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Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number										Ratio of DL to UL
		0	1	2	3	4	5	6	7	8	9	
0	5 ms	D	S	U	U	U	D	S	U	U	U	1:3
1	5 ms	D	S	U	U	D	D	S	U	U	D	1:1
2	5 ms	D	S	U	D	D	D	S	U	D	D	3:1
3	10 ms	D	S	U	U	U	D	D	D	D	D	2:1
4	10 ms	D	S	U	U	D	D	D	D	D	D	3.5:1
5	10 ms	D	S	U	D	D	D	D	D	D	D	8:1
6	5 ms	D	S	U	U	U	D	S	U	U	D	3:5

FIG. 2

(57) **Abstract:** Technology for a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system. The UE can decode downlink control information (DCI) comprising dynamic TDD configuration information. The UE can identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information. The UE can encode data for transmission to a next generation node B (gNB) on one or more uplink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system. The UE can decode data received from the gNB on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system. The UE can also include a memory interface configured to store in a memory the data received from the gNB.

FRAME STRUCTURE FOR UNLICENSED INTERNET OF THINGS

BACKGROUND

[0001] Wireless systems typically include multiple User Equipment (UE) devices
5 communicatively coupled to one or more Base Stations (BS). The one or more BSs may
be Long Term Evolved (LTE) evolved NodeBs (eNB) or New Radio (NR) next generation
NodeBs (gNB) that can be communicatively coupled to one or more UEs by a Third-
Generation Partnership Project (3GPP) network.

Next generation wireless communication systems are expected to be a unified
10 network/system that is targeted to meet vastly different and sometimes conflicting
performance dimensions and services. New Radio Access Technology (RAT) is expected
to support a broad range of use cases including Enhanced Mobile Broadband (eMBB),
Massive Machine Type Communication (mMTC), Mission Critical Machine Type
Communication (uMTC), and similar service types operating in frequency ranges up to
15 100 GHz.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Features and advantages of the disclosure will be apparent from the detailed
description which follows, taken in conjunction with the accompanying drawings, which
20 together illustrate, by way of example, features of the disclosure; and, wherein:

[0003] FIG 1 illustrates an example of a subframe configuration with 2 repetitions, in
accordance with an example;

[0004] FIG 2 displays a table of a TDD system with seven types of uplink-downlink
configurations, in accordance with an example;

25 [0005] FIG 3A illustrates an example of a downlink and uplink subframe configuration,
in accordance with an example;

[0006] FIG 3B illustrates an example of a downlink and uplink subframe configuration,
in accordance with an example;

[0007] FIG 3C illustrates an example of a downlink and uplink subframe configuration,
30 in accordance with an example;

[0008] FIG. 4A illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0009] FIG. 4B illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

5 [0010] FIG. 4C illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0011] FIG. 5A illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

10 [0012] FIG. 5B illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0013] FIG. 6A illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0014] FIG. 6B illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

15 [0015] FIG. 7A illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0016] FIG. 7B illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

20 [0017] FIG. 8A illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

[0018] FIG. 8B illustrates another example of a downlink and uplink subframe configuration, in accordance with an example;

25 [0019] FIG. 9 depicts functionality of a user equipment (UE), configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, in accordance with an example;

[0020] FIG. 10 depicts functionality a next generation node B (gNB) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, in accordance with an example;

[0021] FIG 11 depicts functionality of at least one machine readable storage medium having instructions embodied thereon for a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, in accordance with an example;

5 [0022] FIG 12 illustrates an architecture of a network, in accordance with an example;

[0023] FIG 13 illustrates a diagram of a wireless device (e.g., UE) and a base station (e.g., eNodeB) in accordance with an example;

[0024] FIG 14 illustrates example interfaces of baseband circuitry, in accordance with an example; and

10 [0025] FIG 15 illustrates a diagram of a wireless device (e.g., UE), in accordance with an example.

[0026] 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.

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DETAILED DESCRIPTION

[0027] 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
20 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 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
25 sequence.

EXAMPLE EMBODIMENTS

[0028] An initial overview of technology embodiments is provided below and then specific technology embodiments are described in further detail later. This initial
30 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 intended to limit the scope of the claimed subject matter.

[0029] 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), 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.

[0030] 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). In 3GPP fifth generation (5G) LTE communication systems, the node is commonly referred to as a new radio (NR) or next generation Node B (gNodeB or gNB). The downlink (DL) transmission can be a communication from the node (e.g., eNodeB or gNodeB) to the wireless device (e.g., UE), and the uplink (UL) transmission can be a communication from the wireless device to the node.

[0031] Wireless systems typically include multiple User Equipment (UE) devices communicatively coupled to one or more Base Stations (BS). The one or more BSs may be Long Term Evolved (LTE) evolved NodeBs (eNB) or New Radio (NR) next generation NodeBs (gNB) that can be communicatively coupled to one or more UEs by a Third-Generation Partnership Project (3GPP) network. The UE can be one or more of a smart phone, a tablet computing device, a laptop computer, an internet of things (IOT) device, and/or another type of computing devices that is configured to provide digital communications. As used herein, digital communications can include data and/or voice

communications, as well as control information.

[0032] As used herein, the term “Base Station (BS)” includes “Base Transceiver Stations (BTS),” “NodeBs,” “evolved NodeBs (eNodeB or eNB),” and/or “next generation NodeBs (gNodeB or gNB),” and refers to a device or configured node of a mobile phone network that communicates wirelessly with UEs.

Internet of Things (IoT)

[0033] The present technology describes applications related to the LTE operation of internet of things (IoT) UEs configured to operate in an unlicensed spectrum. For example, one type of LTE deployment in unlicensed spectrum is MulteFire. IoT is envisioned as a significantly important technology component, which has huge potential and may change our daily life entirely by enabling connectivity between a large number of devices. IoT has wide applications in various scenarios, including smart cities, smart environment, smart agriculture, and smart health systems.

[0034] 3GPP has standardized two designs to support IoT services -- enhanced Machine Type Communication (eMTC) and NarrowBand IoT (NB-IoT). As eMTC and NB-IoT UEs are deployed in huge numbers, lowering the cost of these UEs is a key enabler for implementation of IoT. Also, low power consumption is desirable to extend the life time of the battery. In addition, there are substantial use cases of devices deployed deep inside buildings which can use coverage enhancement in comparison to the defined LTE cell coverage footprint. In summary, eMTC and NB-IoT techniques are designed to ensure that the UEs have low cost, low power consumption and enhanced coverage.

LTE Operation in Unlicensed Spectrum

[0035] Both 3GPP LTE Rel-13 eMTC and NB-IoT operates in a licensed spectrum. On the other hand, the scarcity of a licensed spectrum in low frequency band results in a deficit in the data rate boost. Thus, there are emerging interests in the operation of LTE systems in unlicensed spectrum.

[0036] Potential LTE operations in an unlicensed spectrum includes but not limited to the Carrier Aggregation based Licensed Assisted Access (LAA)/enhanced LAA (eLAA) systems, LTE operation in the unlicensed spectrum via dual connectivity (DC), and the standalone LTE system in the unlicensed spectrum, where LTE-based technology solely

operates in unlicensed spectrum without requiring an “anchor” in the licensed spectrum, referred to as MulteFire.

[0037] To extend the benefits of LTE IoT designs into an unlicensed spectrum, MulteFire 1.1 is expected to specify the design for Unlicensed-IoT (U-IoT). Embodiments of the technology described herein fall in the scope of the U-IoT systems, with a focus on the eMTC based U-IoT design. Note that similar approaches can be used on NB-IoT based U-IoT design as well.

Regulations in Unlicensed Spectrum

[0038] One unlicensed frequency band of interest for embodiments of the technology is the 2.4GHz band. For global availability, the design can abide by the regulations in different regions, e.g. the regulations given by the Federal Communications Commission (FCC) in the United States, the regulations given by the European Telecommunications Standards Institute (ETSI) in Europe, and other governmental communications regulatory bodies selected countries. Based on these regulations, frequency hopping can be more appropriate than other forms of modulations, due to a more relaxed power spectrum density (PSD) limitation for frequency hopping. Specifically, frequency hopping has no PSD limit while other wide band modulations have PSD limit of 10 decibel-milliwatts (dBm) per megahertz (dBm/MHz) in regulations given by ETSI. The low PSD limit would result in limited coverage. Thus, embodiments of this technology focus on the U-IoT with frequency hopping.

Design of Frame

[0039] There are three types of frame structures in 3GPP LTE Rel-14: frame structure 1: frequency division duplex (FDD), frame structure 2: time division duplex (TDD) and frame structure 3 (dynamic downlink (DL)/uplink (UL) structure). Moreover, further enhancements to LTE TDD for DL-UL enhanced Interference Management and Traffic Adaption (eIMTA) is supported since 3GPP LTE Rel-12 to dynamically configure a TDD structure, in order to adapt to different traffic patterns.

[0040] 3GPP LTE Rel-13 eMTC supports both FDD which includes half duplex (HD) FDD, full duplex FDD, and TDD (with static configuration). In selected embodiments of the present technology, the design of frame structures 1 and 2 for eMTC based U-IoT

systems is focused on.

Frame Structure Configuration Based on HD-FDD design for eMTC

[0041] The U-IoT systems can have the frame structure following a HD-FDD design for eMTC. The system information, e.g. system information block 1 (SIB1), may indicate the valid DL and UL subframes via two bitmaps, respectively. The bitmap can be X bits, e.g. X=10 or 40. The first/left most bit can correspond to the subframe #0 of the radio frame satisfying $(\text{SFN mod } n) = 0$, where $n = X/10$ and SFN is a system frame number. The pattern can be repeated every X ms. For cases that are not configured with the bitmap for DL or UL valid subframes, the UEs may assume that all the subframes are valid for DL or UL, respectively.

[0042] Note that this approach for configuring valid DL/UL subframes can also be applied to U-IoT systems with a TDD frame structure. Different from static TDD configuration in existing LTE systems and dynamic TDD configurations based on eIMTA below, the valid DL and UL subframes can be configured via a bitmap as discussed above and the configured DL/UL structure can be different from existing TDD configurations in LTE. For cases that are not configured with the bitmap for DL or UL valid subframes, the UEs may assume the valid DL or UL subframes follow a default TDD configuration which can be predefined or configured.

[0043] In another embodiment of this technology, the association between uplink channel and downlink channel can be configured, or defined by default, e.g. the downlink channel is #n, and uplink channel is #(n+1).

Static TDD Configuration for U-IoT

[0044] Static TDD configurations can be used for U-IoT, similar to eMTC with TDD configuration. With repetitions, the DL or UL transmission may be postponed to the next valid DL or UL subframes, respectively. If the UE is configured with repetitions, the UE is not expected to receive more than one physical downlink shared channel (PDSCH) transmission or more than one of a PDSCH and MTC physical downlink control channel (MPDCCH) indicating DL semi-persistent scheduling (SPS) releases, with transmission ending before the Acknowledgement / Non-acknowledgement (A/N) transmission on valid UL subframe(s).

Dynamic TDD Configuration Based on eIMTA for U-IoT

[0045] Compared to a static TDD configuration, a dynamic TDD configuration is more flexible and can adapt to a traffic pattern. A dynamic TDD configuration based on eIMTA design can be adopted for U-IoT. Within the TDD Configuration, there can also be a traffic adaptation timescale. The traffic adaptation timescale can be predefined, or semi-statically configured via higher layer signaling, or can be dynamically indicated via layer one (L1) signaling. The time scale can be X , where X is a positive integer, e.g. $X=10, 20, 40$ or 80ms .

[0046] In one embodiment, the repetitions can be postponed to next valid DL/UL subframes based on the configuration, and the configuration itself will not change as the number of repetitions changes.

[0047] Alternatively, there can be an additional configuration where FIG 1 illustrates an example of a subframe configuration with 2 repetitions. The configuration can be scaled proportional with the number of repetitions configured for DL/UL transmissions. The timescale to update the configuration can take into account the number of repetitions. Two examples with 2 repetitions are illustrated in FIG 1, where in the first example, the TDD frame structure within a radio frame is repeated twice, while in the 2nd example, each DL and UL subframes are repeated twice continuously. The special subframe may or may not be repeated. Note that this method may be applied to the case where the numbers of repetitions are the same across this configuration.

Indication of Configuration

[0048] In one embodiment, there can be an indication of the configuration. The configuration of the frame structure can be indicated via downlink control information (DCI), e.g. DCI format introduced in eIMTA, or via initial signal.

[0049] In another embodiment, the DCI format 1C can be reused for the indication, which can be scrambled via eIMTA-radio network temporary identifier (RNTI), or a newly defined RNTI. The PDCCH can be cell-specific, i.e. with a common search space.

[0050] In one embodiment, the indication information in DCI can indicate the configuration index via N bits (1 out of 2^N predefined TDD configurations) for each component carrier, where N is a positive integer, e.g. $N=3$. It can support carrier

aggregation with up to Y carriers, where Y is a positive integer. So the payload in the DCI is $N * Y$, e.g. $N=3$ and $Y=5$, resulting in a payload of 15 bits. In one example, the TDD configuration and the number of repetitions can both be indicated in the DCI.

Alternatively, only the TDD configuration may be indicated, while the number of repetitions does not impact the TDD configuration.

[0051] In one embodiment, a bitmap can be used to indicate valid DL/UL subframes. The TDD configuration and the number of repetitions can be indicated in the DCI. In one example, the TDD configuration and the number of repetitions can both be indicated in the DCI. Alternatively, only the TDD configuration may be indicated, while the number of repetitions does not impact the TDD configuration.

[0052] In one embodiment, the configuration can determine when to transmit the DCI. As in eIMTA, the transmission of DCI can be based on the timescale of the TDD configuration. In another embodiment, the DCI can be transmitted at the start of each MCOT.

15 **Hybrid Automatic Repeat Request Acknowledgement (HARQ-ACK) Operation**

[0053] In another aspect of the configuration, there can be a HARQ ACK operation. The UL HARQ can be synchronous, similar to legacy LTE. The HARQ-ACK operation can be extended from eIMTA.

[0054] In one embodiment, there can be two reference configurations, one for a UL reference configuration and the other for a DL reference configuration. The reference configurations can be indicated by SIB, e.g. SIB1, or configured via radio resource configuration (RRC). Note that UL and DL reference configurations may be configured via different ways, e.g. UL reference configuration can be cell-specific and indicated via SIB, while DL reference configuration can be indicated via UE-specific dedicated RRC signaling. The UL subframes in a DL reference configuration can be a subset of UL subframes in the UL reference configuration.

[0055] In another embodiment, the actual configuration can change the subframes which are UL in the UL reference configuration and the subframes which are DL in the DL reference configuration to be either DL or UL subframes.

[0056] In another embodiment, the UL HARQ-ACK timing (A/N for the physical uplink

shared channel (PUSCH)) can follow a legacy LTE operation with a TDD configuration that is the same as the UL reference configuration.

[0057] In another embodiment, the DL HARQ-ACK timing (acknowledgement and non-acknowledgement ((A/N) for PDSCH) can follow an eMTC operation with a TDD configuration that is the same as the DL reference configuration. If a repetition is configured, the UL transmission is postponed to the next valid UL subframes. Before the completion of the A/N transmission, the UE may not be expected to receive more than 1 PDSCH transmission or more than 1 of the PDSCH and the MPDCCH transmissions indicating the DL SPS releases.

[0058] In another embodiment, the UL HARQ can be asynchronous, similar to the eMTC (as well as in eLAA and MF 1.0). In this case, the UL reference configuration may not be needed. The DL reference configuration can be indicated via SIB or RRC signaling. The actual configuration can change the DL subframes in the DL reference configuration to be UL subframes, but cannot change the UL subframes in the DL reference configuration.

[0059] In another embodiment, the UL HARQ-ACK timing (A/N for PUSCH) can follow the eMTC operation with asynchronous UL HARQ. For example, the UL grant indicating the new transmission or retransmission of a PUSCH can be transmitted in one or more valid DL subframes, with a HARQ ID, NDI and RV included in the DCI. The UL scheduling timing can follow the actual configuration, i.e. the UL subframes in the actual configuration are considered as the valid UL subframes.

[0060] In another embodiment, the DL HARQ-ACK timing (A/N for PDSCH) can follow the eMTC operation with TDD configuration that is the same as the DL reference configuration. If repetition is configured, the UL transmission is postponed to the next valid UL subframes. Before the completion of the A/N transmission, the UE is not expected to receive more than 1 PDSCH transmission or more than 1 of the PDSCH and the MPDCCH transmissions indicating the DL semi-persistent scheduling (SPS) releases.

[0061] In another embodiment, for a valid frame structure configuration, the frame structure can configure a channel 1 or first channel to be used for channel 2 or a second channel when the transmitter has hopped to channel 2, in the case where the frame structure is not re-configured. Alternatively, the frame structure is invalid when the equipment hops to another channel. Either a new configuration will be indicated, or a

default configuration can be predefined.

Semi-persistent subframe pattern for eMTC-U

[0062] In the current 3GPP agreement, there are eight types of semi-persistent subframe patterns that have been agreed to. The configuration between downlink subframes versus
 5 uplink subframes is decided with consideration on traffic type, regulation, link budget and so on. In one embodiment of the present technology, a semi-persistent subframe is proposed. The semi-persistent subframe indicates the valid downlink subframe and uplink subframe in eMTC-U systems. The eMTC-U system is characterized by the use of frequency hopping where the hopping sequence depends on the carrier sensing procedure
 10 success. The advantage lies in the fact that the proposed embodiments allow a subframe pattern indication according to the traffic condition in eMTC-U systems.

[0063] FIG 2 displays a table of a TDD system with seven types of uplink-downlink configurations. Within the embodiments displayed in the FIG 2 table, the point of periodicity varies from 5 milliseconds (ms) to 10 ms. Each of the subframe numbers 0 to
 15 9, comprise a ratio of downlink to uplink transmissions.

[0064] In one embodiment of the technology, the downlink and uplink ratio on one specific data channel dwell time can be one or multiple values from the following:

- DL:UL < 1:4. This is for an extreme uplink heavy scenario;
- DL:UL = 1:4. Taking a data dwell time of 75ms as an example, one example of
 20 this ratio is a 15ms DL and a 60ms UL.
- DL: UL = 1:3;
- DL:UL = 2:3. Taking a data dwell time of 75ms as an example, one example of this ratio is a 30ms DL and a 45ms UL;
- DL:UL = 3:2. Taking a data dwell time of 75ms as an example, one example of
 25 this ratio is a 45ms DL and a 30ms UL.
- DL:UL = 3:1.
- DL:UL = 4:1. Taking a data dwell time of 75ms as an example, one example of this ratio is a 60ms DL and a 15ms UL.
- DL:UL > 4:1. To support the scenario with a heavy downlink traffic load, wherein
 30 the uplink subframes are mainly for PUCCH.

[0065] These examples are based off of a 75 ms dwell time. However the embodiments disclosed are not limited to only a 75 ms dwell time. Other dwell times may be used

based on system design.

DL Subframe and UL Subframe Allocation

[0066] In one embodiment of the present technology, to avoid the overhead cost by uplink/downlink or downlink/uplink switching, only one switch point may be allowed.

- 5 When a single switch point is used, the dwell time can be divided based on one or more of the following equations.

In one example, $\frac{1}{5} * T_{dwell_data}$ DL subframes followed by $\frac{4}{5} * T_{dwell_data}$ UL subframes per data channel can be used. Taking the data dwell time of 75ms as an example, the dwell time is 15ms DL and 60ms UL. Alternatively, the DL subframes can be a power of two, to enable synchronization signal (SS) design for PDCCH, it can be 16 DL SFs, and 59 UL SFs.

In another example, $\left\lfloor \frac{1}{4} * T_{dwell_data} \right\rfloor$ or $\left\lceil \frac{1}{4} * T_{dwell_data} \right\rceil$ DL subframes followed by remaining UL subframes can be used. Alternatively, the downlink subframe can be the power of 2 around $\frac{1}{4} * T_{dwell_data}$.

- 15 In another example, $\frac{2}{5} * T_{dwell_data}$ DL subframes followed by $\frac{3}{5} * T_{dwell_data}$ UL subframes per data channel can be used. Alternatively, the DL subframes can be the power of two, that is 32 DL SFs, and the remaining are UL subframes.

In another example, $\frac{3}{5} * T_{dwell_data}$ DL subframes followed by $\frac{2}{5} * T_{dwell_data}$ UL subframes per data channel can be used.

- 20 In another example, $\frac{4}{5} * T_{dwell_data}$ DL subframes followed by $\frac{1}{5} * T_{dwell_data}$ UL subframes per data channel can be used.

At the extreme case, most of the configuration can be downlink subframes, and only the 1/2/3/4/5 subframes for UL are used to transmit selected information, such as the physical random access channel (PRACH) and the PUCCH.

[0067] In one embodiment of this invention, two switch points can be supported that are configured as DL1 + UL1 + DL2 + UL2. The downlink subframes can be evenly distributed in DL1 and DL2, and uplink subframes can be evenly distributed in UL1 and UL2. Alternatively, a few UL subframes, e.g. 1/2/3/4/5 can be inserted between DL1 and DL2 for CSI reporting.

[0068] In one embodiment of this invention, the maximum downlink can be 60ms to avoid multiple channel sensing by the eNB.

[0069] In one embodiment of this invention, the following ratio of downlink and uplink can be extended to other dwell times of the data channel, as illustrated in FIG 3 through FIG 8. The DL and UL subframe configuration examples illustrated in FIG 3A to FIG 8B can include PDCCH and PDSCH transmission, or other types of DL communication, in the DL subframes, while the UL SFs can include the physical uplink control channel (PUCCH), the physical uplink shared channel (PUSCH), the physical random access channel (PRACH), a sounding reference signal (SRS) transmission, or other types of uplink communication. The examples illustrated in FIG 3A to FIG 8B are not intended to be limiting. Other UL/DL configurations may be used depending on system design, desired performance, and the ratio of UL to DL transmissions.

[0070] FIG 3A illustrates an example of a downlink and uplink subframe configuration. It is further indicated that there can be 70 DL subframes with 5 UL subframes, or 72 DL subframes with 3 UL subframes. The 3 or 5 uplink subframes can be utilized for PUCCH transmission, including the channel quality indication (CQI), the HARQ-ACK, and the PRACH.

[0071] Alternatively, FIG 3B illustrates an example of a downlink and uplink subframe configuration. Accordingly, it is shown that there can be 60 DL subframes followed by 3 UL subframes followed by 12 DL subframes, where 3 UL subframes is equal to the idle time for DL.

[0072] Alternatively, FIG 3C illustrates another example of a downlink and uplink subframe configuration. Accordingly, it is shown that there can be 60 DL subframes followed by 5 UL subframes followed by 10 DL subframes.

[0073] FIG 4A illustrates another example of a downlink and uplink subframe

configuration. FIG 4A illustrates 60 contiguous DL subframes plus 15 contiguous UL subframes.

[0074] In the alternative, FIG 4B illustrates another example of a downlink and uplink subframe configuration. FIG 4B illustrates that there can be 50 DL subframes, followed by 5 UL subframes, followed by 5 DL subframes, followed by 5 UL subframes, followed by 5 DL subframes, followed by 5 UL subframes.

[0075] In another alternative, FIG 4C illustrates another example of a downlink and uplink subframe configuration. Illustrated within, there can be 30 DL subframes, plus 5 UL subframes, plus 5 DL subframes, plus 5 UL subframes, plus 25 DL subframes, plus 5 UL subframes.

[0076] FIG 5A illustrates another example of a downlink and uplink subframe configuration. As illustrated, 45 DL SFs are followed by 30 UL SFs, then a maximum 15ms UL transmission per channel can be achieved by 2 UEs. If one resource block (RB) is enabled for one UE, then 12 UL UEs can be supported per channel with 15 ms uplink transmission.

[0077] Alternatively, FIG 5B illustrates another example of a downlink and uplink subframe configuration. Accordingly, there can be 25 UL subframes, plus 15 UL subframes, plus 20 UL subframes, plus 15 UL subframes.

[0078] FIG 6A illustrates another example of a downlink and uplink subframe configuration, where there are 32 DL subframes followed by 43 UL subframes. The combination of these subframes can be configured as 32 DL subframes + 43 DL subframes. Alternatively, FIG 6B illustrates another example of a downlink and uplink subframe configuration. Where, the combination of 32 DL subframes with 43 UL subframes can be configured as 16 DL subframes followed by 25 UL subframes followed by 16 DL subframes followed by 25 UL subframes.

[0079] FIG 7A illustrates another example of a downlink and uplink subframe configuration, where there can be 16 DL SFs with 59 UL SFs, for mainly a heavy uplink transmission case. Alternatively, FIG 7B illustrates another example of a downlink and uplink subframe configuration, where there can be 8 DL subframes followed by 30 UL subframes followed by 8 DL subframes followed by 29 UL subframes, which can enable

UL retransmission within one dwell time. The subframe configurations can be indicated in multiple subframes were 30 UL subframes is in a 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes subframe configuration, and the 29 UL subframes is in a 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes followed by 5 UL subframes followed by 4 UL subframes subframe configuration.

[0080] FIG. 8A illustrates another example of a downlink and uplink subframe configuration, where there can be 15 DL SFs with 60 UL SFs, for mainly a heavy uplink transmission case. Alternatively, FIG. 8B illustrates another example of a downlink and uplink subframe configuration, where there can be 7 DL subframes followed by 30 UL subframes followed by 8 DL subframes followed by 29 UL subframes, which can enable UL retransmission within one dwell time.

[0081] FIG. 9 depicts functionality 900 of a user equipment (UE), configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system. The UE can comprise of one or more processors configured to decode downlink control information (DCI) comprising dynamic TDD configuration information 910. The UE can comprise of one or more processors configured to identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information 920. The UE can comprise of one or more processors configured to encode data for transmission to a next generation node B (gNB) on one or more uplink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system 930. The UE can comprise of one or more processors configured to decode data received from the gNB on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system 940.

[0082] In one embodiment, the one or more processors are further configured to encode data in an uplink subframe or decode data in a downlink subframe of a data channel having a selected data dwell time.

[0083] In one embodiment, the one or more processors are further configured to encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected

dwelt time is less than 1 to 4, 1 to 4, 4 to 1, or greater than 4 to 1.

[0084] In one embodiment, the one or more processors are further configured to encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected
5 dwelt time is 1 to 3, 2 to 3, 3 to 2, or 3 to 1.

[0085] In one embodiment, the dwell time is one of 25 milliseconds (ms), 50 ms, 75 ms, or 100 ms.

[0086] In one embodiment, a ratio of the downlink subframes relative to the uplink subframes is irrespective of the selected data dwell time of the data channel.

10 [0087] In one embodiment, the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at a single switch point, wherein the switch point is $\frac{3}{5} * T_{dwell_data}$ DL subframes followed by $\frac{2}{5} * T_{dwell_data}$ UL subframes per data channel.

[0088] In one embodiment, the one or more processors are further configured to switch
15 between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

[0089] In one embodiment, the one or more processors are further configured to switch
20 between the one or more downlink subframes and the one or more uplink subframes at one switch point to form a data dwell time that comprises 45 downlink subframes, followed by 30 uplink subframes.

[0090] In one embodiment, the one or more processors are further configured to encode uplink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more
25 downlink subframes in the selected data dwell time of the data channel in an asynchronous manner.

[0091] In one embodiment, the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a selected

asynchronous HARQ ACK timing.

[0092] In one embodiment, the one or more processors are further configured to encode downlink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more uplink subframes in the selected data dwell time of the data channel in an
5 asynchronous manner.

[0093] In one embodiment, the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a time division duplex configuration that is equivalent to a downlink reference configuration.

[0094] FIG. 10 depicts functionality 1000 a next generation node B (gNB) configured to
10 in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system. The gNB can comprise of one or more processors configured to configure a frame structure for dynamic downlink (DL) and uplink (UL) communication for dynamic TDD configuration information 1010. The gNB can comprise of one or more processors configured to encode downlink control information (DCI) comprising the
15 dynamic TDD configuration information 1020. The gNB can comprise of one or more processors configured to encode data for transmission from the gNB to a user equipment (UE) on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system 1030. The gNB can comprise of one or more processors configured to decode data received at the gNB on one or more uplink
20 subframes of the configured frame structure in the unlicensed spectrum of the U-IoT system 1040.

[0095] In one embodiment, the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form a data dwell time that comprises:

25 70 downlink subframes (DLs) + 5 uplink subframes (ULs)

60 DLs + 5 ULs + 10DLs;

73 DLs + 3 ULs;

60 DLs + 3 ULs + 12 DLs;

60 DLs + 5ULs + 10 DLs;

60 DLs + 15 ULs;

50 DLs + 5ULs + 5 DLs + 5ULs + 5 DLs + 5ULs;

30 DLs + 5ULs + 5 DLs + 5ULs + 25 DLs + 5 ULs;

45 DLs + 30ULs;

5 25 DLs + 15 ULs + 20UL + 15 ULs;

32 DLs + 43 ULs;

16 DLs + 25ULs + 16 DLs + 25ULs;

8 DL + 30 ULs + 8DLs + 29 ULs;

16 DLs + 59 ULs;

10 7 DL + 30 ULs + 8 DLs + 30 ULs; and

15 DLs + 60 ULs.

[0096] In one embodiment, the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises two uplink bursts and one or more downlink bursts.

[0097] In one embodiment, the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form the data dwell time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

[0098] In one embodiment, the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises downlink subframes, followed by uplink subframes, followed by downlink subframes, followed by uplink subframes.

[0099] In one embodiment, the one or more processors are further configured to evenly distribute the downlink subframes and the uplink subframes; or include selected uplink subframes between a first downlink burst and a second downlink burst for channel state information (CSI) reporting in the selected uplink subframes.

[00100] FIG 11 illustrates architecture of a system 1100 of a network in accordance with some embodiments. The system 1100 is shown to include a user equipment (UE) 1101 and a UE 1102. The UEs 1101 and 1102 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular
5 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.

[00101] In some embodiments, any of the UEs 1101 and 1102 can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power
10 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
15 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.

[00102] The UEs 1101 and 1102 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 1110 — the RAN 1110 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a Ne8Gen RAN (NG RAN), or some other type of RAN. The UEs 1101 and 1102 utilize connections 1103 and 1104, respectively, each of which
25 comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 1103 and 1104 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
30 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.

[00103] In this embodiment, the UEs 1101 and 1102 may further directly exchange communication data via a ProSe interface 1105. The ProSe interface 1105 may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[00104] The UE 1102 is shown to be configured to access an access point (AP) 1106 via connection 1107. The connection 1107 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 1106 would comprise a wireless fidelity (WiFi®) router. In this example, the AP 1106 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[00105] The RAN 1110 can include one or more access nodes that enable the connections 1103 and 1104. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), 4G 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 1110 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 1111, 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 1112.

[00106] Any of the RAN nodes 1111 and 1112 can terminate the air interface protocol and can be the first point of contact for the UEs 1101 and 1102. In some embodiments, any of the RAN nodes 1111 and 1112 can fulfill various logical functions for the RAN 1110 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.

[00107] In accordance with some embodiments, the UEs 1101 and 1102 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes 1111 and 1112 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 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.

[00108] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 1111 and 1112 to the UEs 1101 and 1102, 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 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 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.

[00109] The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs 1101 and 1102. 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 1101 and 1102 about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 102 within a cell) may be performed at any of the RAN nodes 1111 and 1112 based on channel quality information fed back from any of the UEs 1101 and 1102. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1101 and 1102.

[00110] 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
5 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
10 PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, $L=1, 2, 4$, or 8).

[00111] 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
15 (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.

[00112] The RAN 1110 is shown to be communicatively coupled to a core network (CN) 1120 —via an S1 interface 1113. In embodiments, the CN 1120 may be an evolved packet core (EPC) network, a Next Generation Packet Core (NPC) network, or some other type of CN. In this embodiment the S1 interface 1113 is split into two parts: the S1-U interface
20 1114, which carries traffic data between the RAN nodes 1111 and 1112 and the serving gateway (S-GW) 1122, and the S1-MOBILITY management entity (MME) interface 1115,
25 which is a signaling interface between the RAN nodes 1111 and 1112 and MMEs 1121.

[00113] In this embodiment, the CN 1120 comprises the MMEs 1121, the S-GW 1122, the Packet Data Network (PDN) Gateway (P-GW) 1123, and a home subscriber server (HSS) 1124. The MMEs 1121 may be similar in function to the control plane of legacy
30 Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 1121 may manage mobility aspects in access such as gateway selection and tracking area list

management. The HSS 1124 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN 1120 may comprise one or several HSSs 1124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1124 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[00114] The S-GW 1122 may terminate the S1 interface 1113 towards the RAN 1110, and routes data packets between the RAN 1110 and the CN 1120. In addition, the S-GW 1122 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.

[00115] The P-GW 1123 may terminate an SGI interface toward a PDN. The P-GW 1123 may route data packets between the EPC network 1123 and external networks such as a network including the application server 1130 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 1125. Generally, the application server 1130 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW 1123 is shown to be communicatively coupled to an application server 1130 via an IP communications interface 1125. The application server 1130 can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 1101 and 1102 via the CN 1120.

[00116] The P-GW 1123 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 1126 is the policy and charging control element of the CN 1120. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with 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 1126 may be

communicatively coupled to the application server 1130 via the P-GW 1123. The application server 1130 may signal the PCRF 1126 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 1126 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 1130.

[00117] FIG 12 illustrates example components of a device 1200 in accordance with some embodiments. In some embodiments, the device 1200 may include application circuitry 1202, baseband circuitry 1204, Radio Frequency (RF) circuitry 1206, front-end module (FEM) circuitry 1208, one or more antennas 1210, and power management circuitry (PMC) 1212 coupled together at least as shown. The components of the illustrated device 1200 may be included in a UE or a RAN node. In some embodiments, the device 1200 may include less elements (e.g., a RAN node may not utilize application circuitry 1202, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 1200 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).

[00118] The application circuitry 1202 may include one or more application processors. For example, the application circuitry 1202 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 1200. In some embodiments, processors of application circuitry 1202 may process IP data packets received from an EPC.

[00119] The baseband circuitry 1204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1204 may

include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 1206 and to generate baseband signals for a transmit signal path of the RF circuitry 1206. Baseband processing circuitry 1204 may interface with the application circuitry 1202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1206. For example, in some embodiments, the baseband circuitry 1204 may include a third generation (3G) baseband processor 1204A, a fourth generation (4G) baseband processor 1204B, a fifth generation (5G) baseband processor 1204C, or other baseband processor(s) 1204D 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 1204 (e.g., one or more of baseband processors 1204A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1206. In other embodiments, some or all of the functionality of baseband processors 1204A-D may be included in modules stored in the memory 1204G and executed via a Central Processing Unit (CPU) 1204E. 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 1204 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1204 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.

[00120] In some embodiments, the baseband circuitry 1204 may include one or more audio digital signal processor(s) (DSP) 1204F. The audio DSP(s) 1204F 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 1204 and the application circuitry 1202 may be implemented together such as, for example, on a system on a chip (SOC).

[00121] In some embodiments, the baseband circuitry 1204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1204 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 1204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00122] RF circuitry 1206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1206 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1208 and provide baseband signals to the baseband circuitry 1204. RF circuitry 1206 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1204 and provide RF output signals to the FEM circuitry 1208 for transmission.

[00123] In some embodiments, the receive signal path of the RF circuitry 1206 may include mixer circuitry 1206a, amplifier circuitry 1206b and filter circuitry 1206c. In some embodiments, the transmit signal path of the RF circuitry 1206 may include filter circuitry 1206c and mixer circuitry 1206a. RF circuitry 1206 may also include synthesizer circuitry 1206d for synthesizing a frequency for use by the mixer circuitry 1206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1208 based on the synthesized frequency provided by synthesizer circuitry 1206d. The amplifier circuitry 1206b may be configured to amplify the down-converted signals and the filter circuitry 1206c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1204 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 1206a of the

receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00124] In some embodiments, the mixer circuitry 1206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1206d to generate RF output signals for the FEM circuitry 1208. The baseband signals may be provided by the baseband circuitry 1204 and may be filtered by filter circuitry 1206c.

[00125] In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a 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 1206a of the receive signal path and the mixer circuitry 1206a 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 1206a of the receive signal path and the mixer circuitry 1206a may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path may be configured for super-heterodyne operation.

[00126] 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 1206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1204 may include a digital baseband interface to communicate with the RF circuitry 1206.

[00127] 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.

[00128] In some embodiments, the synthesizer circuitry 1206d 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 1206d may be a delta-sigma synthesizer, a frequency

multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00129] The synthesizer circuitry 1206d may be configured to synthesize an output frequency for use by the mixer circuitry 1206a of the RF circuitry 1206 based on a frequency input and a divider control input. In some embodiments, the synthesizer
5 circuitry 1206d may be a fractional $N/N+1$ synthesizer.

[00130] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a necessity. Divider control input may be provided by either the baseband circuitry 1204 or the applications processor 1202 depending on the desired output frequency. In some embodiments, a divider control input
10 (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1202.

[00131] Synthesizer circuitry 1206d of the RF circuitry 1206 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
15 digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up
20 into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00132] In some embodiments, synthesizer circuitry 1206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the
25 output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 1206
30 may include an IQ/polar converter.

[00133] FEM circuitry 1208 may include a receive signal path which may include

circuitry configured to operate on RF signals received from one or more antennas 1210, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1206 for further processing. FEM circuitry 1208 may also include a transmit signal path which may include circuitry configured to amplify signals for
5 transmission provided by the RF circuitry 1206 for transmission by one or more of the one or more antennas 1210. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1206, solely in the FEM 1208, or in both the RF circuitry 1206 and the FEM 1208.

[00134] In some embodiments, the FEM circuitry 1208 may include a TX/RX switch
10 to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1206). The transmit signal path of the FEM circuitry 1208 may include a power amplifier (PA) to amplify
15 input RF signals (e.g., provided by RF circuitry 1206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1210).

[00135] In some embodiments, the PMC 1212 may manage power provided to the baseband circuitry 1204. In particular, the PMC 1212 may control power-source selection,
20 voltage scaling, battery charging, or DC-to-DC conversion. The PMC 1212 may often be included when the device 1200 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 1212 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[00136] While FIG 12 shows the PMC 1212 coupled only with the baseband circuitry 1204. However, in other embodiments, the PMC 1212 may be additionally or
25 alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 802, RF circuitry 1206, or FEM 1208.

[00137] In some embodiments, the PMC 1212 may control, or otherwise be part of,
30 various power saving mechanisms of the device 1200. For example, if the device 1200 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 1200 may power down for brief intervals of time and thus save power.

- 5 [00138] If there is no data traffic activity for an extended period of time, then the device 1200 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 1200 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
10 1200 may not receive data in this state, in order to receive data, it can transition back to RRC_Connected state.

- [00139] 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
15 completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

- [00140] Processors of the application circuitry 1202 and processors of the baseband circuitry 1204 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1204, alone or in combination,
20 may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1204 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
25 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.

- [00141] FIG. 13 illustrates example interfaces of baseband circuitry in accordance with
30 some embodiments. As discussed above, the baseband circuitry 1204 of FIG. 12 may comprise processors 1204A-1204E and a memory 1204G utilized by said processors.

Each of the processors 1204A-1204E may include a memory interface, 1304A-1304E, respectively, to send/receive data to/from the memory 1204G

[00142] The baseband circuitry 1204 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 1312 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 1204), an application circuitry interface 1314 (e.g., an interface to send/receive data to/from the application circuitry 1202 of FIG 12), an RF circuitry interface 1316 (e.g., an interface to send/receive data to/from RF circuitry 1206 of FIG 12), a wireless hardware connectivity interface 1318 (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 1320 (e.g., an interface to send/receive power or control signals to/from the PMC 1212).

[00143] FIG 14 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.

[00144] FIG 14 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

[00145] 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.

[00146] Example 1 includes an apparatus of a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, the apparatus comprising: one or more processors configured to: decode downlink control information (DCI) comprising dynamic TDD configuration information; identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information; encode data for transmission to a next generation node B (gNB) on one or more uplink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; decode data received from the gNB on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; and a memory interface configured to store in a memory the data received from the gNB.

[00147] Example 2 includes the apparatus of example 1, wherein the one or more processors are further configured to encode data in an uplink subframe or decode data in a downlink subframe of a data channel having a selected data dwell time.

[00148] Example 3 includes the apparatus of example 1 or 2, wherein the one or more

processors are further configured to encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is less than 1 to 4, 1 to 4, 4 to 1, or greater than 4 to 1.

5 **[00149]** Example 4 includes the apparatus of example 1 or 2, wherein the one or more processors are further configured to encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is 1 to 3, 2 to 3, 3 to 2, or 3 to 1.

10 **[00150]** Example 5 includes the apparatus of example 2 to 4, wherein the dwell time is one of 25 milliseconds (ms), 50 ms, 75 ms, or 100 ms.

[00151] Example 6 includes the apparatus of example 2, wherein a ratio of the downlink subframes relative to the uplink subframes is irrespective of the selected data dwell time of the data channel.

15 **[00152]** Example 7 includes the apparatus of example 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at a single switch point, wherein the switch point is $\frac{3}{5} * T_{dwell_data}$ DL subframes followed by $\frac{2}{5} * T_{dwell_data}$ UL subframes per data channel.

20 **[00153]** Example 8 includes the apparatus of example 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

25 **[00154]** Example 9 includes the apparatus of example 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one switch point to form a data dwell time that comprises 45 downlink subframes, followed by 30 uplink subframes.

[00155] Example 10 includes the apparatus of example 2, wherein the one or more processors are further configured to encode uplink hybrid automatic repeat request

(HARQ) acknowledgment (ACK) in one or more downlink subframes in the selected data dwell time of the data channel in an asynchronous manner.

[00156] Example 11 includes the apparatus of example 10, wherein the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a selected asynchronous HARQ ACK timing.

[00157] Example 12 includes the apparatus of example 2, wherein the one or more processors are further configured to encode downlink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more uplink subframes in the selected data dwell time of the data channel in an asynchronous manner.

[00158] Example 13 includes the apparatus of example 10, wherein the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a time division duplex configuration that is equivalent to a downlink reference configuration.

[00159] Example 14 includes an apparatus of a next generation node B (gNB) configured to in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, the apparatus comprising: one or more processors configured to: configure a frame structure for dynamic downlink (DL) and uplink (UL) communication for dynamic TDD configuration information; encode downlink control information (DCI) comprising the dynamic TDD configuration information; encode data for transmission from the gNB to a user equipment (UE) on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; and decode data received at the gNB on one or more uplink subframes of the configured frame structure in the unlicensed spectrum of the U-IoT system; a memory interface configured to store in a memory the decoded data received at the gNB.

[00160] Example 15 includes the apparatus of example 14, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form a data dwell time that comprises: 70 downlink subframes (DLs) + 5 uplink subframes (ULs); 60 DLs + 5 ULs + 10DLs; 73 DLs + 3 ULs; 60 DLs + 3 ULs + 12 DLs; 60 DLs + 5ULs + 10 DLs; 60 DLs + 15 ULs; 50 DLs + 5ULs + 5 DLs +5ULs + 5 DLs+5ULs; 30 DLs + 5ULs + 5 DLs +5ULs + 25 DLs +5 ULs; 45 DLs + 30ULs; 25 DLs + 15 ULs + 20UL + 15 ULs; 32

DLs + 43 ULs; 16 DLs + 25ULs + 16 DLs + 25ULs; 8 DL + 30 ULs + 8DLs + 29 ULs;
16 DLs + 59 ULs; 7 DL + 30 ULs + 8 DLs + 30 ULs; and 15 DLs + 60 ULs.

[00161] Example 16 includes the apparatus of example 14 or 15, wherein the one or more processors are further configured to switch between the one or more downlink
5 subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises two uplink bursts and one or more downlink bursts.

[00162] Example 17 includes the apparatus of example 16, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form the data dwell
10 time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

[00163] Example 18 includes the apparatus of example 14 or 15, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell
15 time that comprises downlink subframes, followed by uplink subframes, followed by downlink subframes, followed by uplink subframes.

[00164] Example 19 includes the apparatus of example 18, wherein the one or more processors are further configured to: evenly distribute the downlink subframes and the uplink subframes; or include selected uplink subframes between a first downlink burst
20 and a second downlink burst for channel state information (CSI) reporting in the selected uplink subframes.

[00165] Example 20 includes at least one machine readable storage medium having instructions embodied thereon for a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things
25 (U-IoT) system, the instructions when executed by one or more processors at the UE perform the following: decode downlink control information (DCI) comprising dynamic TDD configuration information; identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information; encode data for transmission to a next generation node B (gNB) on one or more uplink
30 subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; and decode data received from the gNB on one or more downlink subframes of

the configured frame structure in an unlicensed spectrum of the U-IoT system.

[00166] Example 21 includes the at least one machine readable storage medium in example 20 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode data in an uplink subframe or decode
5 data in a downlink subframe of a data channel having a selected data dwell time.

[00167] Example 22 includes the at least one machine readable storage medium in example 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the
10 downlink subframes relative to the uplink subframes in the selected dwell time is less than 1 to 4, 1 to 4, 4 to 1, or greater than 4 to 1.

[00168] Example 23 includes the at least one machine readable storage medium in example 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode data in the uplink subframe or
15 decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is 1 to 3, 2 to 3, 3 to 2, or 3 to 1.

[00169] Example 24 includes the at least one machine readable storage medium in example 20 or 21 further comprising instructions, that when executed by one or more
20 processors at the UE, perform the following: switch between the one or more downlink subframes and the one or more uplink subframes at a single switch point, wherein the switch point is $\frac{3}{5} * T_{dwell_data}$ DL subframes followed by $\frac{2}{5} * T_{dwell_data}$ UL subframes per data channel.

[00170] Example 25 includes the at least one machine readable storage medium in example 20 or 21 further comprising instructions, that when executed by one or more
25 processors at the UE, perform the following: switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

30 [00171] Example 26 includes the at least one machine readable storage medium in

example 20 or 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following: switch between the one or more downlink subframes and the one or more uplink subframes at one switch point to form a data dwell time that comprises 45 downlink subframes, followed by 30 uplink subframes.

- 5 **[00172]** Example 27 includes the at least one machine readable storage medium in example 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode uplink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more downlink subframes in the selected data dwell time of the data channel in an asynchronous manner.

- 10 **[00173]** Example 28 includes the at least one machine readable storage medium in example 27 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a selected asynchronous HARQ ACK timing.

- 15 **[00174]** Example 29 includes the at least one machine readable storage medium in example 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode downlink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more uplink subframes in the selected data dwell time of the data channel in an asynchronous manner.

- 20 **[00175]** Example 30 includes the at least one machine readable storage medium in example 27 further comprising instructions, that when executed by one or more processors at the UE, perform the following: encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a time division duplex configuration that is equivalent to a downlink reference configuration.

- 25 **[00176]** Various techniques, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, compact disc-read-only memory (CD-ROMs), hard drives, non-transitory computer readable storage medium, or any other machine-readable storage medium wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the various techniques. In the case of
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), flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). In one example, selected components of the transceiver module can be located in a cloud radio access network (C-RAN). One or more programs that may implement or utilize the various techniques described herein may use an application programming interface (API), reusable controls, and the like. Such programs may be implemented in a high level procedural or object oriented programming language to communicate with a computer system. However, the program(s) may be implemented in assembly or machine language, if desired. In any case, the language may be a compiled or interpreted language, and combined with hardware implementations.

[00177] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[00178] It should be understood that many of the functional units described in this specification have been labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very-large-scale integration (VLSI) circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00179] 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
5 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.

[00180] 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
10 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
15 signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

[00181] 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,
20 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.

[00182] 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
25 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
30 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.

[00183] 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.

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 a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, the apparatus comprising:
5 one or more processors configured to:
 decode downlink control information (DCI) comprising dynamic TDD configuration information;
 identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information;
10 encode data for transmission to a next generation node B (gNB) on one or more uplink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system;
15 decode data received from the gNB on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; and
 a memory interface configured to store in a memory the data received from the gNB.
20
2. The apparatus of claim 1, wherein the one or more processors are further configured to encode data in an uplink subframe or decode data in a downlink subframe of a data channel having a selected data dwell time.
- 25 3. The apparatus of claim 1 or 2, wherein the one or more processors are further configured to encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is less than 1 to 4, 1 to 4, 4 to 1, or greater than 4 to 1.
30
4. The apparatus of claim 1 or 2, wherein the one or more processors are further configured to encode data in the uplink subframe or decode data in the downlink

subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is 1 to 3, 2 to 3, 3 to 2, or 3 to 1.

5 5. The apparatus of claim 2 to 4, wherein the dwell time is one of 25 milliseconds (ms), 50 ms, 75 ms, or 100 ms.

6. The apparatus of claim 2, wherein a ratio of the downlink subframes relative to the uplink subframes is irrespective of the selected data dwell time of the data channel.

10 7. The apparatus of claim 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at a single switch point, wherein the switch point is

$\frac{1}{5} * T_{dwell_data}$ DL subframes followed by $\frac{2}{5} * T_{dwell_data}$ UL subframes per data

15 channel.

8. The apparatus of claim 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that

20 comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

9. The apparatus of claim 1 or 2, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one switch point to form a data dwell time that

25 comprises 45 downlink subframes, followed by 30 uplink subframes.

10. The apparatus of claim 2, wherein the one or more processors are further configured to encode uplink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more downlink subframes in the selected data

30 dwell time of the data channel in an asynchronous manner.

11. The apparatus of claim 10, wherein the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a selected asynchronous HARQ ACK timing.

5 12. The apparatus of claim 2, wherein the one or more processors are further configured to encode downlink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more uplink subframes in the selected data dwell time of the data channel in an asynchronous manner.

10 13. The apparatus of claim 10, wherein the one or more processors are further configured to encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a time division duplex configuration that is equivalent to a downlink reference configuration.

15 14. An apparatus of a next generation node B (gNB) configured to in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, the apparatus comprising:

one or more processors configured to:

20 configure a frame structure for dynamic downlink (DL) and uplink (UL) communication for dynamic TDD configuration information;

encode downlink control information (DCI) comprising the dynamic TDD configuration information;

25 encode data for transmission from the gNB to a user equipment (UE) on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system; and

decode data received at the gNB on one or more uplink subframes of the configured frame structure in the unlicensed spectrum of the U-IoT system;

30 a memory interface configured to store in a memory the decoded data received at the gNB.

15. The apparatus of claim 14, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form a data dwell time that comprises:

- 5 70 downlink subframes (DLs) + 5 uplink subframes (ULs)
- 60 DLs + 5 ULs + 10DLs;
- 73 DLs + 3 ULs;
- 60 DLs + 3 ULs + 12 DLs;
- 60 DLs + 5ULs + 10 DLs;
- 10 60 DLs + 15 ULs;
- 50 DLs + 5ULs + 5 DLs +5ULs + 5 DLs+5ULs;
- 30 DLs + 5ULs + 5 DLs +5ULs + 25 DLs +5 ULs;
- 45 DLs + 30ULs;
- 25 DLs + 15 ULs + 20UL + 15 ULs;
- 15 32 DLs + 43 ULs;
- 16 DLs + 25ULs + 16 DLs + 25ULs;
- 8 DL + 30 ULs + 8DLs + 29 ULs;
- 16 DLs + 59 ULs ;
- 7 DL + 30 ULs + 8 DLs + 30 ULs; and
- 20 15 DLs + 60 ULs.

16. The apparatus of claim 14 or 15, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that

25 comprises two uplink bursts and one or more downlink bursts.

17. The apparatus of claim 16, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at one or more switch points to form the data dwell time

30 that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink subframes, followed by 15 uplink subframes.

18. The apparatus of claim 14 or 15, wherein the one or more processors are further configured to switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises downlink subframes, followed by uplink subframes, followed by
5 downlink subframes, followed by uplink subframes.
19. The apparatus of claim 18, wherein the one or more processors are further configured to:
- evenly distribute the downlink subframes and the uplink subframes; or
10 include selected uplink subframes between a first downlink burst and a second downlink burst for channel state information (CSI) reporting in the selected uplink subframes.
20. At least one machine readable storage medium having instructions embodied
15 thereon for a user equipment (UE) configured to operate in a dynamic time division duplex (TDD) configuration for an unlicensed internet of things (U-IoT) system, the instructions when executed by one or more processors at the UE perform the following:
- decode downlink control information (DCI) comprising dynamic TDD
20 configuration information;
- identify a frame structure for dynamic downlink (DL) and uplink (UL) communication based on the dynamic TDD configuration information;
- encode data for transmission to a next generation node B (gNB) on one or more uplink subframes of the configured frame structure in an unlicensed
25 spectrum of the U-IoT system; and
- decode data received from the gNB on one or more downlink subframes of the configured frame structure in an unlicensed spectrum of the U-IoT system.
21. The at least one machine readable storage medium in claim 20 further comprising
30 instructions, that when executed by one or more processors at the UE, perform the following:

encode data in an uplink subframe or decode data in a downlink subframe of a data channel having a selected data dwell time.

22. The at least one machine readable storage medium in claim 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is less than 1 to 4, 1 to 4, 4 to 1, or greater than 4 to 1.

23. The at least one machine readable storage medium in claim 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode data in the uplink subframe or decode data in the downlink subframe of the data channel, wherein a ratio of the downlink subframes relative to the uplink subframes in the selected dwell time is 1 to 3, 2 to 3, 3 to 2, or 3 to 1.

24. The at least one machine readable storage medium in claim 20 or 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

switch between the one or more downlink subframes and the one or more uplink subframes at a single switch point, wherein the switch point is

$\frac{2}{5} * T_{\text{dwell_data}}$ DL subframes followed by $\frac{3}{5} * T_{\text{dwell_data}}$ UL subframes per data

channel.

25. The at least one machine readable storage medium in claim 20 or 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

switch between the one or more downlink subframes and the one or more uplink subframes at two switch points to form a data dwell time that comprises 25 downlink subframes, followed by 15 uplink subframes, followed by 20 downlink

subframes, followed by 15 uplink subframes.

26. The at least one machine readable storage medium in claim 20 or 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

switch between the one or more downlink subframes and the one or more uplink subframes at one switch point to form a data dwell time that comprises 45 downlink subframes, followed by 30 uplink subframes.

27. The at least one machine readable storage medium in claim 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode uplink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more downlink subframes in the selected data dwell time of the data channel in an asynchronous manner.

28. The at least one machine readable storage medium in claim 27 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a selected asynchronous HARQ ACK timing.

29. The at least one machine readable storage medium in claim 21 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode downlink hybrid automatic repeat request (HARQ) acknowledgment (ACK) in one or more uplink subframes in the selected data dwell time of the data channel in an asynchronous manner.

30. The at least one machine readable storage medium in claim 27 further comprising instructions, that when executed by one or more processors at the UE, perform the following:

encode acknowledgements (ACKs) and non-acknowledgements (NACKs) with a time division duplex configuration that is equivalent to a downlink reference configuration.

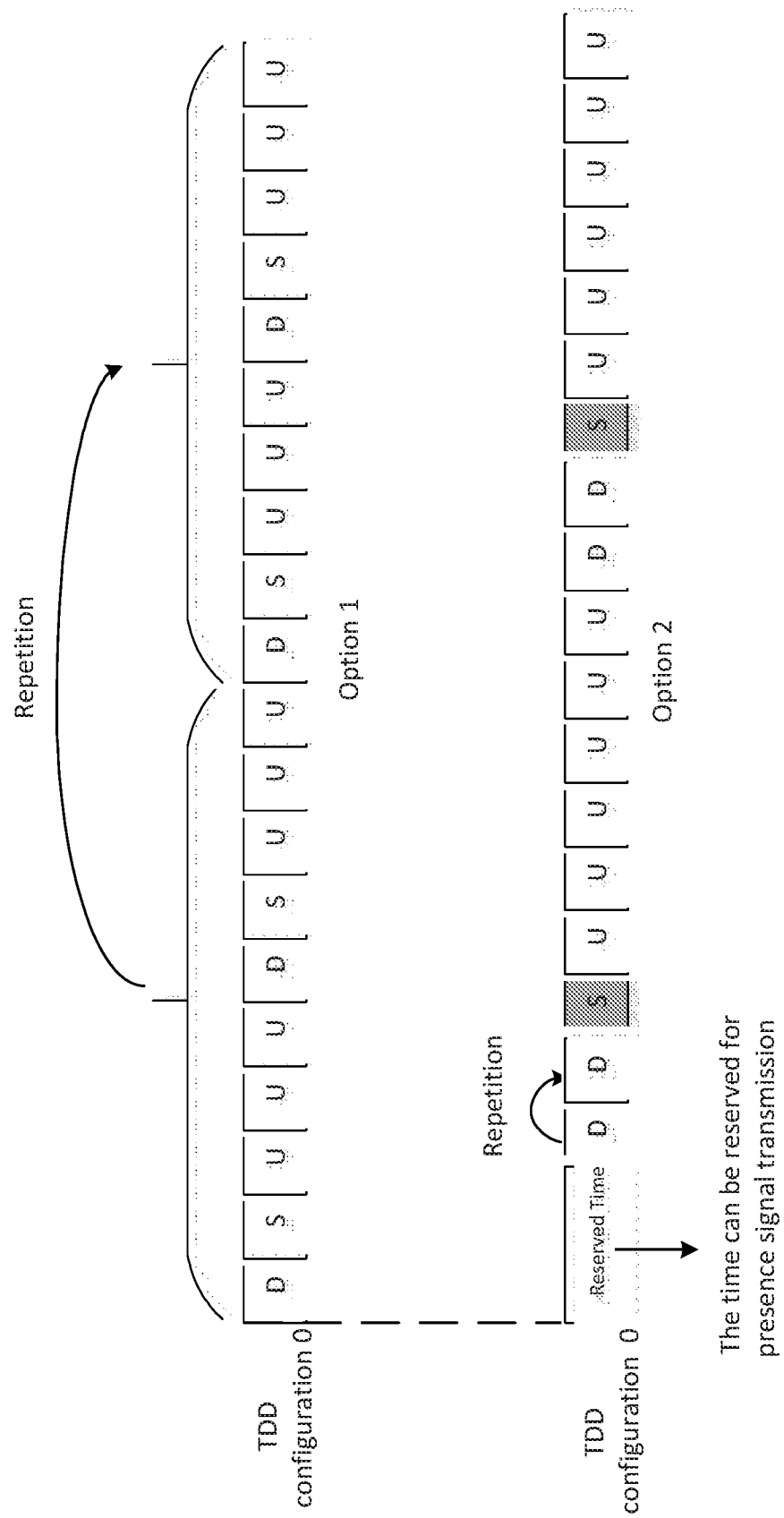


FIG. 1

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number										Ratio of DL to UL
		0	1	2	3	4	5	6	7	8	9	
0	5 ms	D	S	U	U	U	D	S	U	U	U	1:3
1	5 ms	D	S	U	U	D	D	S	U	U	D	1:1
2	5 ms	D	S	U	D	D	D	S	U	D	D	3:1
3	10 ms	D	S	U	U	U	D	D	D	D	D	2:1
4	10 ms	D	S	U	U	D	D	D	D	D	D	3.5:1
5	10 ms	D	S	U	D	D	D	D	D	D	D	8:1
6	5 ms	D	S	U	U	U	D	S	U	U	D	3:5

FIG. 2

70 DLs	5 ULs
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FIG. 3A

60 DLs	5 ULs	10 DLs
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FIG. 3B

60 DLs	3 ULs	12 DLs
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FIG. 3C

FIG. 4B

60 DLs	15 ULs
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FIG. 4A

50 DLs	5 ULs	5 ULs	5 ULs	5 ULs	5 ULs
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FIG. 4B

30 DLs	15 ULs	30 DLs
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FIG. 4C

40 DLs	5 ULs	5 ULs	5 ULs	5 ULs	5 ULs	5 ULs
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FIG. 5A

25 DLs	15 ULs	20 DLs	15 ULs
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FIG. 5B

32 DLs	43 ULs
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FIG. 6A

16 ULs	25 DLs	16 ULs	18 DLs
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FIG. 6B

16 DLs	59 ULs
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FIG. 7A

16 DLs	5 UL s	5 UL s	5 UL s	5 UL s	5 UL s	16 DLs	5 UL s	5 UL s	5 UL s	5 UL s	5 UL s
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FIG. 7B

7 ULs	30 DLs	7 ULs	30 DLs
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FIG. 8A

15 DLs	60 ULs
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FIG. 8B

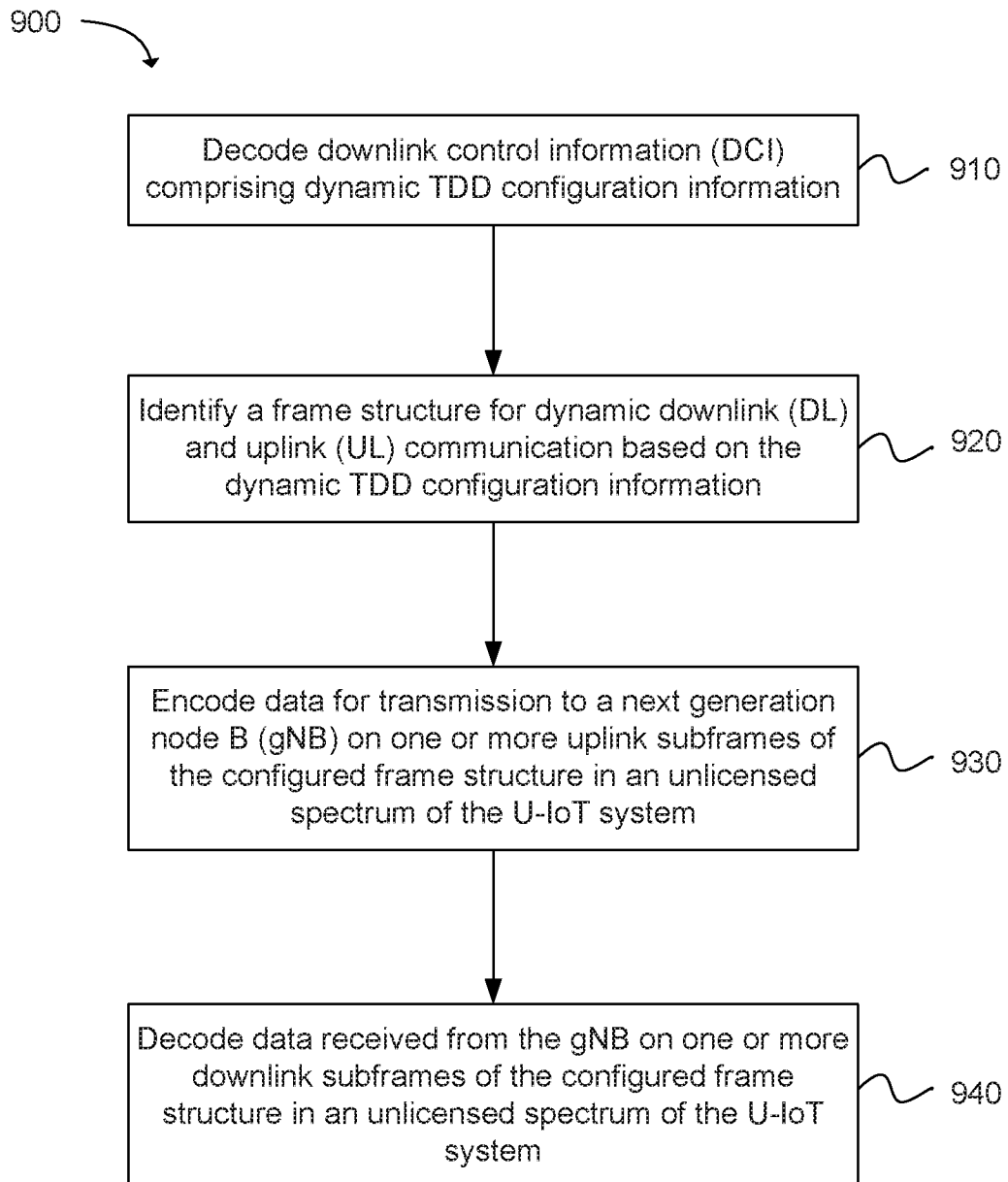


FIG. 9

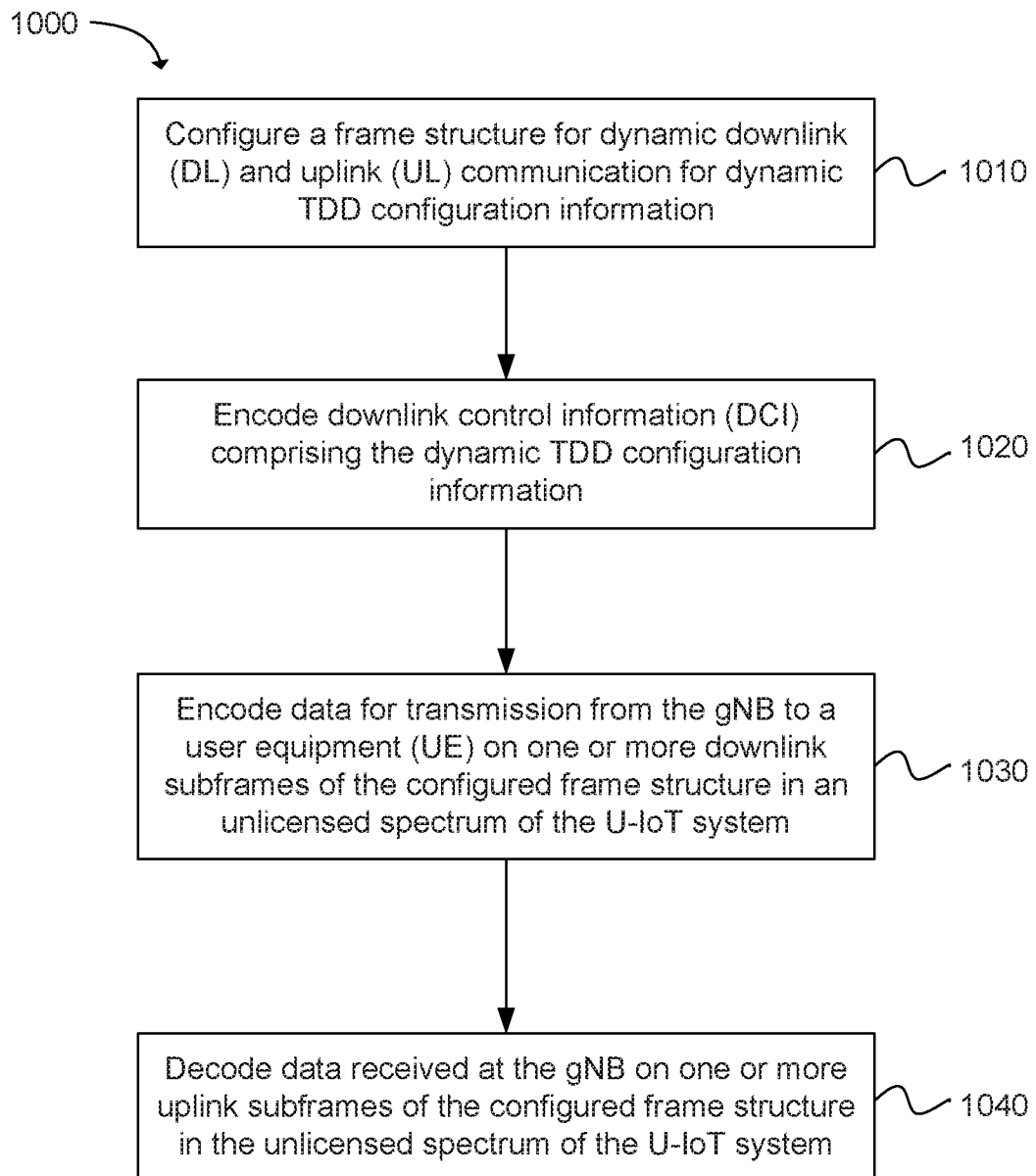


FIG. 10

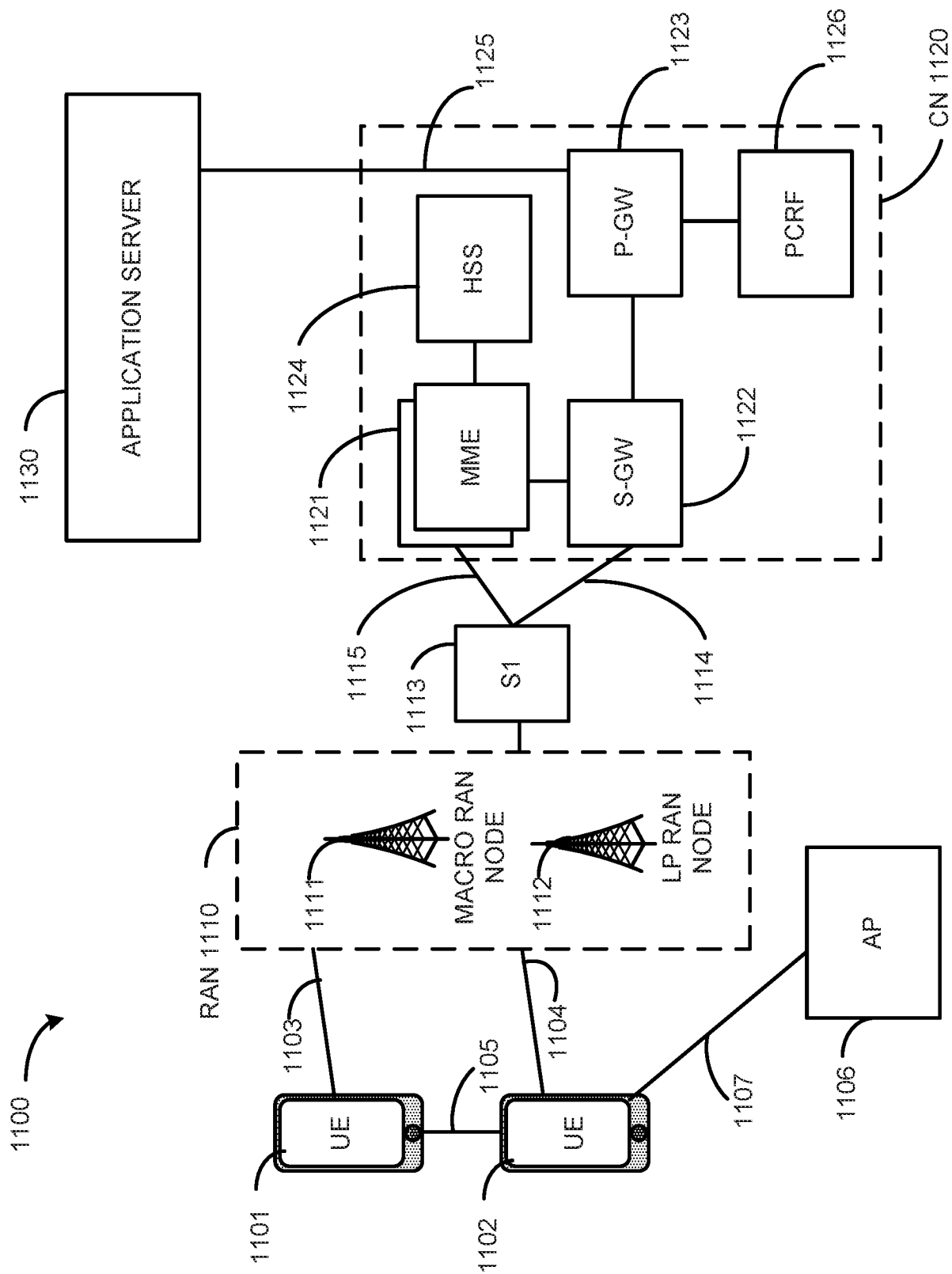


FIG. 11

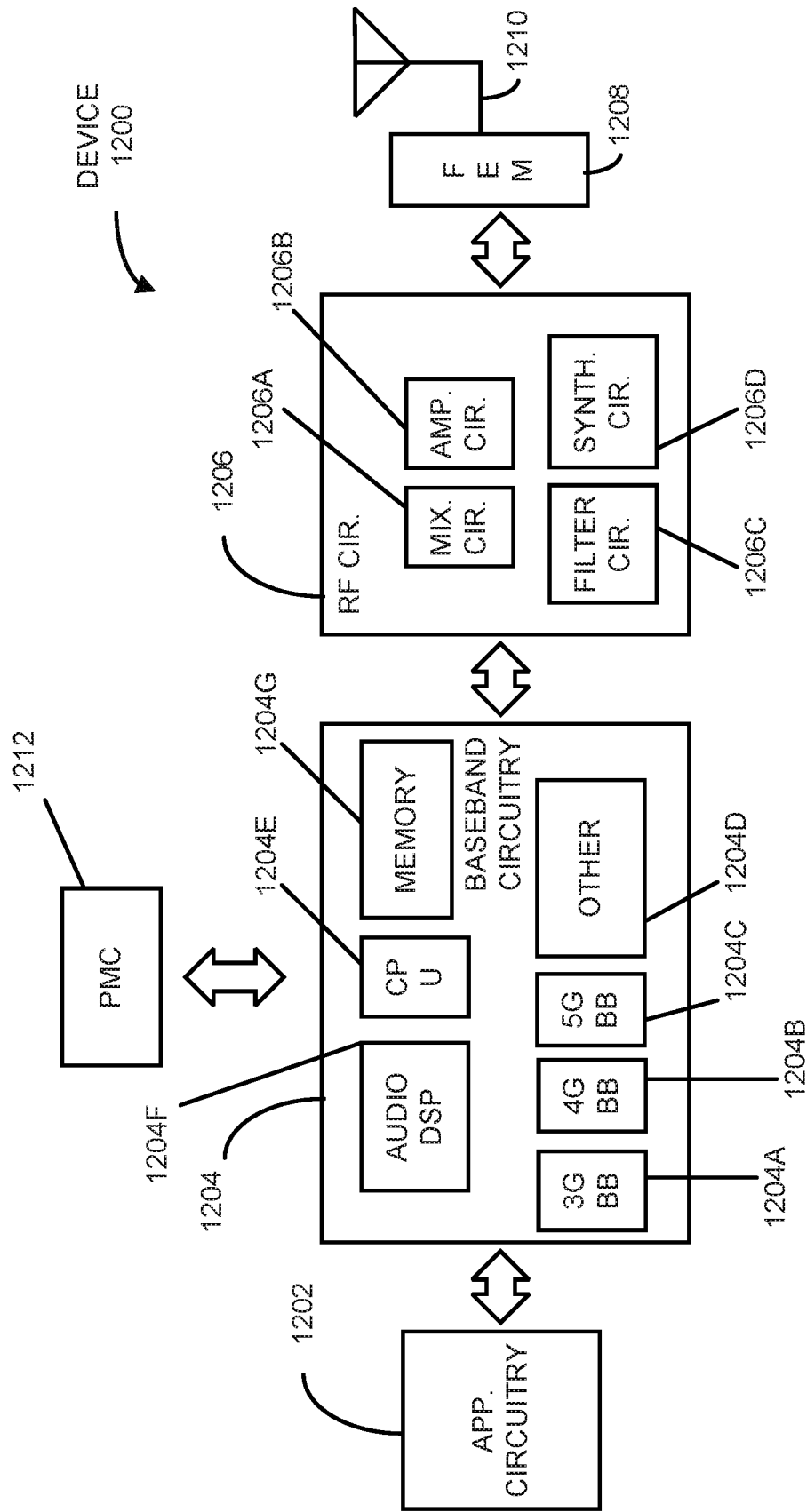


FIG. 12

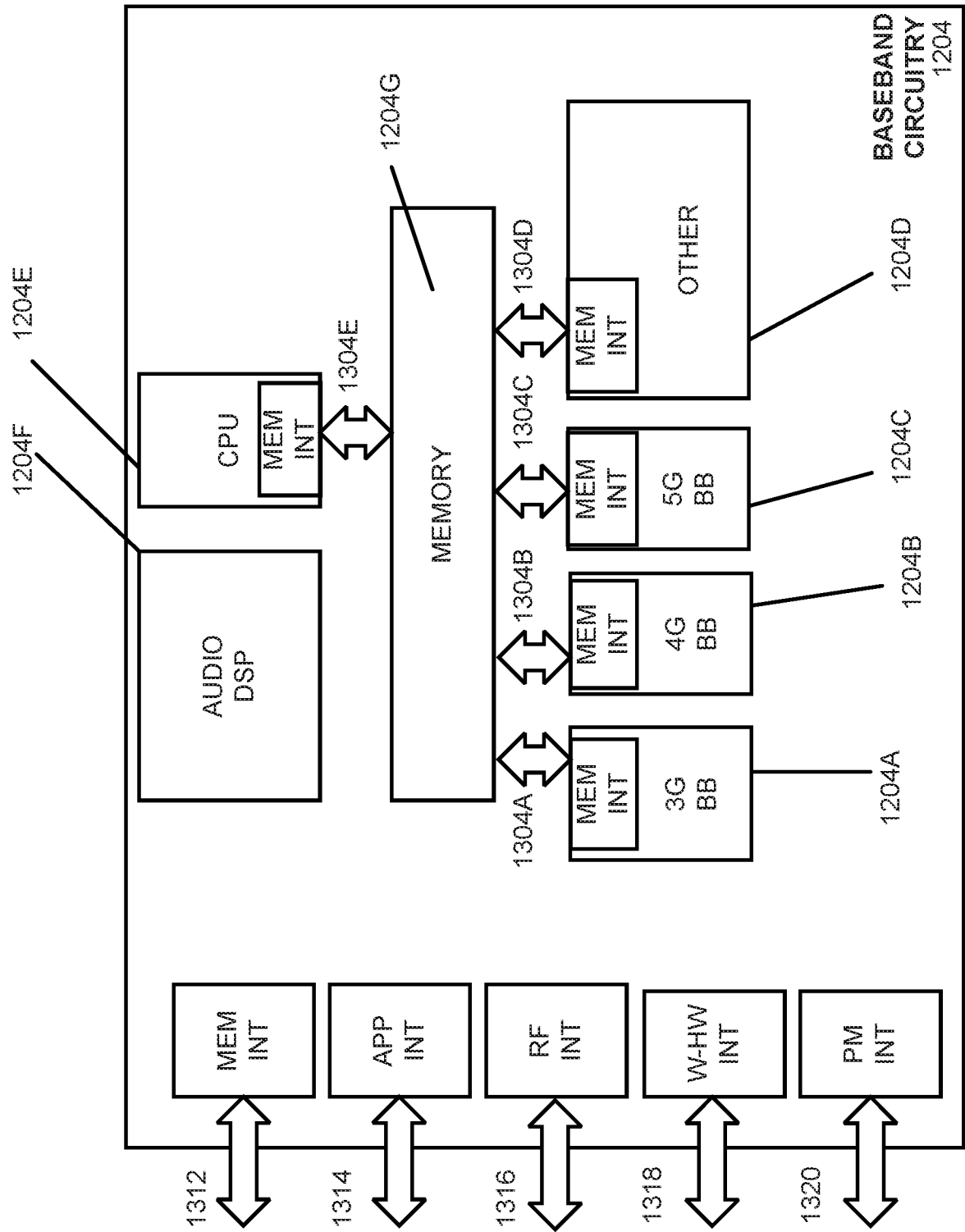


FIG. 13

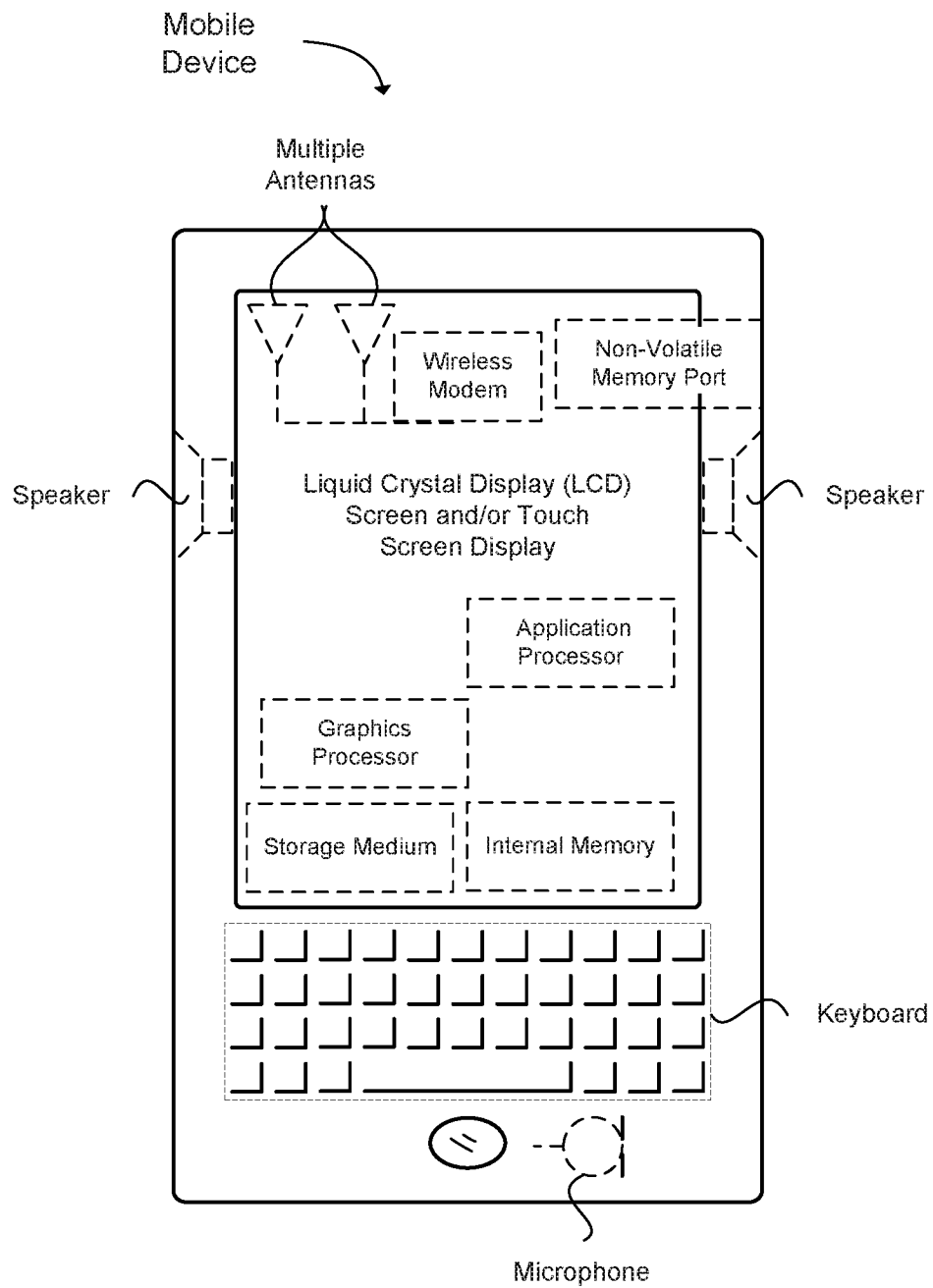


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/016304

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/04
ADD.

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, INSPEC, 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	US 2016/165578 A1 (CHEN WANSHI [US] ET AL) 9 June 2016 (2016-06-09)	1-10, 12-27, 29,30 11,28
A	paragraph [0003] paragraph [0059] paragraph [0063] paragraph [0066] paragraph [0069] - paragraph [0071] paragraph [0106] -----	
X	US 2014/119261 A1 (WANG YIPING [US] ET AL) 1 May 2014 (2014-05-01)	1-10, 12-27, 29,30 11,28
A	paragraph [0023] - paragraph [0028] paragraph [0031] paragraph [0044] - paragraph [0055] ----- -/--	



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

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"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

18 April 2018

Date of mailing of the international search report

30/04/2018

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/016304

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/016304

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