18. At least one machine readable storage medium having instructions embodied thereon for performing physical random access channel (PRACH) transmissions, the instructions when executed by one or more processors at an eNodeB perform the following:
- 5 identifying, at the eNodeB, a PRACH configuration being utilized by a MuLTEfire system that operates in an unlicensed spectrum, wherein the PRACH configuration defines an interlaced structure of physical resource blocks (PRBs) in a regular uplink subframe to be used for PRACH transmissions; and
- 10 decoding, at the eNodeB, a PRACH transmission received from a user equipment (UE) in accordance with the PRACH configuration, wherein the PRACH transmission is transmitted using the interlaced structure of PRBs in the regular subframe in accordance with the PRACH configuration.
- 15 19. The at least one machine readable storage medium of claim 18, wherein the unlicensed spectrum is in a 5 gigahertz (GHz) band.
20. The at least one machine readable storage medium of any of claims 18 to 19, wherein the PRACH configuration defines the interlaced structure of PRBs in the regular uplink subframe to be used for PRACH transmissions in order to
- 20 satisfy a specification defined by a regulatory body.
21. The at least one machine readable storage medium of claim 18, wherein the PRACH transmission includes a number of repeated PRACH preamble
- 25 symbols that are preceded by a cyclic prefix or not preceded by a cyclic prefix, wherein a cyclic prefix duration depends on a maximal delay spread and a maximal round trip delay, wherein the cyclic prefix duration is configured via radio resource control (RRC) signaling.
- 30 22. The at least one machine readable storage medium of claim 18, wherein the PRACH configuration enables a PRACH to be multiplexed via one or more of a cyclic shift, an orthogonal cover code (OCC) or a root sequence.

23. The at least one machine readable storage medium of claim 18, wherein the PRACH configuration defines a number of interlaces to be shared with a number of sets of UEs for the PRACH transmission, wherein PRBs in each interlace are randomly separated into a number of parts allocated to the number of sets, wherein a generated PRB pattern for each UE is irregular to reduce ambiguity in a timing estimation.

1/12

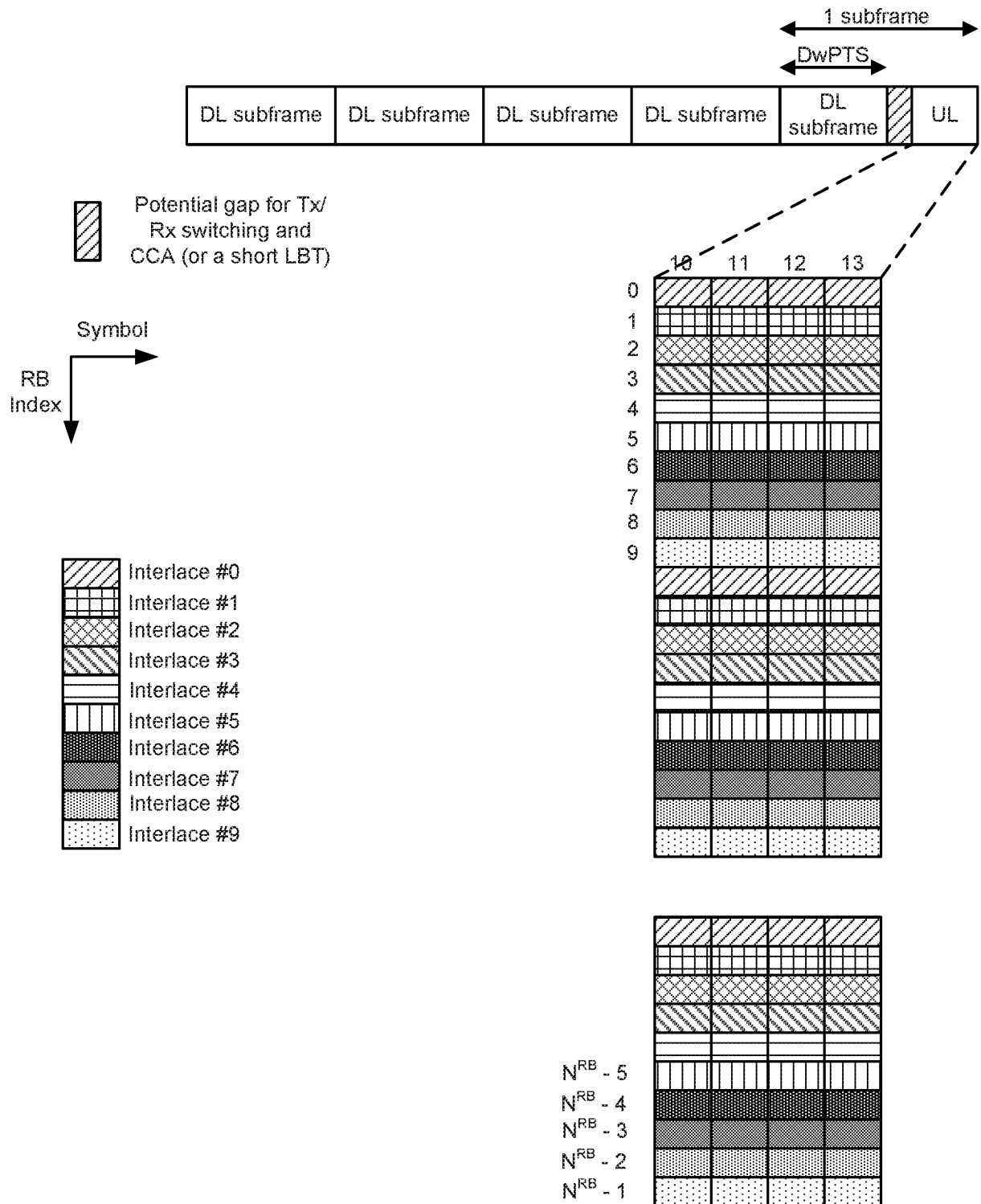


FIG. 1

2/12

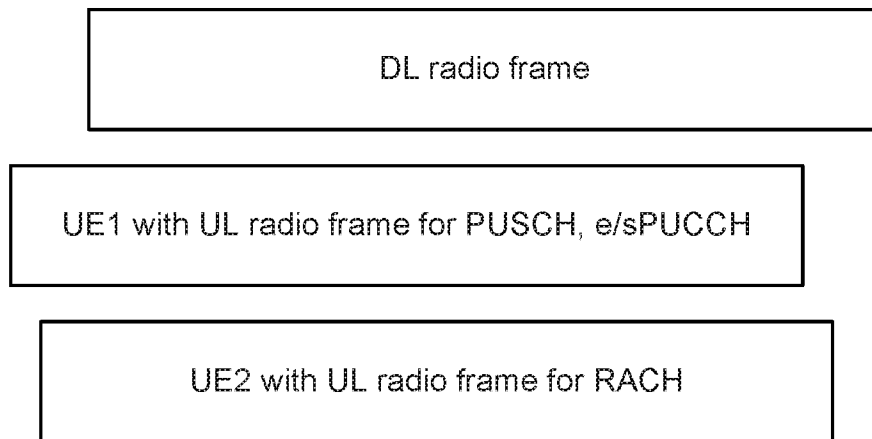


FIG. 2

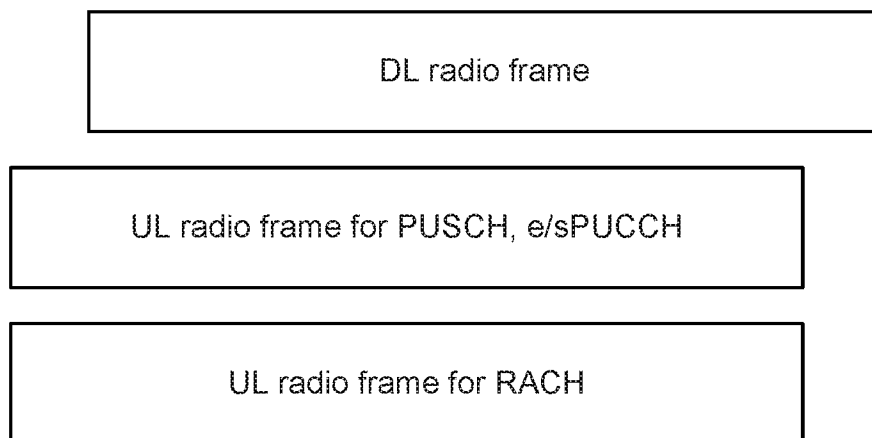


FIG. 3

3/12

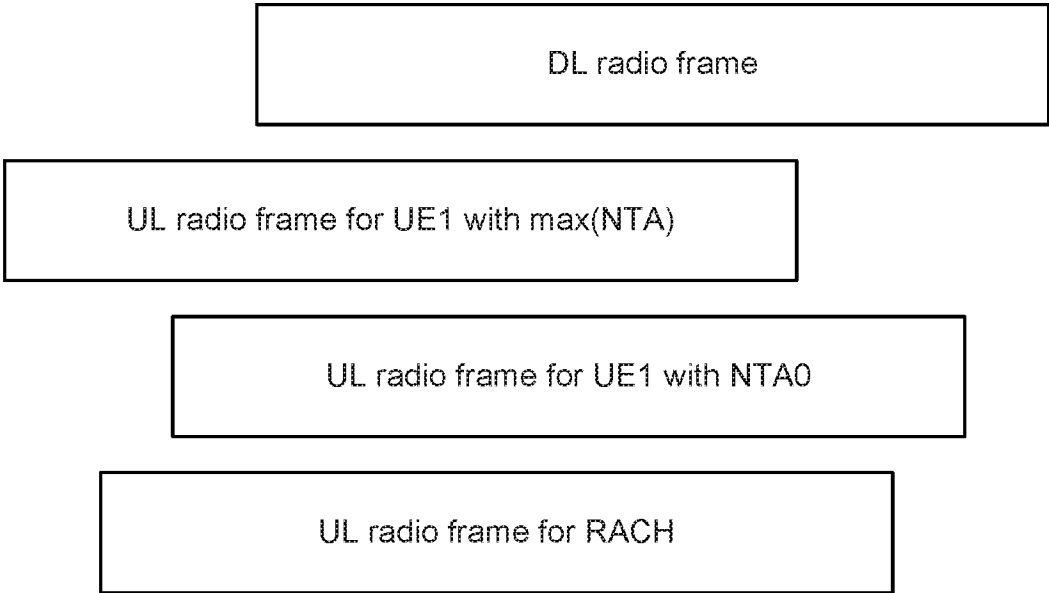


FIG. 4

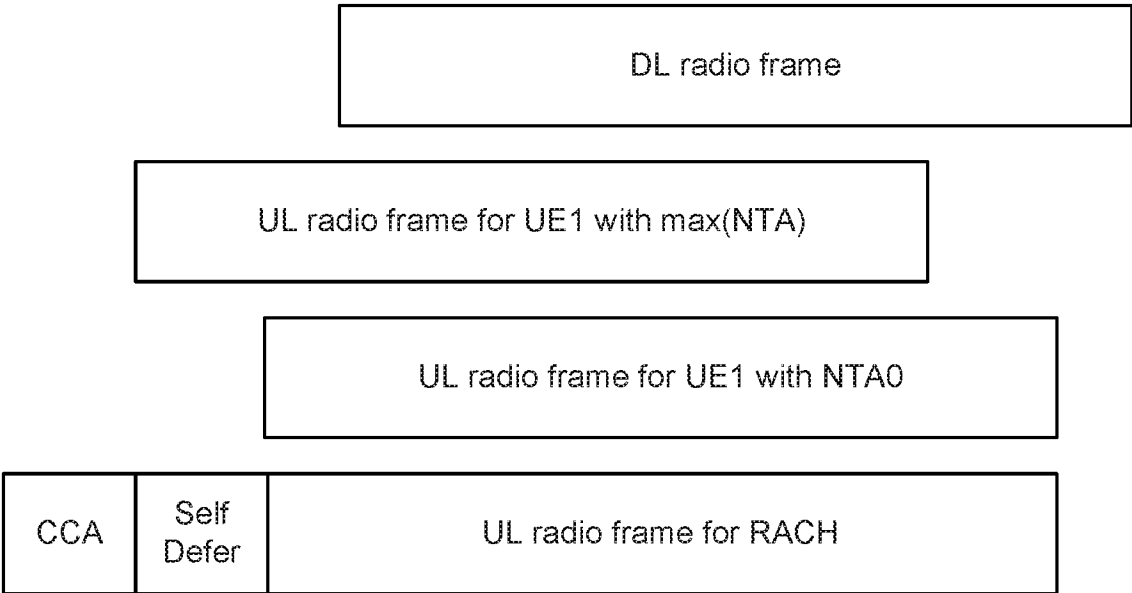


FIG. 5

4/12

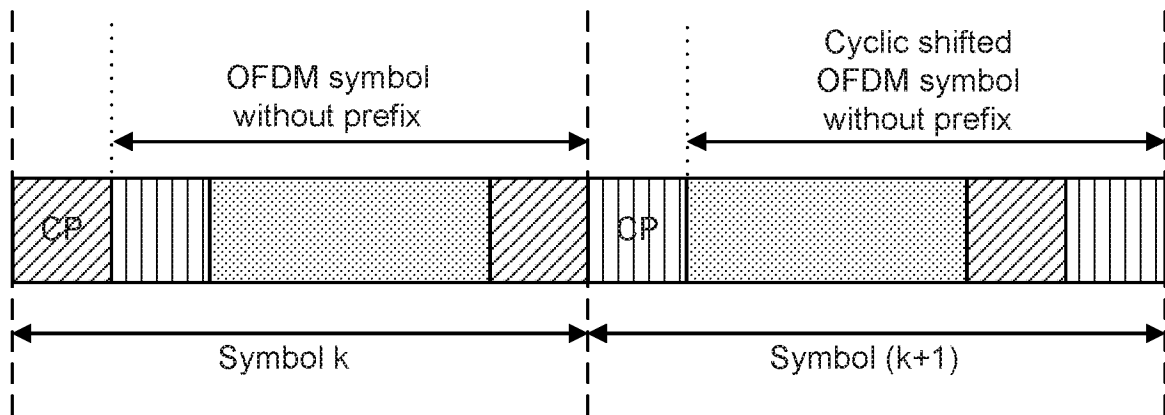


FIG. 6

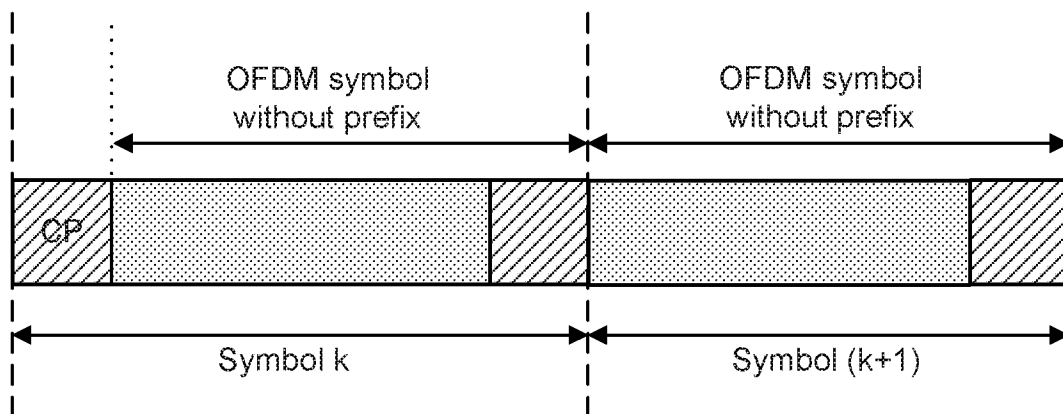


FIG. 7

5/12

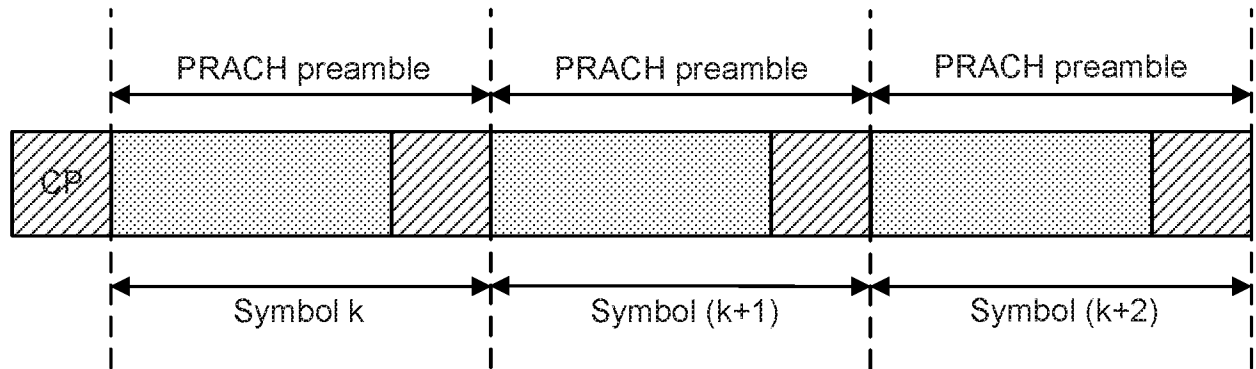


FIG. 8

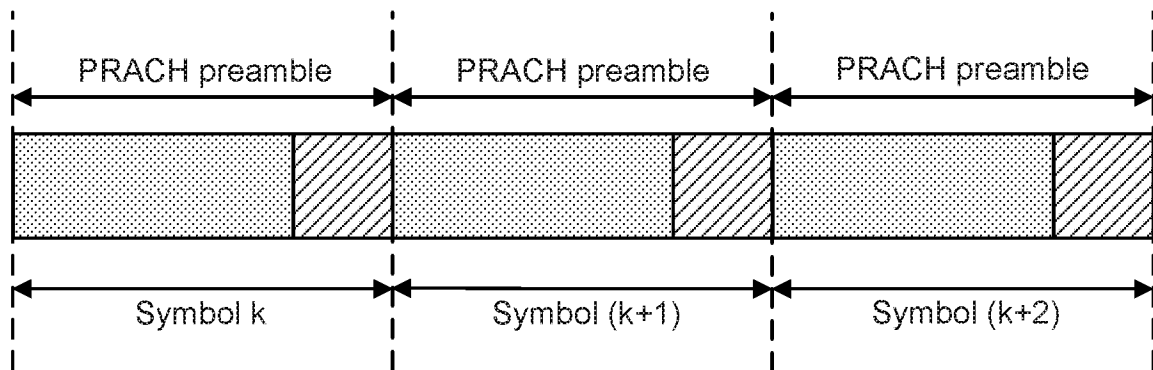


FIG. 9

6/12

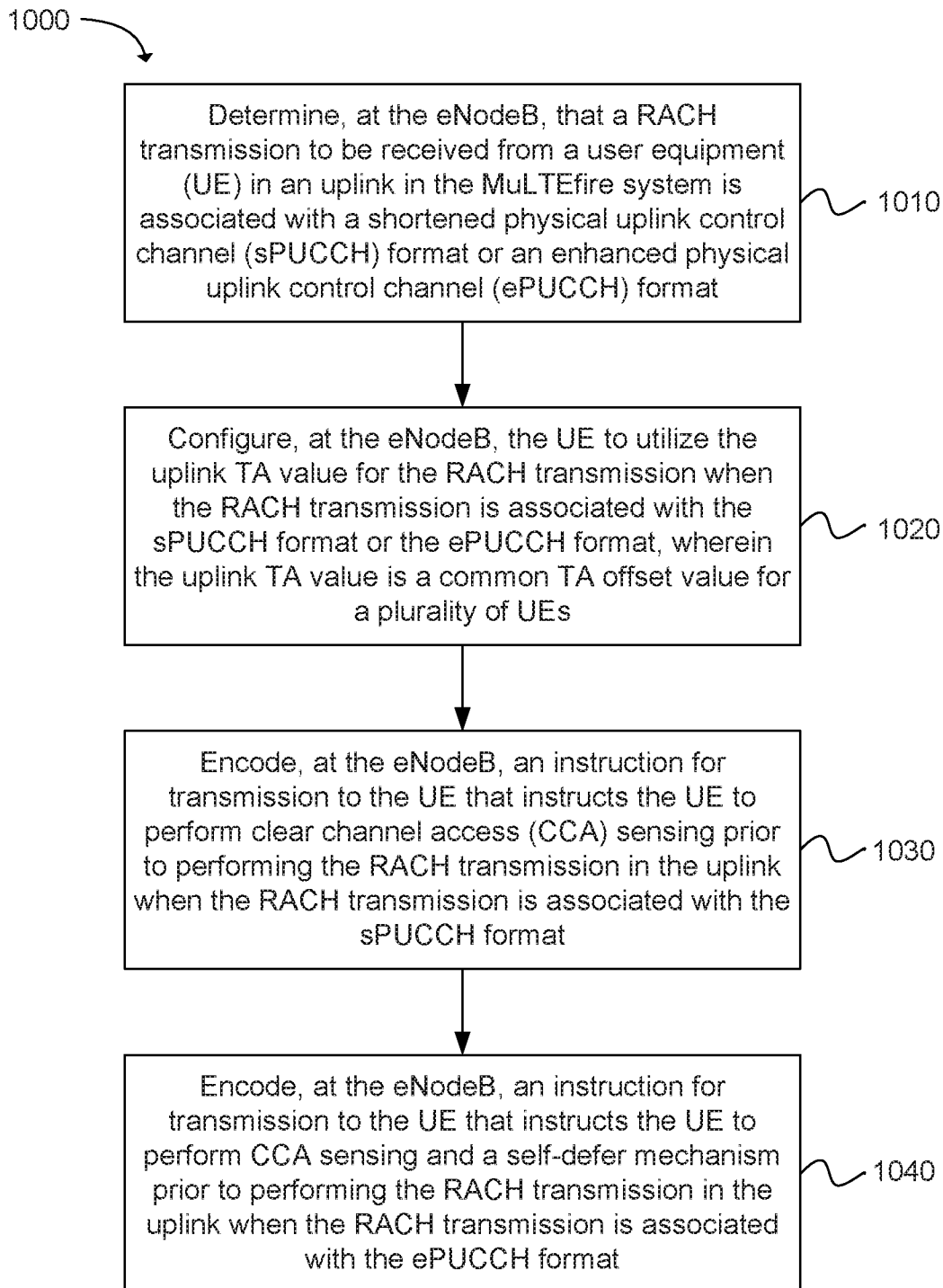


FIG. 10

7/12

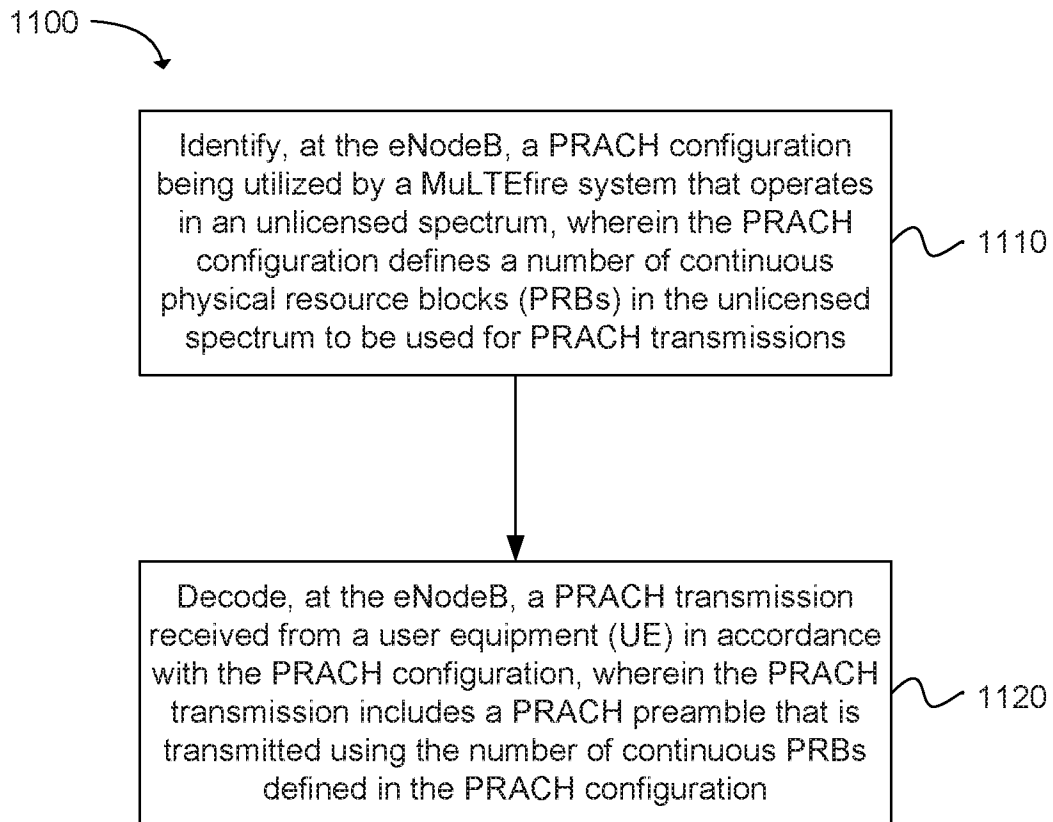


FIG. 11

8/12

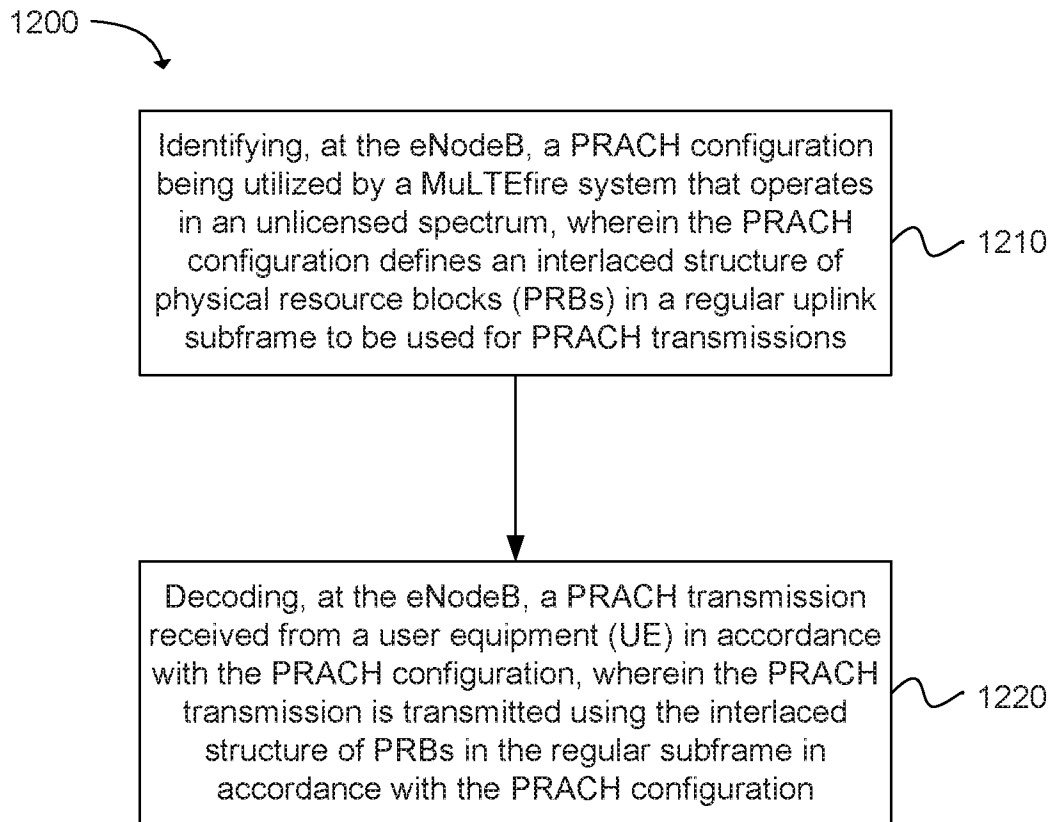


FIG. 12

9/12

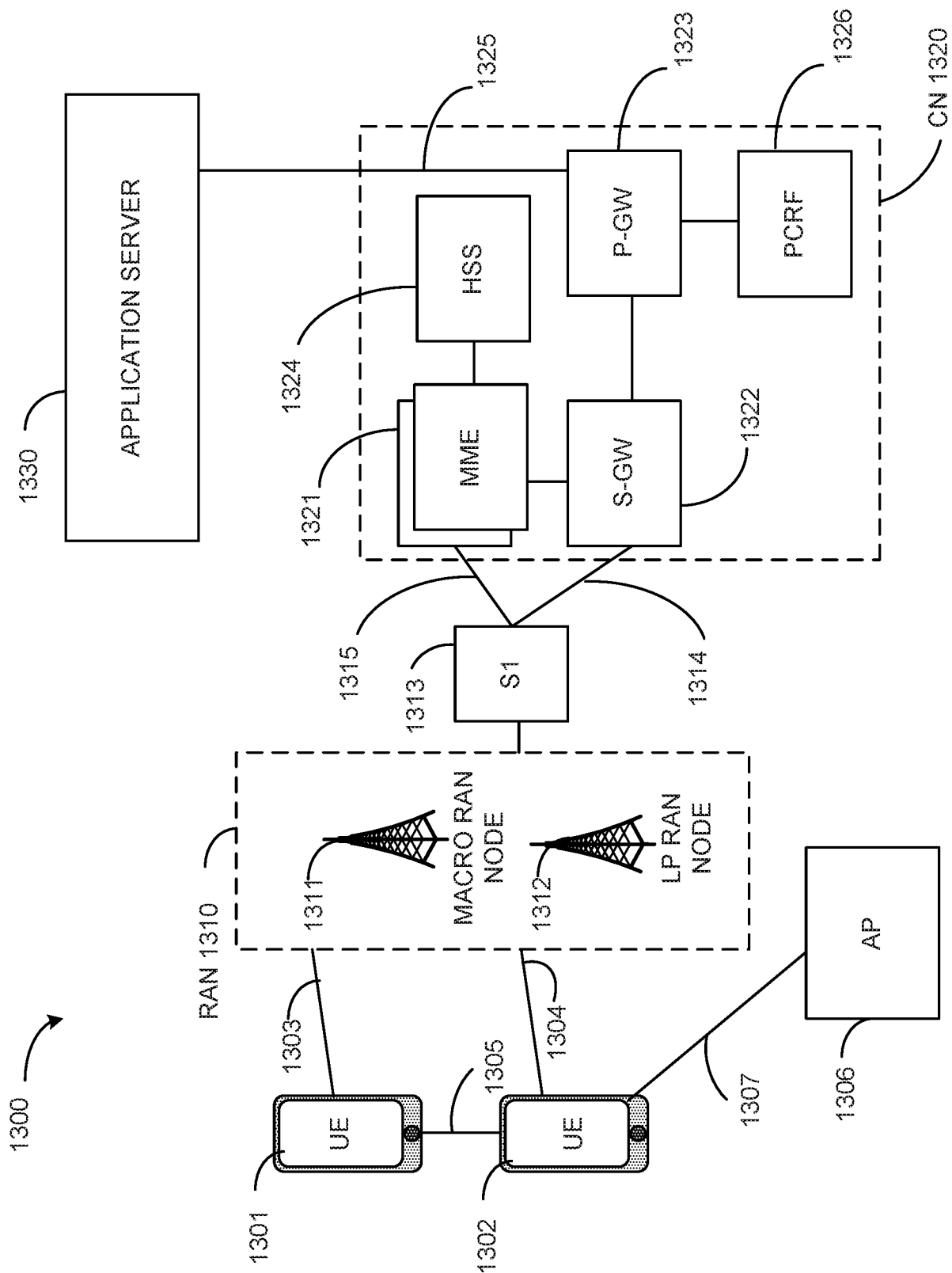


FIG. 13

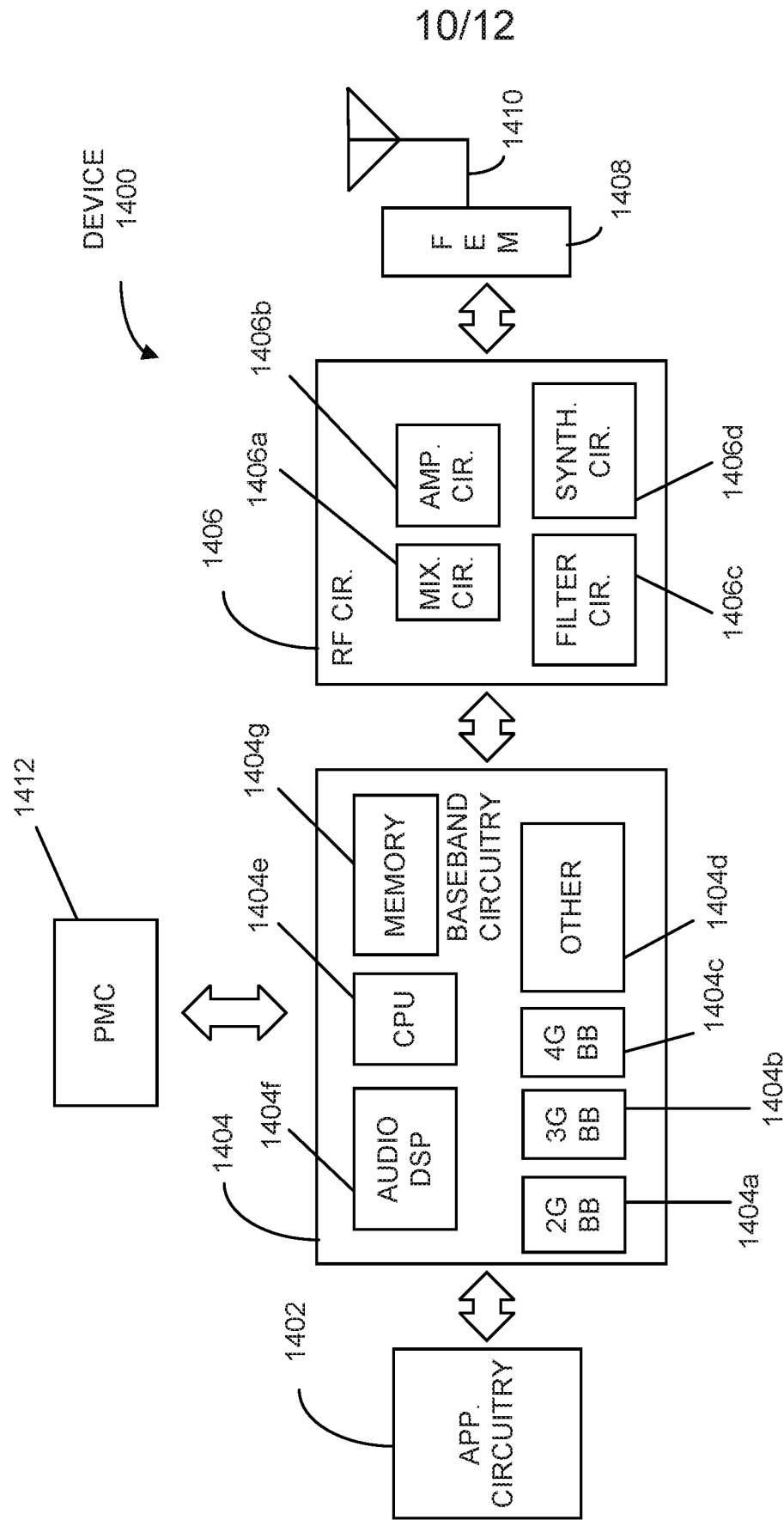


FIG. 14

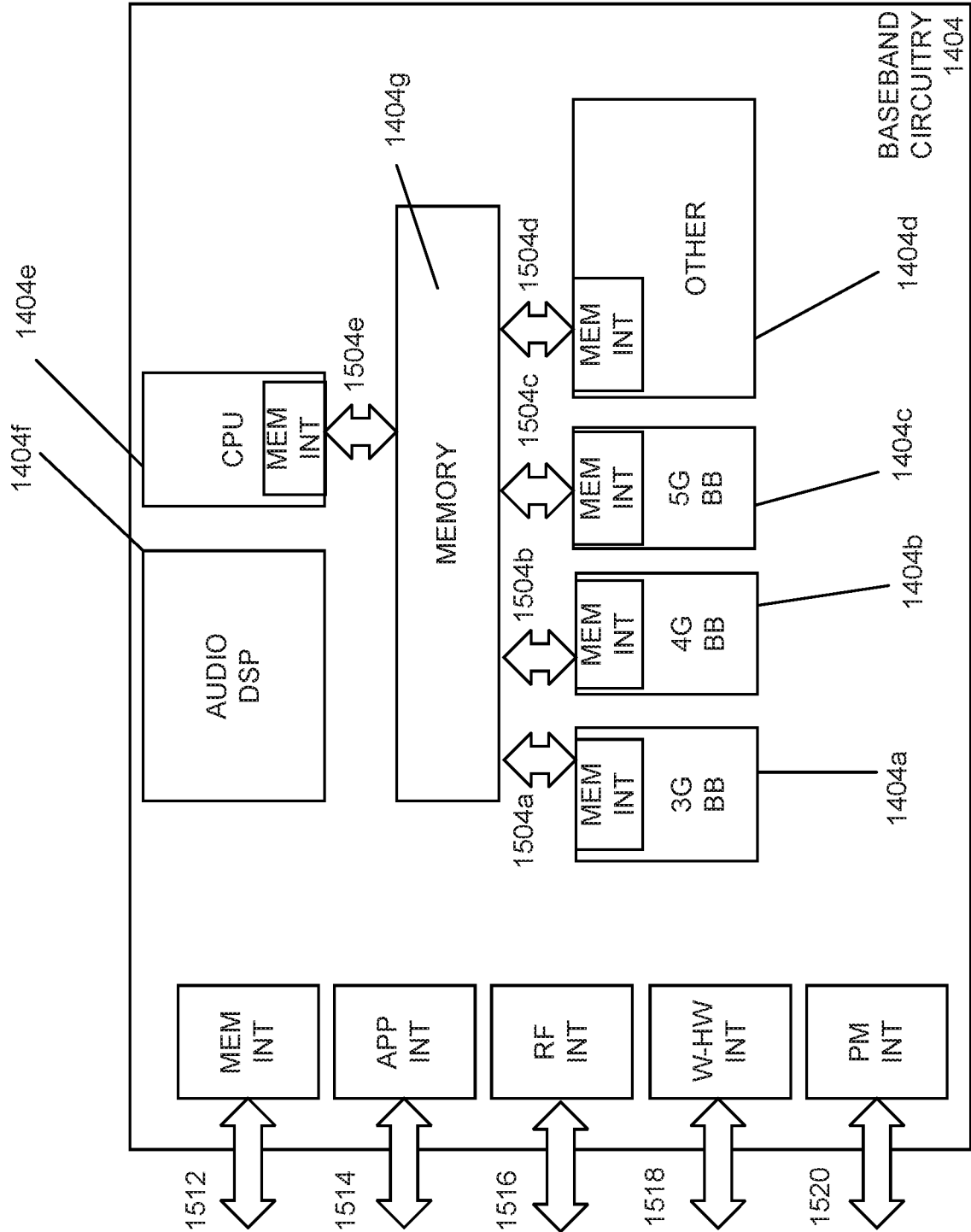


FIG. 15

12/12

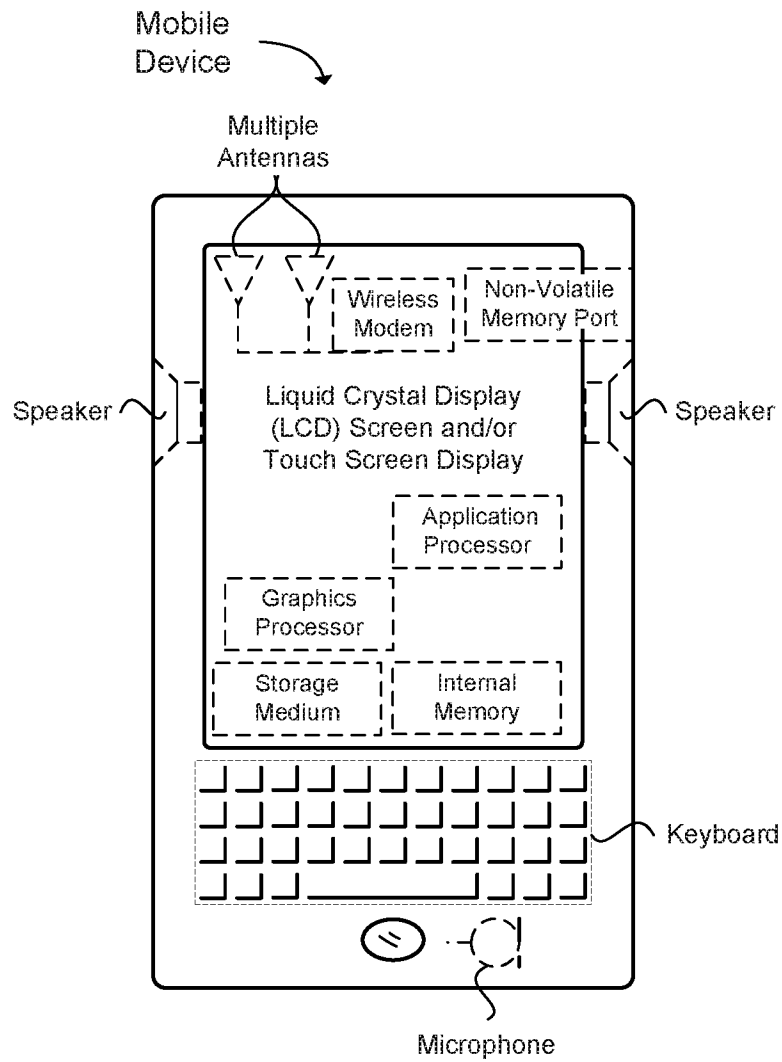


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/049770

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W74/08
ADD. H04L27/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NTT DOCOMO ET AL: "Discussion on PRACH for eLAA UL", 3GPP DRAFT; R1-165189 DISCUSSION ON PRACH FOR ELAA UL_FINAL, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Nanjing; 20160523 - 20160527 14 May 2016 (2016-05-14), XP051089816, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_85/Docs/ [retrieved on 2016-05-14]	11-23
Y	the whole document ----- -/--	1-10

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 November 2017

Date of mailing of the international search report

29/11/2017

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

Martos Riaño, Demian

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/049770

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SAMSUNG: "Discussion on random access procedure for eLAA", 3GPP DRAFT; R1-164749, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Nanjing, China; 20160523 - 20160527 14 May 2016 (2016-05-14), XP051096334, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_85/Docs/ [retrieved on 2016-05-14] the whole document -----	1-10
Y	ERICSSON: "On Channel Access Procedures for PRACH and SRS", 3GPP DRAFT; R1-165154, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Nanjing, China; 20160523 - 20160527 14 May 2016 (2016-05-14), XP051089830, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_85/Docs/ [retrieved on 2016-05-14] the whole document -----	1-10
A	"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification (Release 13)", 3GPP STANDARD; 3GPP TS 36.321, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG2, no. V13.2.0, 7 July 2016 (2016-07-07), pages 1-91, XP051123446, [retrieved on 2016-07-07] page 25 - page 26 ----- -/--	1-23

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/049770

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NOKIA ET AL: "Discussion on PRACH design for eLAA", 3GPP DRAFT; R1-162919 DISCUSSION ON PRACH DESIGN FOR ELAA_FINAL, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Busan, South Korea; 20160411 - 20160415 2 April 2016 (2016-04-02), XP051080411, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-02] the whole document	11-23
A	----- WO 2016/137948 A1 (QUALCOMM INC [US]) 1 September 2016 (2016-09-01) paragraph [00100] - paragraph [00114] -----	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/049770

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016137948 A1	01-09-2016	US 2016323915 A1 WO 2016137948 A1	03-11-2016 01-09-2016
