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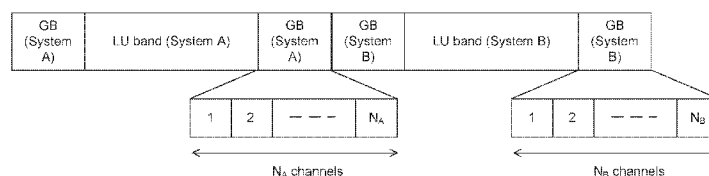


FIG. 3

(57) Abstract: Technology for opportunistic guard band access within a third generation partnership project (3GPP) fifth generation (5G) wireless communication network is disclosed. A base station identifies one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes at least the cellular communication system that the base station belongs to, and another adjacent cellular communication system. The base station processes information, received from the one or more cellular communication systems, to identify and select within the one or more guardbands a set of best available channels suitable for narrowband wireless communications. The base station then selects a particular channel among the best available channels and communicates to an IoT device, information enabling the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements. The IoT device is a wireless device designed for Machine-Type Communications, MTC, with reduced or narrow bandwidth requirements and capabilities, also known as Narrowband, NB, Internet of Things, IoT, device.



NETWORK-ASSISTED OPPORTUNISTIC GUARD BAND ACCESS AND USE
FOR INTERNET OF THINGS (IOT) DEVICES

BACKGROUND

5 [0001] Wireless mobile communication technology uses various standards and protocols to transmit data between a node (e.g., a transmission station such as an eNodeB) 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 an uplink (UL) transmission. 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 10 the IEEE 802.11 standard, which is commonly known to industry groups as WiFi. In 3GPP radio access network (RAN) LTE systems, 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, 15 known as a user equipment (UE). The downlink (DL) transmission can be a communication from the node to the wireless device (e.g., UE), and the uplink (UL) transmission can be a communication from the wireless device to the node.

[0002] In addition, the Internet is evolving from the human-centered connection network by which humans create and consume information to the Internet of things (IoT) 25 network by which information is communicated and processed between things or other distributed components. To implement the IoT, technology elements, such as a sensing technology, wired/wireless communication and network, service interface technology, and security technology are essential. There is a recent ongoing research for inter-object connection technologies, such as the sensor network, machine-to-machine (M2M), or the 30 machine-type communication (MTC). The IoT environment may offer intelligent Internet Technology (IT) services, such as the smart home, smart building, smart city, smart car or

connected car, smart grid, health-care, or smart appliance industry, or state-of-the-art medical services, through conversion or integration of existing information technology (IT) techniques and various industries.

[0003] To support IoT, such as cellular IoT devices, a solution is desired to address usage scenarios with IoT devices that are more power efficient, can be reached in challenging coverage conditions (e.g., indoor and basements) and, more importantly, are cost efficient such that IoT devices can be deployed on a mass scale. Thus, a desire exists for a solution to provide functionality and protocols that are scalable and efficient to meet the constraints for a Cellular IoT system for the lower data rate end of the M2M market.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Features and advantages of the disclosure will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the disclosure; and, wherein:

15 [0005] FIG. 1 illustrates a mobile communication network within a cell in accordance with an example;

[0006] FIG. 2 illustrates a diagram of radio frame resources (e.g., a resource grid) for a downlink (DL) transmission including a physical downlink control channel (PDCCH) in accordance with an example;

20 [0007] FIG. 3 illustrates a downlink (DL) legacy user spectrum and guard band (GB) for two adjacent cellular system in accordance with an example;

[0008] FIG. 4 illustrates a graph of an adjacent channel interference filtering protection (ACIP) in accordance with an example;

25 [0009] FIG. 5 illustrates an intra-system carrier aggregation and inter-system carrier aggregation in accordance with an example;

[0010] FIG. 6 illustrates a flow chart of an aggregation procedure for a base station (BS) within a guard band of a same system in accordance with an example;

[0011] FIG. 7 illustrates a flow chart of an aggregation procedure for a base station (BS) within guard bands of different systems in accordance with an example;

[0012] FIGs. 8A and 8B illustrate a flow chart of opportunistic guard band access in accordance with an example;

[0013] FIG. 9 depicts additional functionality of a base station for performing opportunistic guard band access within a wireless communication network in accordance
5 with an example;

[0014] FIG. 10 depicts functionality of an internet of things (IoT) device to perform opportunistic guard band access with a base station in accordance with an example;

[0015] FIG. 11 depicts additional functionality of a base station for performing opportunistic guard band access within a third generation partnership project (3GPP) fifth
10 generation (5G) wireless communication network in accordance with an example;

[0016] FIG. 12 illustrates a diagram of example components of a User Equipment (UE) device in accordance with an example;

[0017] FIG. 13 illustrates a diagram of example components of a wireless device (e.g. User Equipment “UE”) device in accordance with an example; and

15 [0018] FIG. 14 illustrates a diagram of a node (e.g., eNB) and wireless device (e.g., UE) in accordance with an example.

[0019] 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

[0020] 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
25 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

sequence.

EXAMPLE EMBODIMENTS

[0021] An initial overview of technology embodiments is provided below and then
5 specific technology embodiments are described in further detail later. This initial
summary is intended to aid readers in understanding the technology more quickly but is
not intended to identify key features or essential features of the technology nor is it
intended to limit the scope of the claimed subject matter.

[0022] Mobile communication has evolved significantly from early voice systems to
10 today's highly sophisticated integrated communication platform. Third generation
partnership project (3GPP) next generation wireless communication system, fifth
generation "5G", can provide access to information and sharing of data anywhere,
anytime by various users and applications. In one aspect, 3GPP 5G can be a unified
network/system targeted to meet vastly different, and often times conflicting,
15 performance dimensions and services. Such diverse multi-dimensional constraints can be
driven by different services and applications. In one aspect, 5G can evolve based on 3GPP
long term evolution (LTE)-Advanced (Adv.) ("3GPP LTE-Adv.") with additional new
Radio Access Technologies (RATs) providing a user with an enriched experience with
simple and seamless wireless connectivity solutions. In one aspect, 5G can enable
20 delivering fast, efficient and optimized content and services for everything connected
within a wireless network.

[0023] Moreover, the cellular Internet of Things (CIoT) paradigm can be employed
within the 3GPP LTE 5G communication system to handle sporadic traffic generated by a
large number (up to billions) of devices. However, in order enable wireless access for
25 such a massive number, the challenge arises on how to accommodate the new users or
devices (compared to the existing, legacy devices, such as users or devices defined by
3GPP LTE Releases 8, 9, 10, 11, and/or 12) in existing wireless ecosystems. First, a
usable radio frequency (RF) spectrum can be scarce in the sense that not all the available
bandwidth can be suitable for communication. For cellular systems, carrier frequency can
30 range from several megahertz (MHz) to up to several gigahertz (GHz). For example, a
global system of mobile (GSM) systems can operate in 900 MHz and 1800 MHz bands in

most of Europe, Middle East, Africa, Australia, and Asia in addition to some countries in South America. Similarly, in North America, wideband code division multiple access (WCDMA) systems can be deployed in the 850 MHz and 1900 MHz range, whereas a 3GPP LTE system can cover a wide range of different frequency bands, such as 700, 750, 800, 850, 1900, 1700/2100, 2500 and 2600 MHz in North America. The usable RF spectrum, which is already scarce, is often further fragmented across disparate systems. Thus, accommodating a massive number of next generation devices is a fundamental challenge for the operators to enable coexistence with legacy cellular ecosystems.

[0024] However, one of the main features of IoT devices is the sporadic nature of communication by the IoT devices. The sporadic nature can mean that the IoT devices can be inactive and only periodically needing to communicate with the base station (BS). For example, a large number of smart utility meters can be deployed in a residential community where the meters need to send measurements of the meter to a central controller, such a local base station (BS) every two weeks for billing purposes. Hence, such IoT devices eliminate a need to employ a dedicated (available at all times) resource (bandwidth) assignment. Moreover, low-throughput, low-power and delay-tolerant transmissions can be sufficient to serve the purpose of IoT devices. Thus, the availability of several chunks of narrow band (NB) spectrum can be employed to offload a significant amount IoT traffic into some existing unutilized bands provided the availability of such large number of narrow band spectrum sources can be identified.

[0025] One area where a large number of NB spectrum sources are available is in guard bands located around current cellular channels. Thus, in one aspect, as most cellular systems have some portions of a total bandwidth reserved for guard bands (GBs) to avoid out of band (OOB) radiation between adjacent channels belonging to different systems, a limitation exists on spectrum utilization efficiency. This is because these GBs are not used for data transmissions. Hence, the present technology provides for utilization of such GBs while ensuring that the OOB radiation to the primary licensees of the system, called the legacy users (LUs), remains within the acceptable limits. Ensuring that the OOB radiation is within acceptable limits can enable coexistence of the new devices to communicate in the existing GBs.

[0026] In one aspect, legacy users (LU) can be “primary users” referring to an existing

or licensed user of a spectrum band, which can be an IoT application or any wireless user. For example, for an IoT application coexisting (in space and spectrum) with WiFi, Worldwide Interoperability for Microwave Access (WiMAX) networks, or 3GPP LTE networks, the set of WiFi/WiMAX/LTE users can be the primary user; for an IoT
5 application coexisting with other existing IoT applications, the set of existing applications can be the primary user.

[0027] As used herein, the term opportunistic user (OU) or (“secondary user”) can refer to an IoT application under consideration that is to be deployed in coexistence with existing networks. That is, the LU (e.g., the primary user) can be a licensed user who has
10 purchased use of the spectrum band and an opportunistic user (OU) can be an unlicensed user who is using the spectrum band opportunistically and without interfering with the primary user.

[0028] Thus, the present technology provides a solution to opportunistically accommodate multiple devices within the guard bands (GBs) under the constraint that a
15 minimum OOB interference can be imparted to the LUs. It should be noted that the OOB interference induced by OUs in a system, such as “system A” should not be harmful to system A’s LUs as well as to both the OUs and the LUs of a neighboring system, such as, for example “system B”. In other words, the users (both OUs and LUs) of the adjacent spectrum bands utilized by system B should not incur high interference levels due to the
20 OUs utilizing the GBs of system A. Thus, the present technology provides for signaling to enable deploying the MTC users in the GBs, thereby increasing the system capacity of the existing cellular networks.

[0029] Accordingly, the present technology provides for opportunistic guard band (GB) access within a wireless communication network, such as a third generation partnership
25 project (3GPP) fifth generation (5G) wireless communication network. As used herein, an IoT device is an MTC device that is configured to communicate with other devices via a wireless network connection. The network connection may be a wireless local area network type connection, such as IEEE 802.11, or a wireless wide area network type connection, such as 3GPP LTE or WiMAX. In one aspect, the present technology can
30 apply to any wireless system.

[0030] In one aspect, the present technology provides for opportunistic guard band

access within a third generation partnership project (3GPP) fifth generation (5G) wireless communication network is disclosed. A base station can identify one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system. The base station can process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more available guard bands based on interference measurements in the one or more available guard bands. The base station can communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements.

[0031] In one aspect, the present technology provides for an internet of things (IoT) device to communicate with a base station in a cellular communication system. The IoT device can monitor an initial communication channel (ICCH) for synchronization and system information (SI) communicated from the base station. The IoT device can decode the system information to determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular communication systems. The IoT device can communicate control information and data in the best available channel in the one or more available guard bands to the one or more cellular communication systems.

[0032] In one aspect, the present technology provides for a base station in a cellular communication system to communicate with an opportunistic user, such as an Internet of things (IoT) device. The base station can identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system. The base station can process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands. The base station can associate one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands. The base station can assign an initial communication channel (ICCH) to the one or more

channels in the one or more guard bands having a maximum ACIP value. The base station can communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

[0033] In accordance with one embodiment, an internet of things (IoT) device can identify one or more available guard bands in a first base station and a second base station, wherein the first base station can be in the cellular communication system and the second base station can be located within an adjacent cellular communication system. The IoT device can process information, received from the first base station or the second base station, regarding one or more available guard bands. The IoT device can use one or more available resources opportunistically allocated in the one or more guard bands for a set of one or more IoT devices.

[0034] In one aspect, the present technology provides for a base station to communicate with an Internet of things (IoT) device in a cellular communication system. The base station can identify one or more available guard bands used by the base station (the base station itself) and in a second base station, wherein the base station can be in the cellular communication system and the second base station can be located within an adjacent cellular communication system. The base station can process, for transmission to one or more IoT devices, synchronization information and system information (SI) regarding the one or more available guard bands. The base station can allocate one or more available resources in the one or more guard bands for the one or more IoT devices.

[0035] In one aspect, each base station can identify the available DL/UL guard bands for the serving bandwidth of the base station, but information about available DL/UL guard bands for adjacent bandwidth, especially for DL, can be obtained from coordination with base stations of the adjacent bandwidth, such as via X2 interface. For UL case, the base station may measure available guard bands depending on receiver implementation. As alternative, available DL guard bands for other bandwidths as well as current serving bandwidth can be identified via the report to the serving base station from the serving UEs.

[0036] In one aspect, the present technology provides for a base station to communicate

with an Internet of things (IoT) device in a cellular communication system. The base station can identify an occupancy of legacy IoT device “LU” (e.g., a primary device “LU”) bands and one or more available guard bands in the cellular communication system, and identify LU bands and guard bands in an adjacent cellular communication system. The base station can associate one or more channels in the one or more guard bands, having a minimum adjacent channel interference filtering protection (ACIP) value, to occupied LU bands and occupied guard bands. The base station can assign an initial communication channel (ICCH) to the one or more channels in the one or more available guard bands having a maximum ACIP value. The base station can process, for transmission to one or more IoT devices, synchronization information and system information (SI) on the ICCH to enable one or more opportunistic IoT devices (OU) to listen to the ICCH in order to acquire the synchronization information and the SI. The base station can process information, received from the first base station or the second base station, regarding one or more available guard bands. The base station can use one or more available resources opportunistically allocated in the one or more guard bands for a set of one or more IoT devices.

[0037] FIG. 1 illustrates a mobile communication network within a cell 100 having an evolved node B (eNB or eNodeB) with a mobile device. FIG. 1 illustrates an eNB 104 that can be associated with an anchor cell, macro cell or primary cell. Also, the cell 100 can include a mobile device, such as, for example, a User Equipment (UE or UEs) 108 that can be in communication with the eNB 104. The eNB 104 can be a station that communicates with the UE 108 and can also be referred to as a base station, a node B, an access point, and the like. In one example, the eNB 104 can be a high transmission power eNB, such as a macro eNB, for coverage and connectivity. The eNB 104 can be responsible for mobility and can also be responsible for radio resource control (RRC) signaling. The UE or UEs 108 can be supported by the macro eNB 104. The eNB 104 can provide communication coverage for a particular geographic area. In 3GPP, the term “cell” can refer to a particular geographic coverage area of eNB and/or an eNB subsystem serving the coverage area with an associated carrier frequency and a frequency bandwidth, depending on the context in which the term is used.

[0038] FIG. 2 illustrates a diagram of radio frame resources (e.g., a resource grid) for a downlink (DL) transmission including a physical downlink control channel (PDCCH) in

accordance with an example. In the example, a radio frame 200 of a signal used to transmit the data can be configured to have a duration, T_f , of 10 milliseconds (ms). Each radio frame can be segmented or divided into ten subframes 210i that are each 1 ms long. Each subframe can be further subdivided into two slots 220a and 220b, each with a duration, T_{slot} , of 0.5 ms. In one example, the first slot (#0) 220a can include a physical downlink control channel (PDCCH) 260 and/or a physical downlink shared channel (PDSCH) 266, and the second slot (#1) 220b can include data transmitted using the PDSCH.

[0039] Each slot for a component carrier (CC) used by the node and the wireless device can include multiple resource blocks (RBs) 230a, 230b, 230i, 230m, and 230n based on the CC frequency bandwidth. The CC can include a frequency bandwidth and a center frequency within the frequency bandwidth. In one example, a subframe of the CC can include downlink control information (DCI) found in the PDCCH. The PDCCH in the control region can include one to three columns of the first OFDM symbols in a subframe or physical RB (PRB), when a legacy PDCCH is used. The remaining 11 to 13 OFDM symbols (or 14 OFDM symbols, when legacy PDCCH is not used) in the subframe can be allocated to the PDSCH for data (for short or normal cyclic prefix). For example, as used herein, the term 'slot' may be used for 'subframe', or 'transmission time interval (TTI)' can be used for 'frame' or 'frame duration'. In addition, a frame may be considered a user transmission specific quantity (such as a TTI associated with a user and a data flow).

[0040] Each RB (physical RB or PRB) 230i can include 12 subcarriers 236 of 15 kHz subcarrier spacing, for a total of 180 kHz (on the frequency axis) and 6 or 7 orthogonal frequency-division multiplexing (OFDM) symbols 232 (on the time axis) per slot. The RB can use seven OFDM symbols if a short or normal cyclic prefix is employed. The RB can use six OFDM symbols if an extended cyclic prefix is used. The resource block can be mapped to 84 resource elements (REs) 240i using short or normal cyclic prefixing, or the resource block can be mapped to 72 REs (not shown) using extended cyclic prefixing. The RE can be a unit of one OFDM symbol 242 by one subcarrier (i.e., 15 kHz) 246.

[0041] Each RE can transmit two bits 250a and 250b of information in the case of quadrature phase-shift keying (QPSK) modulation. Other types of modulation can be used, such as 16 quadrature amplitude modulation (QAM) to transmit 4 bits per RE or 64

QAM to transmit six bits in each RE, or bi-phase shift keying (BPSK) modulation to transmit a lesser number of bits (a single bit) in each RE. The RB can be configured for a downlink transmission from the eNodeB to the UE, or the RB can be configured for an uplink transmission from the UE to the eNodeB.

5 [0042] In one aspect, a wireless service can be deployed with one or more GBs used to minimize the OOB emission to other adjacent licensed frequency spectrums. For example, for a 10 MHz 3GPP LTE deployment, the GBs can span up to 1MHz at the edge of frequency bands. In such a deployment, one of the two GBs can be sub-divided into several NB channels (N_i) where $i = A, B$, and A and B designate GBs around an
10 associated LU band for a cellular System A and System B (as shown in FIG. 3). The NB channels in the subdivided GB can be supported by the base station (BS) to accommodate communication by several low-throughput, low-power, delay-tolerant devices as illustrated in FIG. 3.

[0043] FIG. 3 provides an example illustration of a block diagram 300 of a downlink
15 (DL) legacy (primary) user spectrum and guard band for two adjacent cellular systems. As such, the present technology allows opportunistic communications over vacant GBs with an intelligent assistance from a BS by periodically identifying and updating the set of vacant channels over which ensure that no harmful interference is imparted to the LUs. It should be noted that the OUs can communicate with the same legacy BS (e.g., an eNB
20 as defined in 3GPP LTE releases 8, 9, 10, 11, and/or 12) without the need to deploy additional base stations to provide the extra bandwidth that is obtained in the NB channels in the GB.

[0044] In one aspect (e.g., option 1), the present technology provides for a first
25 embodiment having the associated channels and signaling procedures, as described herein. In one aspect, the OUs can be constrained to identify and know an initial communication channel (ICCH) to achieve synchronization and obtain the system information (SI) broadcast by the BS. The ICCH can be allocated among one or more available vacant channels in such a way that the OOB interference generated by the OU link to the LU link of the same system and the OU link to the LU link of a neighboring
30 system is minimized. For example, the BS can select a channel which incurs a minimum average interference to the LUs of the BS's system and the LUs and OUs of the

neighboring systems (e.g., an adjacent or neighboring cellular system) over a predefined or selected time interval. While examples are provided of a single adjacent BS, this is not intended to be limiting. Interference may be taken into account for multiple adjacent base stations, and the associated LUs and OUs. In one aspect, the one or more sub-procedures
5 can be used to identify the channel that would generate the minimum harmful interference out of the NB channels in the GB.

[0045] In one aspect, the channel with the least interference can be the threshold value for the minimum value of interference. In one aspect, after identifying the channel with least interference, then the channel can be assigned if the interference due to assigning the
10 channel is not impact on the current LU and existing OUs.

[0046] In one aspect, the sub-procedures can include each of the following. For example, the BS can identify the occupancy (presence/absence of the corresponding LUs and/or OUs) of three bands: (i) the nearest GB of the neighboring system, (ii) the LU band of the nearest neighboring system, and (iii) the LU band of the BS's system. The
15 presence/absence of interference can be identified by using, for example, an energy detector. The adjacent channel interference filtering protection (ACIP) can be calculated for one or more of the bands (e.g., the three bands). The ACIP can depend upon the frequency separation of the bands, as depicted in FIG 4, which depicts a graph 400 of an adjacent channel interference filtering protection (ACIP). In one aspect, the ACIP can be
20 the filtering gain against neighboring frequencies. In particular, when a filter tuned to a certain frequency is applied, the amplitude of the signals transmitted on the frequency can be preserved, whereas the magnitude of the signals of all the other bands can be attenuated. The ratio of this attenuation to the gain of the tuned frequency can be called the adjacent channel interference protection. It should be noted that this protection can
25 depend on the frequency separation. The further the frequency band from the desired frequency of the filter can increase its attenuation thus increasing the ACIP. In one aspect, each channel number (CN) can be associated with/to a minimum of the ACIPs of the occupied bands of the three measured bands. The ICCH can be assigned to the band with the maximum ACIP.

30 **[0047]** For detected interference levels and selection of a band/NB channel based on the detected interference levels consider an example. Consider system X with two guard band

channels A and B. Now assume an energy detector is used to identify the occupancy of three bands: 1) the nearest GB of the neighboring systems, 2) the nearest LU band of the neighboring systems, and 3) the LU band of system X. Now assume that the GB of the nearest neighbor, referred to as band C, is occupied. Furthermore, assume that LU band of the neighbor is unoccupied, by the LU band of system X is occupied, referred to as band D. Now system X evaluates the ACIP between channel A and the two bands C and D (e.g., ACIPAC and ACIPAD) and assigns the lowest of the two to channel A. Similarly system X evaluates the ACIP between channel B and two bands C and D (e.g., ACIPBC and ACIPCD) and assigns the lowest of the two to channel B. In this example, consider that channel A has a higher ACIP. In this case, system X can assign the ICCH to channel A since it is further away from the neighboring bands and thus provides a higher filtering protection.

[0048] The BS can transmit synchronization signals frequently (e.g., periodically transmit) so that OUs can synchronize with the system. The synchronization signal can be transmitted either on the ICCH and/or on a dedicated channel for synchronization. After listening to the synchronization signals by one or more OUs, the one or more OUs can be aligned with a DL multi-frame / frame/ sub-frame / time-slot of the system.

[0049] Alternatively, the BS can be configured to not transmit the ICCH in the guard band. In such a case, the BS can send the system information (SI) in a broadcast channel of the LUs' bandwidth. Subsequently, the OUs can be constrained to receive the synchronization signal and the broadcasted system information in the LUs' system bandwidth to be synchronized and acquire the LUs' system information.

[0050] After achieving synchronization, the OUs can receive broadcast Information, such as, for example, Opportunistic Communication System Information (OC-SI), which can carry critical SI messages to perform the Opportunistic Communication (OC). In one aspect, the features of OC-SI can be defined as follows. In one aspect, the OC-SI can be constrained to be periodically broadcast on the ICCH where the OC-SI's periodicity can be pre-determined and/or configured to accommodate users experiencing severe signal attenuation. One or more transmission parameters (e.g. exact frame, sub-frame, slot info, modulation/coding info) of the OC-SI can be predefined, identified, and known by/to the OUs and BS.

[0051] Similarly, in the alternative case in which the OUs acquire the system information and the synchronization from the LU's band, the synchronization and system information can be periodically transmitted on the synchronization and/or broadcast channels. In one aspect, information carried in the OC-SI can include 1) the channel numbers (CNs) of the best available channels (BACs) of the NB channels, 2) the UL and DL channels' bands information can be included, and the UL and DL channels' bands information can be calculated by the BS in such a way that the communication over these channels impart minimal interference to the LUs of its system as well as the LUs and OUs of its neighboring bands, as previously discussed. It should be noted that a list of the BACs can be ordered with respect to the OOB radiation values. In one example, the list can be organized in descending order, wherein the channel resulting in the least OOB radiation can be listed first, following a same procedure for ACIP based selection of the CN for ICCH assignment.

[0052] If the BS detects that an interference is equal to /or greater than a defined threshold observed in a GB channel (OOB emissions) because too many users are attempting access, the BS can send a probability of admission (PA) parameter on the OC-SI to reduce the congestion and reject the extra users to provide the protection for the LU. In this case, the OUs attempting access can generate a uniformly distributed random variable between 0 and 1 and can select to enter the system only if the outcome is less than the PA.

[0053] Furthermore, the PA can also be used for access barring. In other words, if the PA is less than a selected threshold, then one or more OUs can consider it (the PA) as access barring where the threshold is predetermined. It should be noted that the PA parameter can be based on the following three values: 1) a current intra-OU interference level measured by the BS, 2) an additional interference margin to provide extra protection for the system's LUs as well as the neighboring systems' LUs and OUs, and/or 3) an ACIP due to the frequency separation (i.e., filtering protection).

[0054] To reduce the congestion among the OUs, the BS can send the probabilities of channel selection, with each PA corresponding to one of the BACs. In this case, the device can select a uniformly distributed random variable between 0 and 1 and according to the output, the OU can select one of the available BACs. This can allow the BS

increased control on the number of devices attempting communication on each of the BACs and thus control the probability of collisions among the OUs and the OOB emissions to the LUs. The BACs selection probability can be included in the SI transmitted on the ICCH.

5 **[0055]** In one aspect, based on the number of OUs, the BS can elect to work either in a contention-based mode and/or a contention-free mode for UL transmissions. In the contention-based mode, one or more OU devices can randomly access the available resources on the UL channel using a contention-based access scheme, (e.g., slotted ALOHA or a carrier sense multiple access “CSMA” variant). In this case, the constraint
10 for resource scheduling by the BS can be eliminated.

[0056] In the contention-free mode, after performing the initial attachment procedure, the OUs can listen to a predefined opportunistic user control channel (OUCCH) over which the physical resources allocated for each of the devices can be assigned. It should be noted that the physical resources can be defined based on the underlying multiple
15 access scheme of the OU system (e.g., time-slots “TDMA system”, sub-channels FDMA).

[0057] In one aspect, the OU, on reception of the resource assignment on the DL-OUCCH, can send the OU’s packets on the UL-OUDCH and can wait for acknowledgment/negative acknowledgement (ACK/NACK), if necessary, depending upon the communication mode. In one aspect, for the Acknowledged UL transmission
20 mode, the BS can transmit the ACK/NACK response on the OUCCH. In this case, the OUs can either continuously monitor the OUCCH for an ACK/NACK, and/or the OU can wake-up after a predefined number of time-slots and listen to the OUCCH for the ACK/NACK packet.

[0058] In one aspect, in order to reduce the signaling overhead, the BS can elect to
25 schedule the resources (e.g., conservatively schedule) to mitigate degradation in the link quality, such as, for example, by using a lower modulation scheme than can be supported by the current link quality (e.g., such as by using a binary phase-shift keying “BPSK” rather than an 8-phase shift keying 8-PSK).

[0059] In an additional aspect (e.g., option 2), the present technology provides for a
30 second embodiment that can aggregate multiple BACs. These aggregated BACs can either belong to the same system’s GBs (within the same band) or to disparate systems’

GBs (across different bands). Option 2 can provide for: 1) some users which may have larger data volumes to report to the BS (for instance, OU gateways) which can collect and report a massive number of IoT data, such as the smart meter readings in a factory setting that would mandate faster reporting, and thus demand a higher throughput), 2) further
 5 enhance the spectral utilization efficiency in order to accommodate more OUs (due to additional spectrum availability), and 3) reduce the inter-OUs interference by dispersing the OUs across multiple frequency bands.

[0060] FIG. 5 illustrates a block diagram 500 of an intra-system carrier aggregation and inter-system carrier aggregation in accordance with an example. In one aspect, in a 10 MHz 3GPP LTE deployment, for example, the GBs can span up to 1MHz at the edge of frequency bands. In such a deployment, one of the two GBs can be sub-divided into several NB channels (n_i) where $i = A, B$ (as shown in FIG. 5) by the base station (BS) to accommodate several low-throughput, low-power, delay-tolerant devices as illustrated in FIG. 5. As illustrated, an intra-system carrier aggregation can include the NB channels
 15 (n_A) and an inter-system carrier aggregation that can include one or more of the NB channels (n_A) and the NB channels (n_B). As such, the present technology allows opportunistic communications with over vacant GBs from a BS by identifying the vacant channels from NB channels (n_A) in the intra-system carrier aggregation and/or vacant channels from the NB channels (n_A) and the NB channels (n_B) in the inter-system carrier
 20 aggregation, and also ensuring that no harmful interference is imparted to the LUs.

[0061] More specifically, consider the two systems, System A and System B, operating in FIG. 5, where each system has n_A and n_B available BACs. Based on the desired bandwidth, the BACs within a system (intra-system aggregation) or across the two systems (inter-system aggregation) can be applied. Thus, to support the aforementioned
 25 motivations, any combination of the following procedures can be undertaken. In one aspect, aggregation within the same system's GBs (intra-system aggregation), the base station can identify all the available BACs. The base station can aggregate the needed number of BACs. The base station can send its updated BACs list (CNs) to the OUs. For aggregation across multiple systems' GBs (inter-system aggregation), the base station can
 30 identify all the available BACs across multiple systems by coordinating with other systems' base stations using, for example, an X2 connection. In this case, the base station can request the available BACs from the other BSs. The base station can wait for the

BACs to be granted from the other BSs. The base station can aggregate the needed number of BACs. The base station can update the BACs list (CNs) to the OUs.

[0062] In an additional aspect (e.g., option 3), the present technology provides for a third embodiment that can provide dynamic adaptation to the allocation of the OU channels, where, in particular, an available set of BACs can be allocated for data transmission (i.e., the OUDCHs can be dynamically allocated, especially towards the edge of the GBs, depending upon the traffic load in the neighboring LU band and OU GB, such as, for example, the LU band and OU GB of system B).

[0063] Option 3 can accommodate more OUs by further minimizing the OOB interference thereby further enhancing the spectral utilization efficiency, and reducing the interference to the LUs by increasing the adjacent channel interference protection due to larger frequency separation between the LUs' bands and the channels allocated for OUs. For example, if the number of LUs in the neighboring LU bands are significantly less (especially, around a weekday midnight, the number of users in the LU bands could be much lower). In such cases, more number of OUDCHs could be allocated towards the GB edges which may not be possible say, during the busy hours of the LU users. The ability to allocate bandwidth near the GB edges can enable the implementation of a dynamic BAC allocation scheme at the BS. In option 3, the base station can identify the OU and LU loads of its neighboring system using, for example, an energy detector. If the neighboring system is lightly loaded (e.g., a traffic load at or below a selected traffic load threshold), the base station can adjust its BACs such that it minimizes the OOB emission to its LU band. To do so, the base station can elect to move the additional OUs towards the edge of the BS's GBs.

[0064] FIG. 6 illustrates a flow chart 600 of an aggregation procedure for a base station (BS) within one or more guard bands of the same system. The functionality 600 can be implemented as a method or the functionality 600 can be executed as instructions on a machine, where the instructions can include one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums. The functionality 600 can comprise one or more processors and memory configured to: search for all available best available channels (BAC) within a system, as in block 610. The functionality 600 can comprise one or more processors and memory configured to:

aggregate a number of BACs (e.g., a needed number of BAC), as per requested data rate, as in block 620. The functionality 600 can comprise one or more processors and memory configured to: update channel numbers (CN) to opportunistic users (OU), as in block 630.

[0065] FIG. 7 illustrates a flow chart 700 of an aggregation procedure for a base station (BS) within a guard band of a different system. The functionality 700 can be implemented as a method or the functionality 700 can be executed as instructions on a machine, where the instructions can include one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums. The functionality 700 can comprise one or more processors and memory configured to: execute (X2) based signaling (e.g., base station-to-base station signaling) to identify one or more best available channels (BAC), which are available for use, as in block 710. In one aspect, the BAC can be defined as channels that have the least amount of interference (e.g., below a selected interference threshold). The functionality 700 can comprise one or more processors and memory configured to request access to additional (e.g., new) best available channel(s) from a host base station (BS), as in block 720. The functionality 700 can comprise one or more processors and memory configured to: determine if access to a host base station (e.g., host of the IoT device) has been granted, as in block 730. If no, the functionality can return to block 720. If yes, the functionality 700 can comprise one or more processors and memory configured to: aggregate a number of BACs (e.g., a needed number of BAC), as per user requested data rate), as in block 740. The functionality 700 can comprise one or more processors and memory configured to: update channel numbers (CN) to the opportunistic users (OU), as in block 750.

[0066] FIGs. 8A-8B illustrate a flow chart 800 of opportunistic guard band access in a wireless communication network, such as, for example, a third generation partnership project (3GPP) fifth generation (5G) wireless communication network. The functionality 800 can be implemented as a method or the functionality 800 can be executed as instructions on a machine, where the instructions can include one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums. The functionality 800 can comprise one or more processors and memory configured to: identify, by a base station (BS), an occupancy of a legacy user (LU) band of the base station, an adjacent system LU band, and a guard band (GB), as in block 802. The functionality 800 can comprise one or more processors and memory configured to:

calculate an adjacent channel interference filtering protection (ACIP) between the occupied bands and the guard band, as in block 804. The functionality 800 can comprise one or more processors and memory configured to: associate each channel in the GB with a minimum ACIP value to an occupied band, as in block 806. It should be noted that if
5 there are no occupied bands, a maximum ACIP value can be selected. The functionality 800 can comprise one or more processors and memory configured to: determine if the BS has allocated initial communication channel(s) (ICCH), as in block 808. If no, the functionality 800 can comprise one or more processors and memory configured to: listen to a synchronization channel, by the OU, in the LU band and listen to the LU to acquire the SI, as in block 818. From block 818, the functionality 800 can comprise one or more
10 processors and memory configured to: send to an opportunistic user (OU), such as an opportunistic IoT device, by the base station, system information (SI) in the LU band, such as by using a broadcast channel, as in block 820. Returning to block 808, if the ICCH(s) is allocated, the functionality 800 can comprise one or more processors and
15 memory configured to: assign the ICCH to a channel in the GB having a maximum ACIP value, as in block 810.

[0067] The functionality 800 in FIG. 8 can further comprise one or more processors and memory configured to: transmit (e.g., periodically transmit at selected times), synchronization and system information on the ICCH, as in block 812. The functionality
20 800 can comprise one or more processors and memory configured to: listen to the ICCH by an OU to acquire the SI, as in block 814. From block 814 or from block 820, the functionality 800 can comprise one or more processors and memory configured to: acquire, by one or more OUs, an ordered list of the BACs in the GB with respect to the out of band (OOB) emissions based on the ACIP, as in block 816. The functionality 800
25 can comprise one or more processors and memory configured to: determine if probability of admission (PA) parameter(s) exist in the SI, as in block 819. If yes, the functionality 800 can comprise one or more processors and memory configured to: select, by each OU, a random number (RA) between 0 and 1, as in block 821. The functionality 800 can comprise one or more processors and memory configured to: determine if the random
30 number (RA) is less than and/or equal to the PA parameter, as in block 821. If yes, the functionality 800 can move to block 828. If no, the functionality 800 can comprise one or more processors and memory configured to: prevent transmission from an OU having the

RA less than the value of the PA parameter, as in block 824.

[0068] Returning to block 819, if there are no PA parameter(s) in the SI, the functionality 800 can comprise one or more processors and memory configured to: determine if there are probabilities assigned to the BAC(s), as in block 828. If no, the
5 functionality 800 can comprise one or more processors and memory configured to: select a first probability, as in block 830. If yes, the functionality 800 can comprise one or more processors and memory configured to: generate a between 0 and 1 and select the BAC to transmit, as in block 832. From both blocks 830 and 832, the functionality 800 can
10 comprise one or more processors and memory configured to: determine if the base station of the IoT device is operating in a contention mode, as in block 834. That is, the contention mode can be, for example, when the BS is configured to allow the OU to try (e.g., contend) to communicate via the GB without being assigned an UL grant. If no, the
15 functionality 800 can comprise one or more processors and memory configured to: listen to a predefined opportunistic user control channel (OUCCH) to acquire an uplink (UL) grant, as in block 836. If yes, the functionality 800 can comprise one or more processors and memory configured to: transmit the data, as in block 838. That is, the OU can transmit the data since the OU will be able to communicate if the OU selects an RA less than the PA. The OU can also transmit given the OU listens to the OUCCH to acquire the UL grant.

20 [0069] Another example provides functionality 900 of base station to perform opportunistic guard band access with an opportunistic user, such as within a third generation partnership project (3GPP) fifth generation (5G) communication network, as shown in the flow chart in FIG. 9. The functionality 900 can be implemented as a method or the functionality can be executed as instructions on a machine, where the
25 instructions can include one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums.

[0070] The base station can comprise one or more processors and memory configured to: identify one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular
30 communication systems includes the cellular communication system and an adjacent cellular communication system, as in block 910. That is, each base station can identify

the available DL/UL guard bands for its serving bandwidth, but information about available DL/UL guard bands for adjacent bandwidth, especially for DL, can be obtained from the coordination with their base stations, such as via X2 interface. For UL case, the base station may measure available guard bands depending on receiver
5 implementation. As alternative, available DL guard bands for other bandwidths as well as current serving bandwidth can be identified via the report to the serving base station from the serving UEs.

[0071] The base station can comprise one or more processors and memory configured to: process information, received from the one or more cellular
10 communication systems, to select a channel in a plurality of best available channels in the one or more available guard bands based on interference measurements in the one or more available guard bands, as in block 920. The base station can comprise one or more processors and memory configured to: communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the
15 one or more available guard bands based on the interference measurements, as in block 930.

[0072] Another example provides functionality 1000 of a an intent of things (IoT) device for performing opportunistic guard band access within a wireless communication network within a wireless communication network, as shown in the
20 flow chart in FIG. 10. The functionality 1000 can be implemented as a method or the functionality can be executed as instructions on a machine, where the instructions are included on one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums. The IoT device can comprise one or more processors and memory configured to: monitor an initial communication channel
25 (ICCH) for synchronization and system information (SI) communicated from the base station, as in block 1010.

[0073] The IoT device can comprise one or more processors and memory configured to: decode the system information to determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular
30 communication systems, as in block 1020. The IoT device can comprise one or more processors and memory configured to: Communicate control information and data in

the best available channel in the one or more available guard bands to the one or more cellular communication systems, as in block 1030.

[0074] Another example provides functionality 1100 of a base station to perform opportunistic guard band access within wireless communication network (e.g., a third generation partnership project (3GPP) fifth generation (5G) wireless communication network), as shown in the flow chart in FIG. 11. The functionality 1100 can be implemented as a method or the functionality can be executed as instructions on a machine, where the instructions are included on one or more computer readable mediums or one or more transitory or non-transitory machine readable storage mediums. The base station can comprise one or more processors and memory configured to: identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system, as in block 1110. The base station can comprise one or more processors and memory configured to process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands, as in block 1120. The base station can comprise one or more processors and memory configured to: associate one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands, as in block 1130. The base station can comprise one or more processors and memory configured to: assign an initial communication channel (ICCH) to the one or more channels in the one or more guard bands having a maximum ACIP value, as in block 1140. The base station can communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices, as in block 1150.

[0075] FIG. 12 illustrates a diagram of example components of a User Equipment (UE) device in accordance with an example. Fig. 12 illustrates, for one aspect, example components of a User Equipment (UE) device 1200. In some aspects, the UE device 1200 can include application circuitry 1202, baseband circuitry 1204, Radio Frequency (RF) circuitry 1206, front-end module (FEM) circuitry 1208 and one or more antennas

1210, coupled together at least as shown.

[0076] The application circuitry 1202 can include one or more application processors. For example, the application circuitry 1202 can include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) can include any
5 combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors can be coupled with and/or can include memory/storage and can be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

10 [0077] The processor(s) can include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors can be coupled with and/or can include a storage medium 1212, and can be configured to execute instructions stored in the storage medium 1212 to enable various applications and/or operating systems to run on the system.

15 [0078] The baseband circuitry 1204 can include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1204 can include one or more baseband processors and/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
20 1204 can 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 aspects, the baseband circuitry 1204 can include a second generation (2G) baseband processor 1204a, third generation (3G) baseband processor 1204b, fourth generation (4G) baseband processor 1204c, and/or other baseband processor(s) 1204d for
25 other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1204 (e.g., one or more of baseband processors 1204a-d) can handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1206. The radio control functions can include, but are not limited to, signal
30 modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some aspects, modulation/demodulation circuitry of the baseband circuitry 1204 can include

Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some aspects, encoding/decoding circuitry of the baseband circuitry 1204 can include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Aspects of modulation/demodulation and encoder/decoder functionality are not limited to these examples and can include other suitable functionality in other aspects.

[0079] In some aspects, the baseband circuitry 1204 can include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 1204e of the baseband circuitry 1204 can be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some aspects, the baseband circuitry can include one or more audio digital signal processor(s) (DSP) 1204f. The audio DSP(s) 1204f can include elements for compression/decompression and echo cancellation and can include other suitable processing elements in other aspects. Components of the baseband circuitry can be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some aspects. In some aspects, some or all of the constituent components of the baseband circuitry 1204 and the application circuitry 1202 can be implemented together such as, for example, on a system on a chip (SOC).

[0080] In some aspects, the baseband circuitry 1204 can provide for communication compatible with one or more radio technologies. For example, in some aspects, the baseband circuitry 1204 can support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Aspects in which the baseband circuitry 1204 is configured to support radio communications of more than one wireless protocol can be referred to as multi-mode baseband circuitry.

[0081] RF circuitry 1206 can enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various aspects, the RF circuitry 1206 can include switches, filters, amplifiers, etc. to facilitate the

communication with the wireless network. RF circuitry 1206 can include a receive signal path which can 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 can also include a transmit signal path which can 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.

[0082] In some aspects, the RF circuitry 1206 can include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1206 can include mixer circuitry 1206a, amplifier circuitry 1206b and filter circuitry 1206c. The transmit signal path of the RF circuitry 1206 can include filter circuitry 1206c and mixer circuitry 1206a. RF circuitry 1206 can 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 aspects, the mixer circuitry 1206a of the receive signal path can 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 can be configured to amplify the down-converted signals and the filter circuitry 1206c can 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 can be provided to the baseband circuitry 1204 for further processing. In some aspects, the output baseband signals can be zero-frequency baseband signals, although the output baseband signals do not have to be zero-frequency baseband signals. In some aspects, mixer circuitry 1206a of the receive signal path can comprise passive mixers, although the scope of the aspects is not limited in this respect.

[0083] In some aspects, the mixer circuitry 1206a of the transmit signal path can 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 can be provided by the baseband circuitry 1204 and can be filtered by filter circuitry 1206c. The filter circuitry 1206c can include a low-pass filter (LPF), although the scope of the aspects is not limited in this respect.

[0084] In some aspects, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path can include two or more mixers and can

be arranged for quadrature downconversion and/or upconversion respectively. In some aspects, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path can include two or more mixers and can be arranged for image rejection (e.g., Hartley image rejection). In some aspects, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a can be arranged for direct downconversion and/or direct upconversion, respectively. In some aspects, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path can be configured for super-heterodyne operation.

[0085] In some aspects, the output baseband signals and the input baseband signals can be analog baseband signals, although the scope of the aspects is not limited in this respect. In some alternate aspects, the output baseband signals and the input baseband signals can be digital baseband signals. In these alternate aspects, the RF circuitry 1206 can include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1204 can include a digital baseband interface to communicate with the RF circuitry 1206.

[0086] In some dual-mode embodiments, a separate radio IC circuitry can be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[0087] In some embodiments, the synthesizer circuitry 1206d can 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 can be suitable. For example, synthesizer circuitry 1206d can be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0088] The synthesizer circuitry 1206d can 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 circuitry 1206d can be a fractional $N/N+1$ synthesizer.

[0089] In some embodiments, frequency input can be provided by a voltage controlled oscillator (VCO), although that is not a constraint. Divider control input can 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 (e.g., N) can be

determined from a look-up table based on a channel indicated by the applications processor 1202.

[0090] Synthesizer circuitry 1206d of the RF circuitry 1206 can include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider can be a dual modulus divider (DMD) and the phase accumulator can be a digital phase accumulator (DPA). In some embodiments, the DMD can 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 can 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 can be configured to break a VCO period up into Nd equal packets of phase, where Nd 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.

[0091] In some embodiments, synthesizer circuitry 1206d can be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency can 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 can be a LO frequency (fLO). In some embodiments, the RF circuitry 1206 can include an IQ/polar converter.

[0092] FEM circuitry 1208 can include a receive signal path which can 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 can also include a transmit signal path which can include circuitry configured to amplify signals for transmission provided by the RF circuitry 1206 for transmission by one or more of the one or more antennas 1210.

[0093] In some embodiments, the FEM circuitry 1208 can include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry can include a receive signal path and a transmit signal path. The receive signal path of the

FEM circuitry can include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1206). The transmit signal path of the FEM circuitry 1208 can include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1206), and one or more
5 filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1210).

[0094] In some embodiments, the UE device 1200 can include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

10 [0095] FIG. 13 illustrates a diagram of a wireless device (e.g., UE) in accordance with an example. FIG. 13 provides an example illustration of the wireless device, such as a user equipment (UE) UE, a mobile station (MS), a mobile wireless device, a mobile communication device, a tablet, a handset, or other type of wireless device. In one aspect, the wireless device can include at least one of an antenna, a touch sensitive display
15 screen, a speaker, a microphone, a graphics processor, a baseband processor, an application processor, internal memory, a non-volatile memory port, and combinations thereof.

[0096] The wireless device can include one or more antennas configured to communicate with a node or transmission station, such as a base station (BS), an evolved
20 Node B (eNB), a baseband unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a relay station (RS), a radio equipment (RE), a remote radio unit (RRU), a central processing module (CPM), or other type of wireless wide area network (WWAN) access point. The wireless device can be configured to communicate using at least one wireless communication standard including 3GPP LTE, WiMAX, High Speed
25 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 mobile device can include a storage medium. In one aspect, the storage
30 medium can be associated with and/or communicate with the application processor, the graphics processor, the display, the non-volatile memory port, and/or internal memory. In

one aspect, the application processor and graphics processor are storage mediums.

[0097] FIG. 14 illustrates a diagram 1400 of a node 1410 (e.g., eNB and/or a base station) and wireless device (e.g., UE) in accordance with an example. The node can include a base station (BS), a Node B (NB), an evolved Node B (eNB), a baseband unit (BBU), a remote radio head (RRH), a remote radio equipment (RRE), a remote radio unit (RRU), or a central processing module (CPM). In one aspect, the node can be a Serving GPRS Support Node. The node 1410 can include a node device 1412. The node device 1412 or the node 1410 can be configured to communicate with the wireless device 1420. The node device 1412 can be configured to implement the technology described. The node device 1412 can include a processing module 1414 and a transceiver module 1416. In one aspect, the node device 1412 can include the transceiver module 1416 and the processing module 1414 forming a circuitry 1418 for the node 1410. In one aspect, the transceiver module 1416 and the processing module 1414 can form a circuitry of the node device 1412. The processing module 1414 can include one or more processors and memory. In one embodiment, the processing module 1422 can include one or more application processors. The transceiver module 1416 can include a transceiver and one or more processors and memory. In one embodiment, the transceiver module 1416 can include a baseband processor.

[0098] The wireless device 1420 can include a transceiver module 1424 and a processing module 1422. The processing module 1422 can include one or more processors and memory. In one embodiment, the processing module 1422 can include one or more application processors. The transceiver module 1424 can include a transceiver and one or more processors and memory. In one embodiment, the transceiver module 1424 can include a baseband processor. The wireless device 1420 can be configured to implement the technology described. The node 1410 and the wireless devices 1420 can also include one or more storage mediums, such as the transceiver module 1416, 1424 and/or the processing module 1414, 1422. In one aspect, the components described herein of the transceiver module 1416 can be included in one or more separate devices that may used in a cloud-RAN (C-RAN) environment

Examples

[0099] The following examples pertain to specific invention embodiments and point out

specific features, elements, or steps that can be used or otherwise combined in achieving such embodiments.

[00100] Example 1 includes an apparatus of a base station, the base station configured to communicate with an internet of things (IoT) device in a cellular communication system, the apparatus comprising one or more processors and memory configured to: identify one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more available guard bands based on interference measurements in the one or more available guard bands; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements.

[00101] Example 2 includes the apparatus of example 1, wherein the one or more processors and memory are further configured to identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users.

[00102] Example 3 includes the apparatus of example 2, wherein the one or more processors and memory are further configured to: calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system; or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00103] Example 4 includes the apparatus of example 1 or 3, wherein the one or more processors and memory are further configured to detect the presence or absence of one or more legacy users (LU) or one or more opportunistic users (OU) of the adjacent cellular

communication system using an energy detector.

[00104] Example 5 includes the apparatus of example 4, wherein the one or more processors and memory are further configured to assign an initial communication channel (ICCH) to the band in the group of bands having a maximum ACIP value.

5 [00105] Example 6 includes the apparatus of example 1 or 5, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using an initial communication channel (ICCH).

[00106] Example 7 includes the apparatus of example 6, wherein the one or more
10 processors and memory are further configured to set a periodicity of the broadcast for the SI based on signal attenuation experienced by one or more opportunistic users (OU) experiencing.

[00107] Example 8 includes the apparatus of example 7, wherein the ICCH enables the
15 one or more opportunistic users (OU) to: listen to the ICCH in the one or more available guard bands to synchronize and decode the SI; or listen to synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more guard bands.

[00108] Example 9 includes the apparatus of example 1 or 8, wherein the SI contains a
list of best available channels (BACs), wherein the BACs are channels in the one or more
20 available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00109] Example 10 includes the apparatus of example 1, wherein the one or more
processors and memory are further configured communicate, to the IoT device, an
25 admission parameter in the SI to limit a number of simultaneous access attempts the BACs by one or more opportunistic users (OU).

[00110] Example 11 includes the apparatus of example 1 or 10, wherein the admission parameter represents a probability the one or more opportunistic users (OU) attempts to access the cellular communication system.

30 [00111] Example 12 includes the apparatus of example 1, wherein the selected channel

is a opportunistic user control channel (OUCCH), an opportunistic user data channel (OUDCH), and initial communication channel (ICCH), and wherein the base station communicates with a second base station in the adjacent communication system using an X2 communication interface.

5 [00112] Example 13 includes the apparatus of example 1, wherein the base station is configured to enable the one or more opportunistic users (OU) to operate in a contention-based mode, a contention-free mode, an acknowledged communication mode.

[00113] Example 14 includes the apparatus of example 1 or 13, wherein in the contention based mode, the one or more opportunistic users (OU) access the system
10 resources broadcasted in the ICCH or broadcasted in the broadcast channel of the LU bands without a priori scheduling by the base station, and wherein in the contention free mode, the OUs perform initial attachment for system admission using an access scheme and the OUs listen to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the one or more opportunistic users (OU)
15 is accepted by the base station.

[00114] Example 15 includes the apparatus of example 1, wherein the one or more processors and memory are further configured to communicate resource assignments on a downlink (DL) opportunistic user control channel (OUCCH) and communicate an acknowledgment/negative acknowledgement (ACK/NACK) on an uplink (UL)
20 opportunistic user control data channel (OUDCH).

[00115] Example 16 includes the apparatus of example 1 or 15, wherein in the acknowledged communication mode, the base station selects to transmit an acknowledgement packet after a selected number of time slots to allow the one or more opportunistic users (OU) to enter into a sleep mode.

25 [00116] Example 17 includes the apparatus of example 1, wherein the one or more processors and memory are further configured to aggregate one or more of the plurality of BACs to provide a selected communication bandwidth, wherein each of the aggregated BAC of the plurality of BACs are selected from guard bands of the cellular communication system or are selected from a plurality of cellular communication systems
30 from the one or more cellular communication systems.

[00117] Example 18 includes an apparatus of an internet of things (IoT) device, the IoT

device configured to communicate with a base station in a cellular communication system, the apparatus comprising one or more processors and memory configured to: monitor an initial communication channel (ICCH) for synchronization and system information (SI) communicated from the base station; decode the system information to
5 determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular communication systems; and communicate control information and data in the best available channel in the one or more available guard bands to the one or more cellular communication systems.

10 **[00118]** Example 19 includes the apparatus of example 18, wherein the ICCH is located in a guard band or a legacy user (LU) band.

[00119] Example 20 includes the apparatus of example 18, wherein the one or more processors and memory are further configured to monitor synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more available guard bands.

15 **[00120]** Example 21 includes the apparatus of example 18, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

20 **[00121]** Example 22 includes the apparatus of example 18 or 21, wherein the one or more processors and memory are further configured process an admission parameter, received from the base station, in the SI to limit a number of access attempts to the BACs, and the admission parameter represents a probability the IoT device attempts to access the cellular communication system, wherein the IoT device is an opportunistic user.

25 **[00122]** Example 23 includes the apparatus of example 18, wherein the IoT device is configured to operate in a contention-based mode, a contention-free mode, or an acknowledged communication mode.

[00123] Example 24 includes the apparatus of example 18 or 23, wherein in the contention based mode, the IoT device accesses system resources broadcasted in the
30 ICCH or broadcasted in the broadcast channel of legacy user (LU) bands without a priori scheduling by the base station, and wherein in the contention free mode, the IoT device

performs initial attachment for system admission using an access scheme and the IoT device listens to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the IoT device is accepted by the base station.

[00124] Example 25 includes the apparatus of example 18, wherein the one or more
5 processors and memory are further configured to: process resource assignments, received from the base station, in a downlink (DL) opportunistic user control channel (OUCCH); and communicate an acknowledgment/negative acknowledgement (ACK/NACK) in an uplink (UL) opportunistic user control data channel (OUDCH).

[00125] Example 26 includes the apparatus of example 18 or 25, wherein in the
10 acknowledged communication mode, process an acknowledgement packet, received from the base station after a selected number of time slots, to allow the IoT device to enter into a sleep mode.

[00126] Example 27 includes at least one machine readable storage medium having instructions embodied thereon for a base station to communicate with an internet of
15 things (IoT) device in a cellular communication system, the instructions when executed cause the base station to: identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more
20 cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands; associate one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands; assign an initial communication channel (ICCH) to
25 the one or more channels in the one or more guard bands having a maximum ACIP value; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

[00127] Example 28 includes the at least one machine readable storage medium of
30 example 27, further comprising instructions which when executed cause the base station

to: identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; and calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system; or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00128] Example 29 includes the at least one machine readable storage medium of example 28, further comprising instructions which when executed cause the base station to: identify available downlink (DL) guard bands and available uplink (UL) guard bands; or obtain available DL guard bands and UL guard bands from an alternative base station, wherein the base station communicates the alternative base station via an X2 communication interface.

[00129] Example 30 includes the at least one machine readable storage medium of example 28, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using the ICCH, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00130] Example 31 includes an apparatus of a base station, the base station configured to communicate with an internet of things (IoT) device in a cellular communication system, the apparatus comprising one or more processors and memory configured to: identify one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more cellular

communication systems, to select a channel in a plurality of best available channels in the one or more available guard bands based on interference measurements in the one or more available guard bands; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements.

[00131] Example 32 includes the apparatus of example 31, wherein the one or more processors and memory are further configured to identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users.

[00132] Example 33 includes the apparatus of example 32, wherein the one or more processors and memory are further configured to: calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system; or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00133] Example 34 includes the apparatus of example 33, wherein the one or more processors and memory are further configured to detect the presence or absence of one or more legacy users (LU) or one or more opportunistic users (OU) of the adjacent cellular communication system using an energy detector.

[00134] Example 35 includes the apparatus of example 34, wherein the one or more processors and memory are further configured to assign an initial communication channel (ICCH) to the band in the group of bands having a maximum ACIP value.

[00135] Example 36 includes the apparatus of example 35, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using an initial communication channel (ICCH).

[00136] Example 37 includes the apparatus of example 36, wherein the one or more

processors and memory are further configured to set a periodicity of the broadcast for the SI based on signal attenuation experienced by one or more opportunistic users (OU) experiencing.

5 [00137] Example 38 includes the apparatus of example 37, wherein the ICCH enables the one or more opportunistic users (OU) to: listen to the ICCH in the one or more available guard bands to synchronize and decode the SI; or listen to synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more guard bands.

10 [00138] Example 39 includes the apparatus of example 38, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

15 [00139] Example 40 includes the apparatus of example 31, wherein the one or more processors and memory are further configured communicate, to the IoT device, an admission parameter in the SI to limit a number of simultaneous access attempts the BACs by one or more opportunistic users (OU).

20 [00140] Example 41 includes the apparatus of example 31, wherein the admission parameter represents a probability the one or more opportunistic users (OU) attempts to access the cellular communication system.

25 [00141] Example 42 includes the apparatus of example 31, wherein the selected channel is a opportunistic user control channel (OUCCH), an opportunistic user data channel (OUDCH), and initial communication channel (ICCH), and wherein the base station communicates with a second base station in the adjacent communication system using an X2 communication interface.

[00142] Example 43 includes the apparatus of example 31, wherein the base station is configured to enable the one or more opportunistic users (OU) to operate in a contention-based mode, a contention-free mode, an acknowledged communication mode.

30 [00143] Example 44 includes the apparatus of example 43, wherein in the contention based mode, the one or more opportunistic users (OU) access the system resources

broadcasted in the ICCH or broadcasted in the broadcast channel of the LU bands without a priori scheduling by the base station, and wherein in the contention free mode, the OUs perform initial attachment for system admission using an access scheme and the OUs listen to a physical downlink (DL) control channel (PDCCH) to obtain scheduled
5 resources if an admission request of the one or more opportunistic users (OU) is accepted by the base station.

[00144] Example 45 includes the apparatus of example 31, wherein the one or more processors and memory are further configured to communicate resource assignments on a downlink (DL) opportunistic user control channel (OUCCH) and communicate an
10 acknowledgment/negative acknowledgement (ACK/NACK) on an uplink (UL) opportunistic user control data channel (OUDCH).

[00145] Example 46 includes the apparatus of example 45, wherein in the acknowledged communication mode, the base station selects to transmit an acknowledgement packet after a selected number of time slots to allow the one or more opportunistic users (OU) to
15 enter into a sleep mode.

[00146] Example 47 includes the apparatus of example 31, wherein the one or more processors and memory are further configured to aggregate one or more of the plurality of BACs to provide a selected communication bandwidth, wherein each of the aggregated BAC of the plurality of BACs are selected from guard bands of the cellular
20 communication system or are selected from a plurality of cellular communication systems from the one or more cellular communication systems.

[00147] Example 48 includes an apparatus of an internet of things (IoT) device, the IoT device configured to communicate with a base station in a cellular communication system, the apparatus comprising one or more processors and memory configured to:
25 monitor an initial communication channel (ICCH) for synchronization and system information (SI) communicated from the base station; decode the system information to determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular communication systems; and communicate control information and data in the best available channel in the one or more available guard
30 bands to the one or more cellular communication systems.

[00148] Example 49 includes the apparatus of example 48, wherein the ICCH is located

in a guard band or a legacy user (LU) band.

[00149] Example 50 includes the apparatus of example 48, wherein the one or more processors and memory are further configured to monitor synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more
5 available guard bands.

[00150] Example 51 includes the apparatus of example 48, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the
10 list of BACs has a highest OOB emission.

[00151] Example 52 includes the apparatus of example 51, wherein the one or more processors and memory are further configured process an admission parameter, received from the base station, in the SI to limit a number of access attempts to the BACs, and the admission parameter represents a probability the IoT device attempts to access the
15 cellular communication system, wherein the IoT device is an opportunistic user.

[00152] Example 53 includes the apparatus of example 48, wherein the IoT device is configured to operate in a contention-based mode, a contention-free mode, or an acknowledged communication mode.

[00153] Example 54 includes the apparatus of example 53, wherein in the contention
20 based mode, the IoT device accesses system resources broadcasted in the ICCH or broadcasted in the broadcast channel of legacy user (LU) bands without a priori scheduling by the base station, and wherein in the contention free mode, the IoT device performs initial attachment for system admission using an access scheme and the IoT device listens to a physical downlink (DL) control channel (PDCCH) to obtain scheduled
25 resources if an admission request of the IoT device is accepted by the base station.

[00154] Example 55 includes the apparatus of example 48, wherein the one or more processors and memory are further configured to: process resource assignments, received from the base station, in a downlink (DL) opportunistic user control channel (OUCCH); and communicate an acknowledgment/negative acknowledgement (ACK/NACK) in an
30 uplink (UL) opportunistic user control data channel (OUDCH).

[00155] Example 56 includes the apparatus of example 55, wherein in the acknowledged communication mode, process an acknowledgement packet, received from the base station after a selected number of time slots, to allow the IoT device to enter into a sleep mode.

5 [00156] Example 57 includes at least one non-transitory machine readable storage medium having instructions embodied thereon for a base station to communicate with an internet of things (IoT) device in a cellular communication system, the instructions when executed cause the base station to: identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more
10 cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands; associate one or more channels in the one or more guard bands with
15 a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands; assign an initial communication channel (ICCH) to the one or more channels in the one or more guard bands having a maximum ACIP value; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based
20 on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

[00157] Example 58 includes the at least one non-transitory machine readable storage medium of example 57, further comprising instructions which when executed cause the base station to: identify an occupancy or loading of one or more legacy users (LU) or one
25 or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; and calculate an adjacent channel interference
30 filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system;

or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00158] Example 59 includes the at least one non-transitory machine readable storage medium of example 58, further comprising instructions which when executed cause the
5 base station to: identify available downlink (DL) guard bands and available uplink (UL) guard bands; or obtain available DL guard bands and UL guard bands from an alternative base station, wherein the base station communicates the alternative base station via an X2 communication interface.

[00159] Example 60 includes the at least one non-transitory machine readable storage
10 medium of example 58, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using the ICCH, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list
15 of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00160] Example 61 includes an apparatus of a base station, the base station configured to communicate with an internet of things (IoT) device in a cellular communication system, the apparatus comprising one or more processors and memory configured to:
20 identify one or more available guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the
25 one or more available guard bands based on interference measurements in the one or more available guard bands; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements.

[00161] Example 62 includes the apparatus of example 61, wherein the one or more
30 processors and memory are further configured to: identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard

band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system; or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00162] Example 63 includes the apparatus of example 61 or 62, wherein the one or more processors and memory are further configured to: detect the presence or absence of one or more legacy users (LU) or one or more opportunistic users (OU) of the adjacent cellular communication system using an energy detector; assign an initial communication channel (ICCH) to the band in the group of bands having a maximum ACIP value; broadcast, to the IoT device, synchronization signals and system information (SI) using an initial communication channel (ICCH); or set a periodicity of the broadcast for the SI based on signal attenuation experienced by one or more opportunistic users (OU) experiencing; listen to the ICCH in the one or more available guard bands to synchronize and decode the SI; or listen to synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more guard bands, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00163] In Example 64, the subject matter of Example 61 or any of the Examples described herein may further include, wherein the one or more processors and memory are further configured communicate, to the IoT device, an admission parameter in the SI to limit a number of simultaneous access attempts the BACs by one or more opportunistic users (OU), wherein the admission parameter represents a probability the one or more opportunistic users (OU) attempts to access the cellular communication system, and wherein the selected channel is a opportunistic user control channel (OUCCH), an opportunistic user data channel (OUDCH), and initial communication channel (ICCH),

and wherein the base station communicates with a second base station in the adjacent communication system using an X2 communication interface, or wherein the base station is configured to enable the one or more opportunistic users (OU) to operate in a contention-based mode, a contention-free mode, an acknowledged communication mode.

5 [00164] In Example 65, the subject matter of Example 61 or any of the Examples described herein may further include, wherein in the contention based mode, the one or more opportunistic users (OU) access the system resources broadcasted in the ICCH or broadcasted in the broadcast channel of the LU bands without a priori scheduling by the base station, and wherein in the contention free mode, the OUs perform initial attachment
10 for system admission using an access scheme and the OUs listen to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the one or more opportunistic users (OU) is accepted by the base station.

[00165] In Example 66, the subject matter of Example 61 or any of the Examples described herein may further include, wherein the one or more processors and memory
15 are further configured to communicate resource assignments on a downlink (DL) opportunistic user control channel (OUCCH) and communicate an acknowledgment/negative acknowledgement (ACK/NACK) on an uplink (UL) opportunistic user control data channel (OUDCH), wherein in the acknowledged communication mode, the base station selects to transmit an acknowledgement packet
20 after a selected number of time slots to allow the one or more opportunistic users (OU) to enter into a sleep mode.

[00166] In Example 67, the subject matter of Example 61 or any of the Examples described herein may further include, wherein the one or more processors and memory are further configured to aggregate one or more of the plurality of BACs to provide a
25 selected communication bandwidth, wherein each of the aggregated BAC of the plurality of BACs are selected from guard bands of the cellular communication system or are selected from a plurality of cellular communication systems from the one or more cellular communication systems.

[00167] Example 68 includes an apparatus of an internet of things (IoT) device, the IoT
30 device configured to communicate with a base station in a cellular communication system, the apparatus comprising one or more processors and memory configured to:

monitor an initial communication channel (ICCH) for synchronization and system information (SI) communicated from the base station; decode the system information to determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular communication systems; and communicate control
5 information and data in the best available channel in the one or more available guard bands to the one or more cellular communication systems.

[00168] Example 69 includes the apparatus of example 68, wherein the one or more processors and memory are further configured to monitor synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more
10 available guard bands, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission, wherein the ICCH is located in a guard band or a legacy user (LU) band.

[00169] Example 70 includes the apparatus of example 68 or 69, wherein the one or more processors and memory are further configured process an admission parameter, received from the base station, in the SI to limit a number of access attempts to the BACs, and the admission parameter represents a probability the IoT device attempts to access the cellular communication system, wherein the IoT device is an opportunistic user, wherein
20 the IoT device is configured to operate in a contention-based mode, a contention-free mode, or an acknowledged communication mode, wherein in the contention based mode, the IoT device accesses system resources broadcasted in the ICCH or broadcasted in the broadcast channel of legacy user (LU) bands without a priori scheduling by the base station, and wherein in the contention free mode, the IoT device performs initial
25 attachment for system admission using an access scheme and the IoT device listens to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the IoT device is accepted by the base station.

[00170] In Example 71, the subject matter of Example 68 or any of the Examples described herein may further include, wherein the one or more processors and memory
30 are further configured to: process resource assignments, received from the base station, in a downlink (DL) opportunistic user control channel (OUCCH); and communicate an

acknowledgment/negative acknowledgement (ACK/NACK) in an uplink (UL) opportunistic user control data channel (OUDCH), wherein in the acknowledged communication mode, process an acknowledgement packet, received from the base station after a selected number of time slots, to allow the IoT device to enter into a sleep mode.

[00171] Example 72 includes least one machine readable storage medium having instructions embodied thereon for a base station to communicate with an internet of things (IoT) device in a cellular communication system, the instructions when executed cause the base station to: identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands; associate one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands; assign an initial communication channel (ICCH) to the one or more channels in the one or more guard bands having a maximum ACIP value; and communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

[00172] Example 73 includes the at least one machine readable storage medium of example 72, further comprising instructions which when executed cause the base station to: identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; and calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular

communication system; and the LU band of the cellular communication system; or associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00173] In Example 74, the subject matter of Example 72 or any of the Examples described herein may further include, further comprising instructions which when executed cause the base station to: identify available downlink (DL) guard bands and available uplink (UL) guard bands; or obtain available DL guard bands and UL guard bands from an alternative base station, wherein the base station communicates the alternative base station via an X2 communication interface.

[00174] In Example 75, the subject matter of Example 72 or any of the Examples described herein may further include, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using the ICCH, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00175] Example 76 includes a device to communicate with an internet of things (IoT) device in a cellular communication system, the device comprising: means for identifying one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system; means for processing information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands; means for associating one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands; means for assigning an initial communication channel (ICCH) to the one or more channels in the one or more guard bands having a maximum ACIP value; and means for communicating, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available

guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

[00176] Example 77 includes the device of Example 76, further comprising: means for identifying an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; and means for calculating an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising: a nearest guard band in the adjacent cellular communication system; an LU band of the adjacent cellular communication system; and the LU band of the cellular communication system; or means for associating one or more available physical resources with the band in the group of bands with a minimum ACIP value.

[00177] Example 78 includes the device of Example 77, further comprising: means for identifying available downlink (DL) guard bands and available uplink (UL) guard bands; or means for obtaining available DL guard bands and UL guard bands from an alternative base station, wherein the base station communicates the alternative base station via an X2 communication interface.

[00178] Example 79 includes the device of Example 78, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using the ICCH, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

[00179] As used herein, the term "circuitry" can 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 aspects,

the circuitry can be implemented in, or functions associated with the circuitry can be implemented by, one or more software or firmware modules. In some aspects, circuitry can include logic, at least partially operable in hardware.

[00180] 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. Circuitry can include hardware, firmware, program code, executable code, computer instructions, and/or software. A non-transitory computer readable storage medium can be a computer readable storage medium that does not include signal. In the case of program code execution on programmable computers, the computing device may include a processor, a storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), at least one input device, and at least one output device. The volatile and non-volatile memory and/or storage elements may be a random-access memory (RAM), erasable programmable read only memory (EPROM), flash drive, optical drive, magnetic hard drive, solid state drive, or other medium for storing electronic data. The node and wireless device may also include a transceiver module (i.e., transceiver), a counter module (i.e., counter), a processing module (i.e., processor), and/or a clock module (i.e., clock) or timer module (i.e., timer). 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.

[00181] As used herein, the term processor can include general purpose processors, specialized processors such as VLSI, FPGAs, or other types of specialized processors, as well as base band processors used in transceivers to send, receive, and process wireless communications.

[00182] 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.

[00183] Modules may also be implemented in software for execution by various types of processors. An identified module of executable code may, for instance, comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module may not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the module and achieve the stated purpose for the module.

[00184] Indeed, a module of executable code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. The modules may be passive or active, including agents operable to perform desired functions.

[00185] Reference throughout this specification to "an example" or "exemplary" means that a particular feature, structure, or characteristic described in connection with the example is included in at least one embodiment of the present technology. Thus, appearances of the phrases "in an example" or the word "exemplary" in various places throughout this specification are not necessarily all referring to the same embodiment.

[00186] As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists

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

[00187] 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.

[00188] 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 base station, the base station configured to communicate
5 with an internet of things (IoT) device in a cellular communication system, the
apparatus comprising one or more processors and memory configured to:

 identify one or more available guard bands in one or more cellular
bands of one or more cellular communication systems, wherein the one or
more cellular communication systems includes the cellular communication
10 system and an adjacent cellular communication system;

 process information, received from the one or more cellular
communication systems, to select a channel in a plurality of best available
channels in the one or more available guard bands based on interference
measurements in the one or more available guard bands; and
15 communicate, to the IoT device, information to enable the IoT device
to opportunistically use the selected channel in the one or more available
guard bands based on the interference measurements.
2. The apparatus of claim 1, wherein the one or more processors and memory are
20 further configured to identify an occupancy or loading of one or more legacy
users (LU) or one or more opportunistic users (OU) in:

 a nearest guard band in the adjacent cellular communication system;

 an LU band of the adjacent cellular communication system; and

 the LU band of the cellular communication system, wherein the LU are
25 licensed users of the LU band in the cellular communication system or the
adjacent cellular communication system and the OU are unlicensed users.
3. The apparatus of claim 2, wherein the one or more processors and memory are
further configured to:

calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising:

a nearest guard band in the adjacent cellular communication system;

5 an LU band of the adjacent cellular communication system; and
the LU band of the cellular communication system; or

associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

10 4. The apparatus of claim 1 or 3, wherein the one or more processors and memory are further configured to detect the presence or absence of one or more legacy users (LU) or one or more opportunistic users (OU) of the adjacent cellular communication system using an energy detector.

15 5. The apparatus of claim 4, wherein the one or more processors and memory are further configured to assign an initial communication channel (ICCH) to the band in the group of bands having a maximum ACIP value.

20 6. The apparatus of claim 1 or 5, wherein the one or more processors and memory are further configured to broadcast, to the IoT device, synchronization signals and system information (SI) using an initial communication channel (ICCH).

25 7. The apparatus of claim 6, wherein the one or more processors and memory are further configured to set a periodicity of the broadcast for the SI based on signal attenuation experienced by one or more opportunistic users (OU) experiencing.

8. The apparatus of claim 7, wherein the ICCH enables the one or more opportunistic users (OU) to:

listen to the ICCH in the one or more available guard bands to synchronize and decode the SI; or

- 5 listen to synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more guard bands.

9. The apparatus of claim 1 or 8, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

10

10. The apparatus of claim 1, wherein the one or more processors and memory are further configured communicate, to the IoT device, an admission parameter in the SI to limit a number of simultaneous access attempts the BACs by one or more opportunistic users (OU).

15

11. The apparatus of claim 1 or 10, wherein the admission parameter represents a probability the one or more opportunistic users (OU) attempts to access the cellular communication system.

20

12. The apparatus of claim 1, wherein the selected channel is a opportunistic user control channel (OUCCH), an opportunistic user data channel (OUDCH), and initial communication channel (ICCH), and wherein the base station communicates with a second base station in the adjacent communication system using an X2 communication interface.

25

13. The apparatus of claim 1, wherein the base station is configured to enable the one or more opportunistic users (OU) to operate in a contention-based mode, a contention-free mode, an acknowledged communication mode.

5 14. The apparatus of claim 1 or 13, wherein in the contention based mode, the one or more opportunistic users (OU) access the system resources broadcasted in the ICCH or broadcasted in the broadcast channel of the LU bands without a priori scheduling by the base station, and wherein in the contention free mode, the OUs perform initial attachment for system admission using an access
10 scheme and the OUs listen to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the one or more opportunistic users (OU) is accepted by the base station.

15 15. The apparatus of claim 1, wherein the one or more processors and memory are further configured to communicate resource assignments on a downlink (DL) opportunistic user control channel (OUCCH) and communicate an acknowledgment/negative acknowledgement (ACK/NACK) on an uplink (UL) opportunistic user control data channel (OUDCH).

20 16. The apparatus of claim 1 or 15, wherein in the acknowledged communication mode, the base station selects to transmit an acknowledgement packet after a selected number of time slots to allow the one or more opportunistic users (OU) to enter into a sleep mode.

25 17. The apparatus of claim 1, wherein the one or more processors and memory are further configured to aggregate one or more of the plurality of BACs to provide a selected communication bandwidth, wherein each of the aggregated BAC of the plurality of BACs are selected from guard bands of the cellular communication system or are selected from a plurality of cellular

communication systems from the one or more cellular communication systems.

5 18. An apparatus of an internet of things (IoT) device, the IoT device configured to communicate with a base station in a cellular communication system, the apparatus comprising one or more processors and memory configured to:

monitor an initial communication channel (ICCH) for synchronization and system information (SI) communicated from the base station;

10 decode the system information to determine a best available channel in one or more available guard bands in one or more cellular bands of one or more cellular communication systems; and

communicate control information and data in the best available channel in the one or more available guard bands to the one or more cellular communication systems.

15

19. The apparatus of claim 18, wherein the ICCH is located in a guard band or a legacy user (LU) band.

20 20. The apparatus of claim 18, wherein the one or more processors and memory are further configured to monitor synchronization and broadcast channels in one or more LU bands if the ICCH is not transmitted in the one or more available guard bands.

25 21. The apparatus of claim 18, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

22. The apparatus of claim 18 or 21, wherein the one or more processors and memory are further configured process an admission parameter, received from the base station, in the SI to limit a number of access attempts to the BACs, and the admission parameter represents a probability the IoT device attempts to access the cellular communication system, wherein the IoT device is an opportunistic user.

23. The apparatus of claim 18, wherein the IoT device is configured to operate in a contention-based mode, a contention-free mode, or an acknowledged communication mode.

24. The apparatus of claim 18 or 23, wherein in the contention based mode, the IoT device accesses system resources broadcasted in the ICCH or broadcasted in the broadcast channel of legacy user (LU) bands without a priori scheduling by the base station, and wherein in the contention free mode, the IoT device performs initial attachment for system admission using an access scheme and the IoT device listens to a physical downlink (DL) control channel (PDCCH) to obtain scheduled resources if an admission request of the IoT device is accepted by the base station.

25. The apparatus of claim 18, wherein the one or more processors and memory are further configured to:

process resource assignments, received from the base station, in a downlink (DL) opportunistic user control channel (OUCCH); and

communicate an acknowledgment/negative acknowledgement (ACK/NACK) in an uplink (UL) opportunistic user control data channel (OUDCH).

26. The apparatus of claim 18 or 25, wherein in the acknowledged communication mode, process an acknowledgement packet, received from the base station after a selected number of time slots, to allow the IoT device to enter into a sleep mode.

5

27. At least one machine readable storage medium having instructions embodied thereon for a base station to communicate with an internet of things (IoT) device in a cellular communication system, the instructions when executed cause the base station to:

10 identify one or more guard bands in one or more cellular bands of one or more cellular communication systems, wherein the one or more cellular communication systems includes the cellular communication system and an adjacent cellular communication system;

15 process information, received from the one or more cellular communication systems, to select a channel in a plurality of best available channels in the one or more guard bands based on interference measurements in the one or more guard bands;

20 associate one or more channels in the one or more guard bands with a minimum adjacent channel interference filtering protection (ACIP) value to occupied LU bands and occupied guard bands;

 assign an initial communication channel (ICCH) to the one or more channels in the one or more guard bands having a maximum ACIP value; and

25 communicate, to the IoT device, information to enable the IoT device to opportunistically use the selected channel in the one or more available guard bands based on the interference measurements in the one or more guard bands for a set of one or more IoT devices.

28. The at least one machine readable storage medium of claim 27, further comprising instructions which when executed cause the base station to:

identify an occupancy or loading of one or more legacy users (LU) or one or more opportunistic users (OU) in:

a nearest guard band in the adjacent cellular communication system;

5 an LU band of the adjacent cellular communication system; and

the LU band of the cellular communication system, wherein the LU are licensed users of the LU band in the cellular communication system or the adjacent cellular communication system and the OU are unlicensed users; and

10 calculate an adjacent channel interference filtering protection (ACIP) value for each band in a group of bands comprising:

a nearest guard band in the adjacent cellular communication system;

an LU band of the adjacent cellular communication system; and

15 the LU band of the cellular communication system; or

associate one or more available physical resources with the band in the group of bands with a minimum ACIP value.

20 29. The at least one machine readable storage medium of claim 28, further comprising instructions which when executed cause the base station to:

identify available downlink (DL) guard bands and available uplink (UL) guard bands; or

25 obtain available DL guard bands and UL guard bands from an alternative base station, wherein the base station communicates the alternative base station via an X2 communication interface.

30. The at least one machine readable storage medium of claim 28, wherein the one or more processors and memory are further configured to broadcast, to the

IoT device, synchronization signals and system information (SI) using the ICCH, wherein the SI contains a list of best available channels (BACs), wherein the BACs are channels in the one or more available guard bands having an out of band (OOB) emission below a defined threshold, wherein a
5 first BAC in the list of BACs has a lowest OOB emission and a last BAC in the list of BACs has a highest OOB emission.

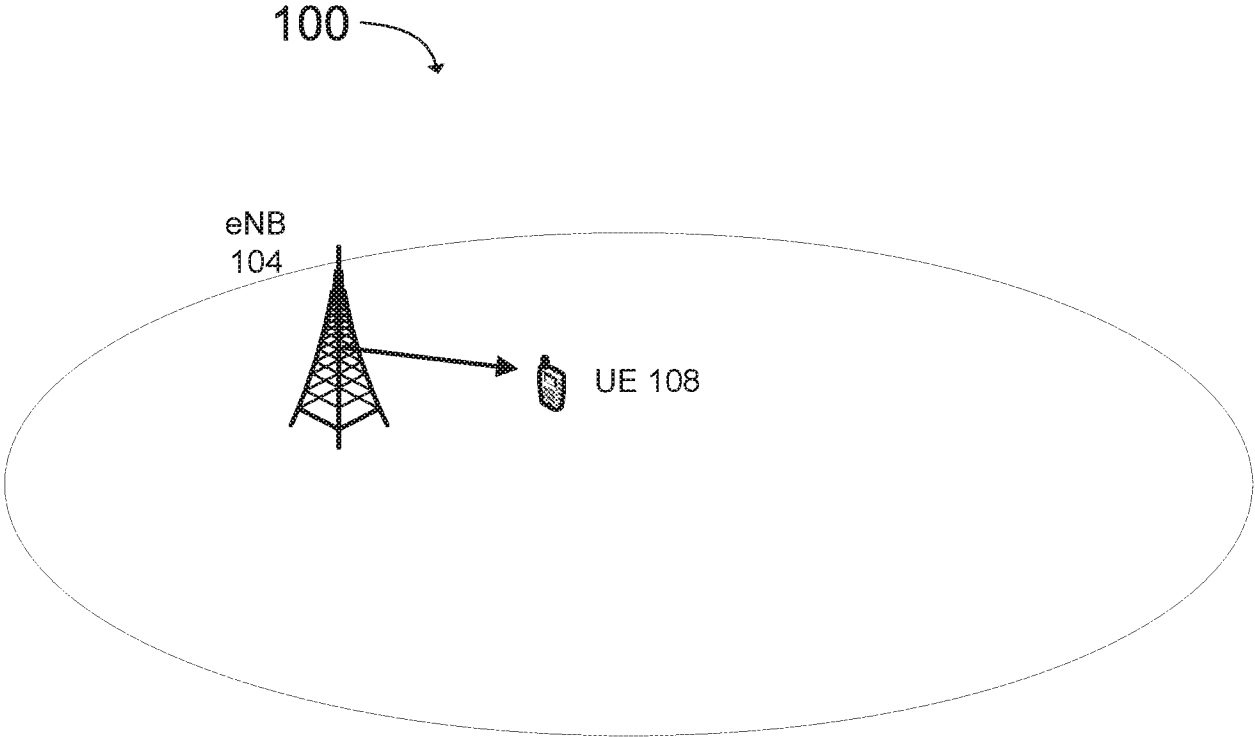


FIG. 1

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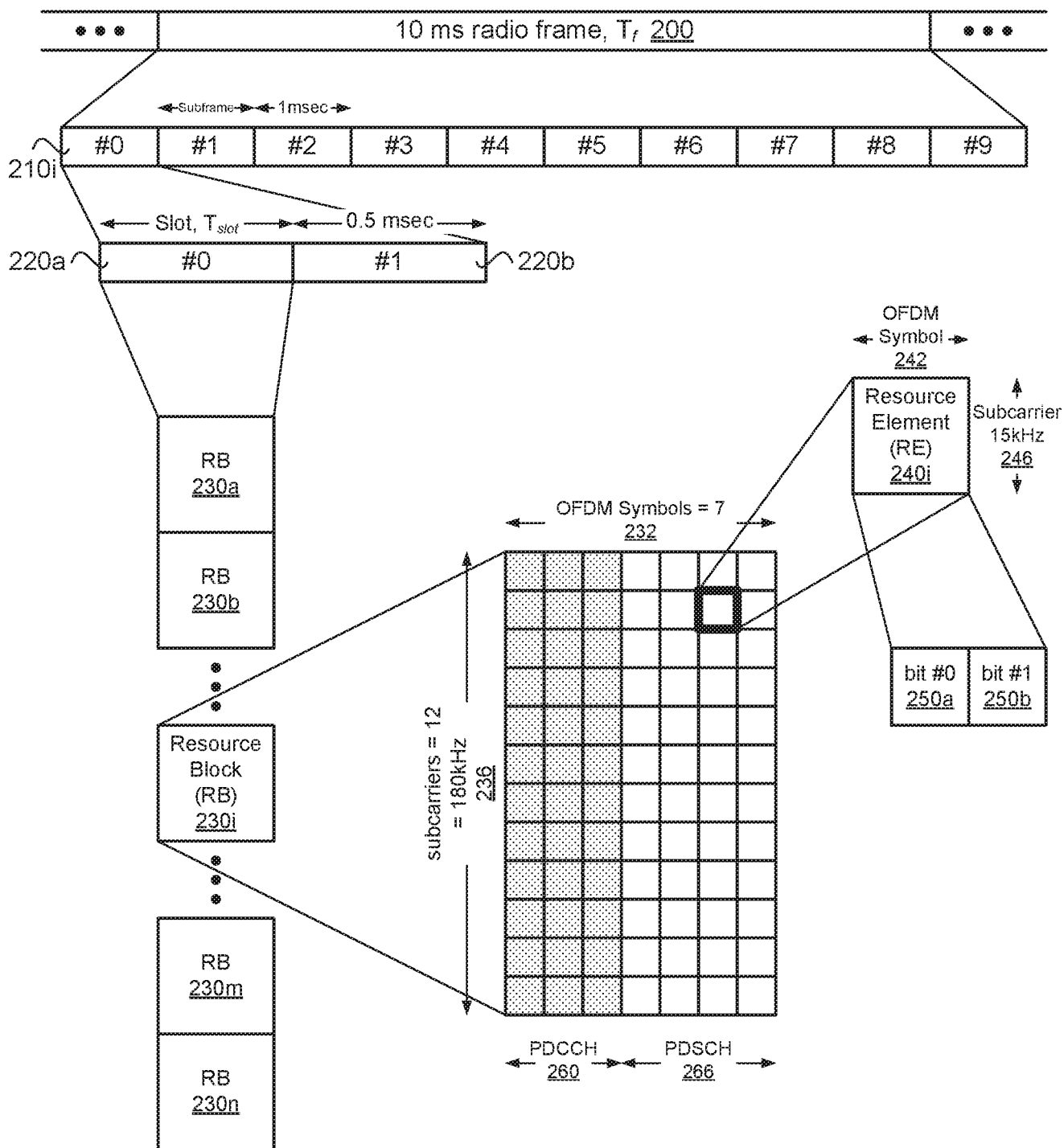


FIG. 2

300

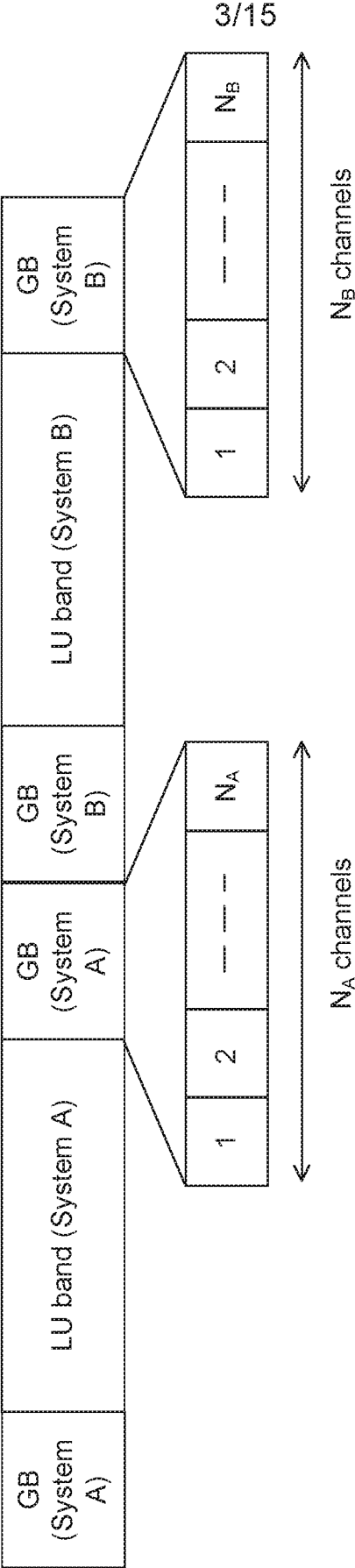


FIG. 3

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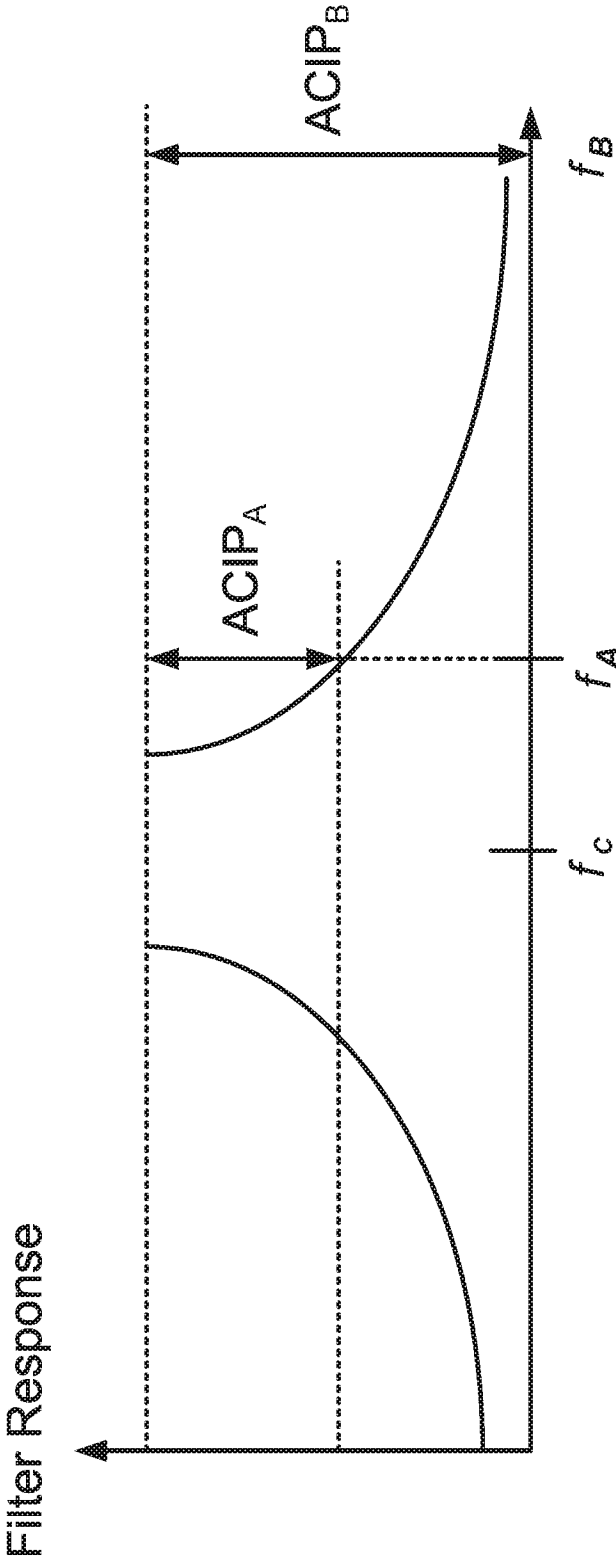
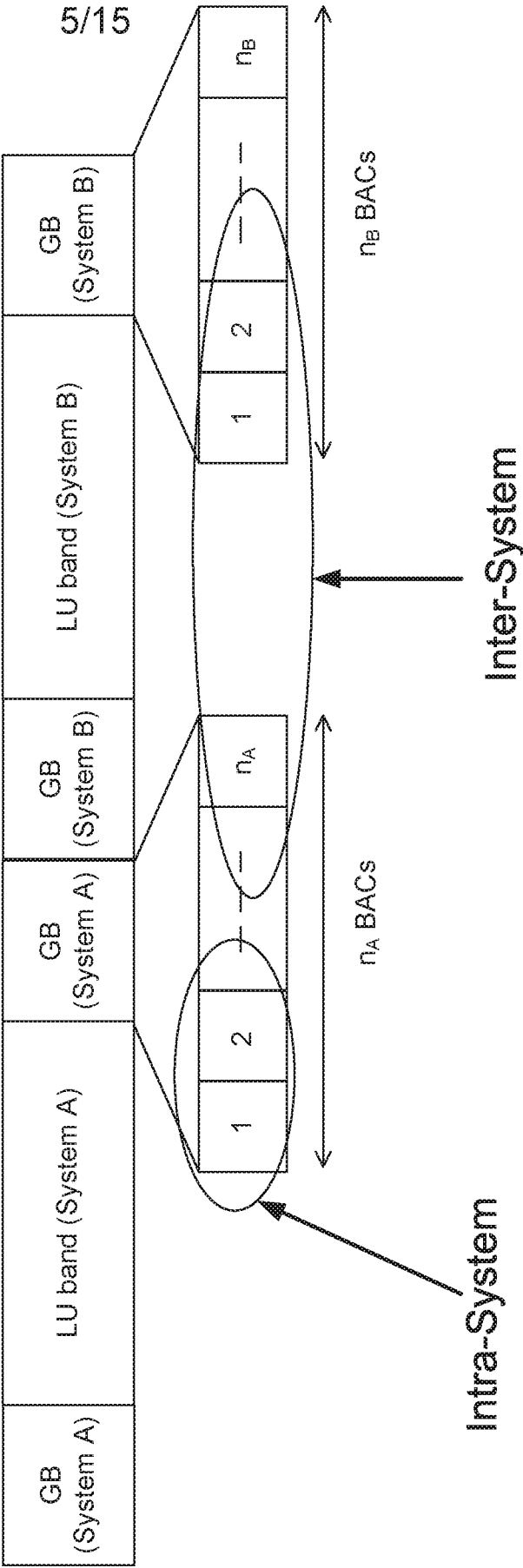


FIG. 4

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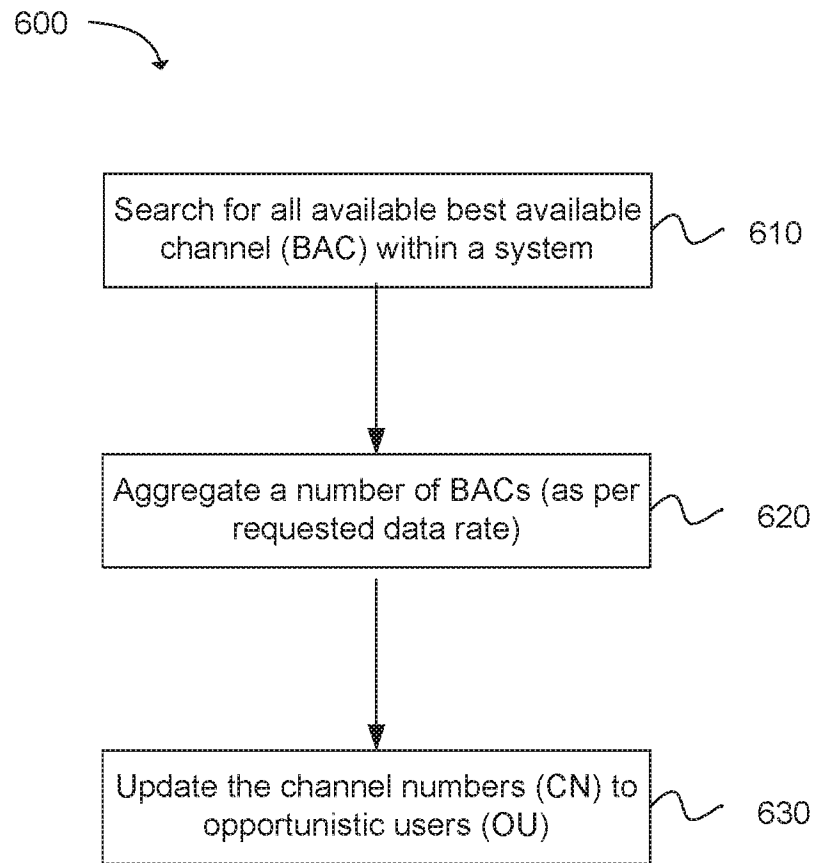


FIG. 6

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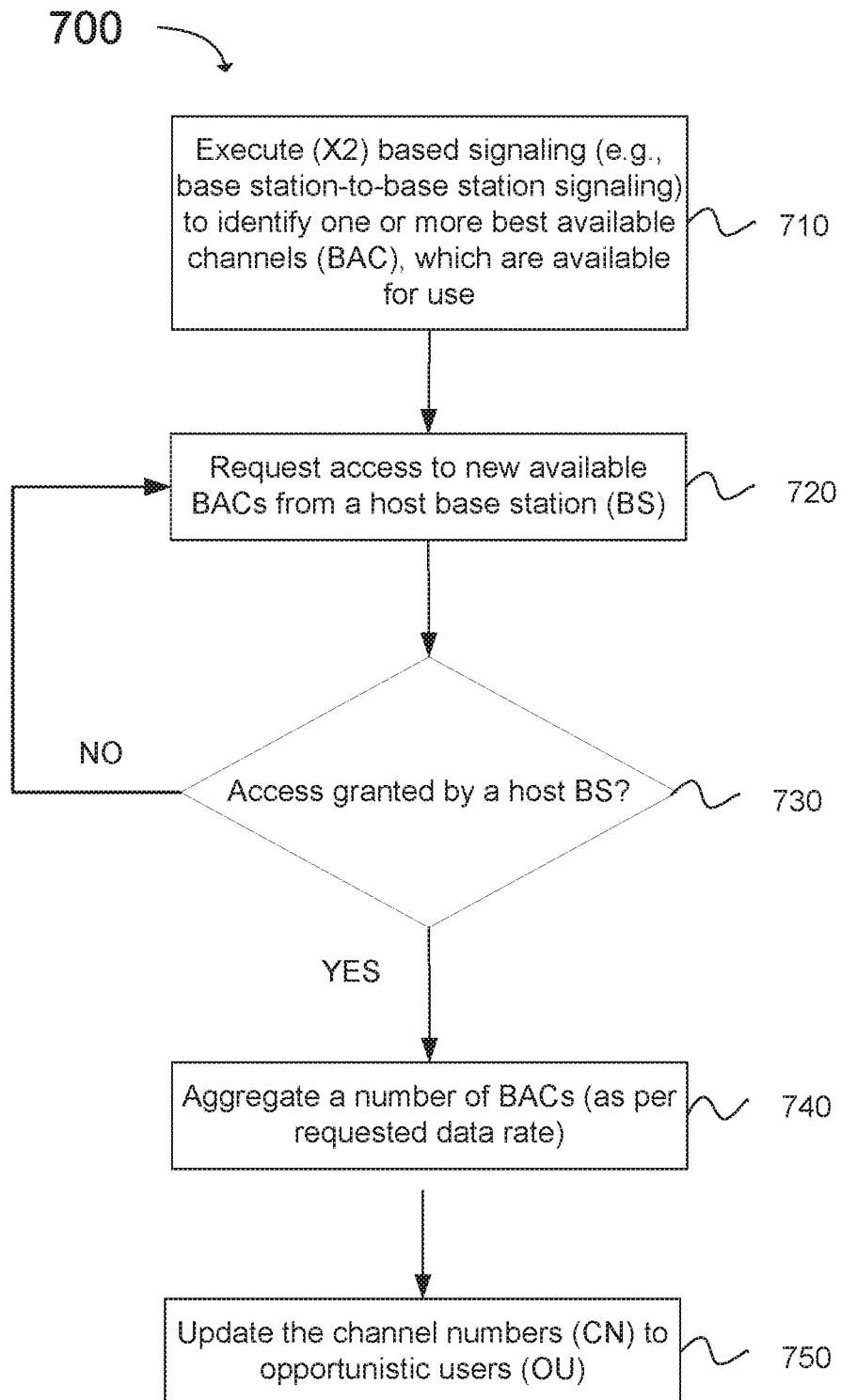


FIG. 7

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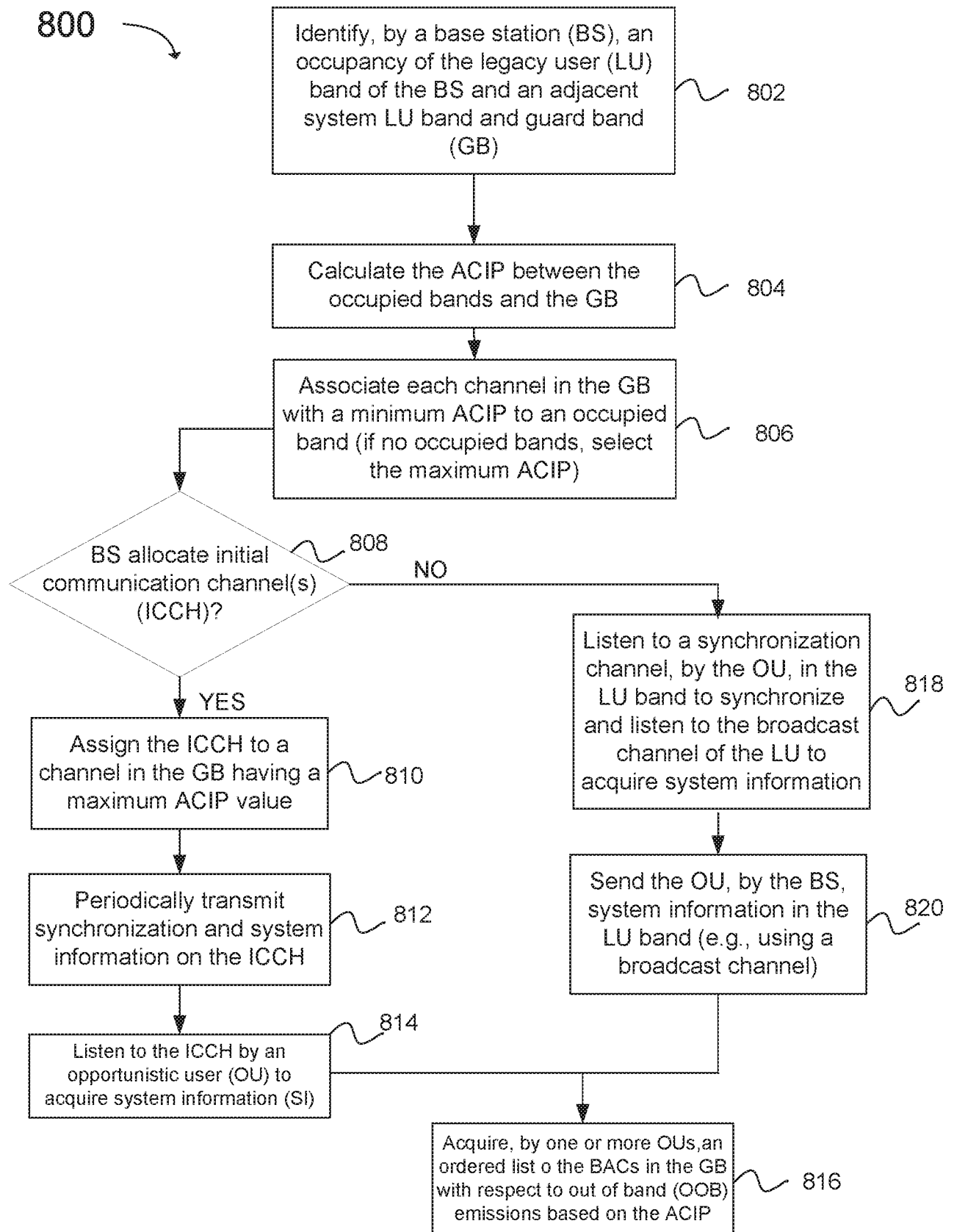


FIG. 8A

A

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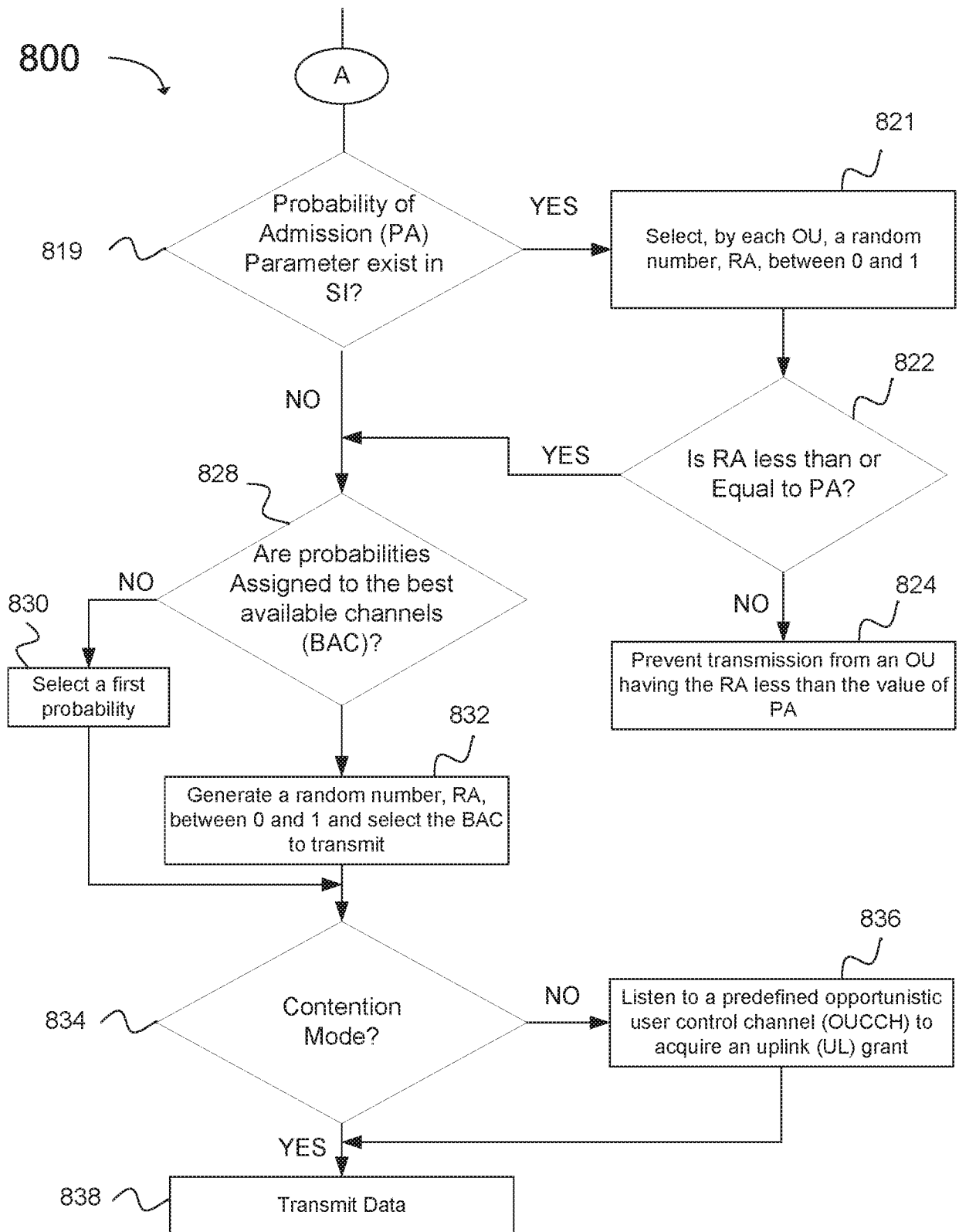


FIG. 8B

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900

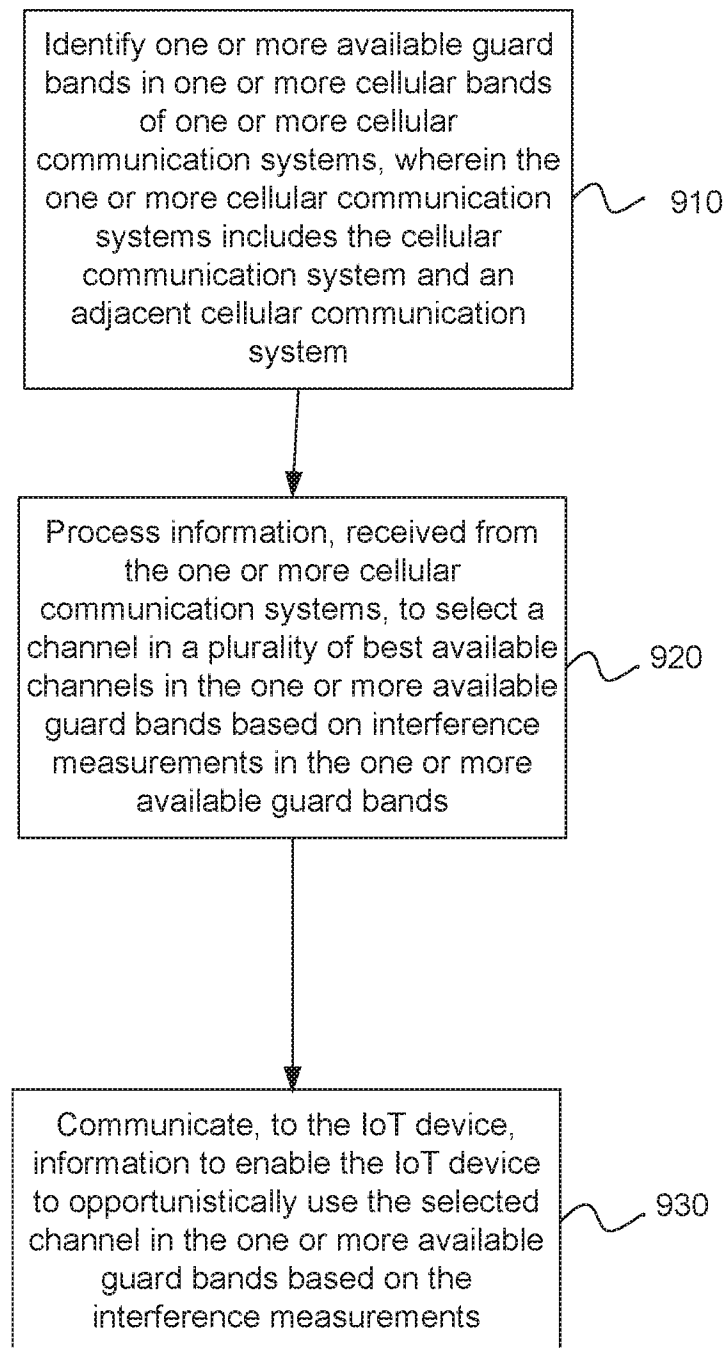


FIG. 9

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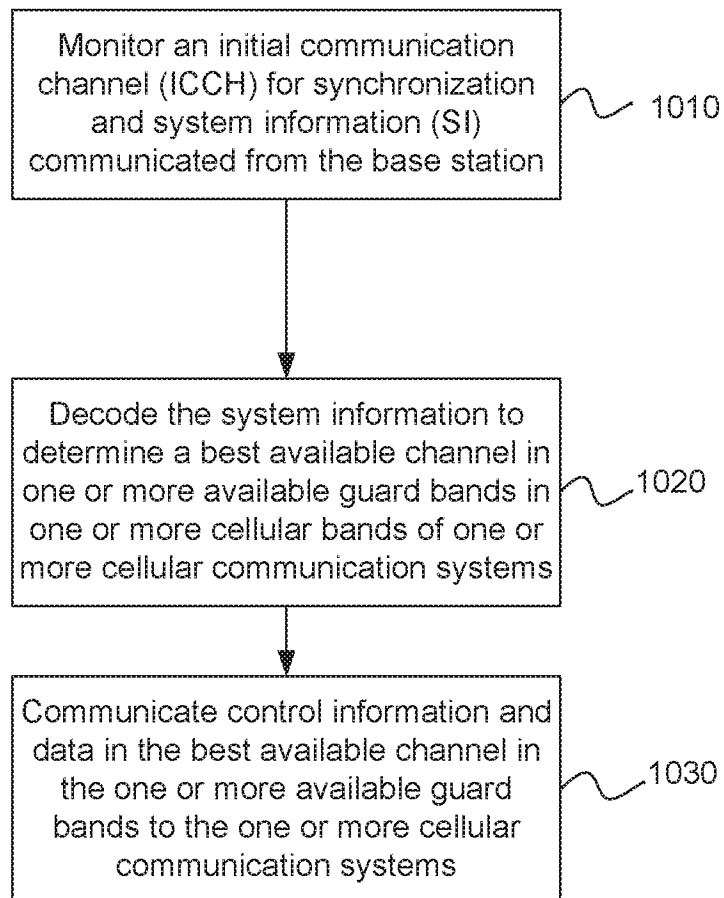
1000 

FIG. 10

12/15

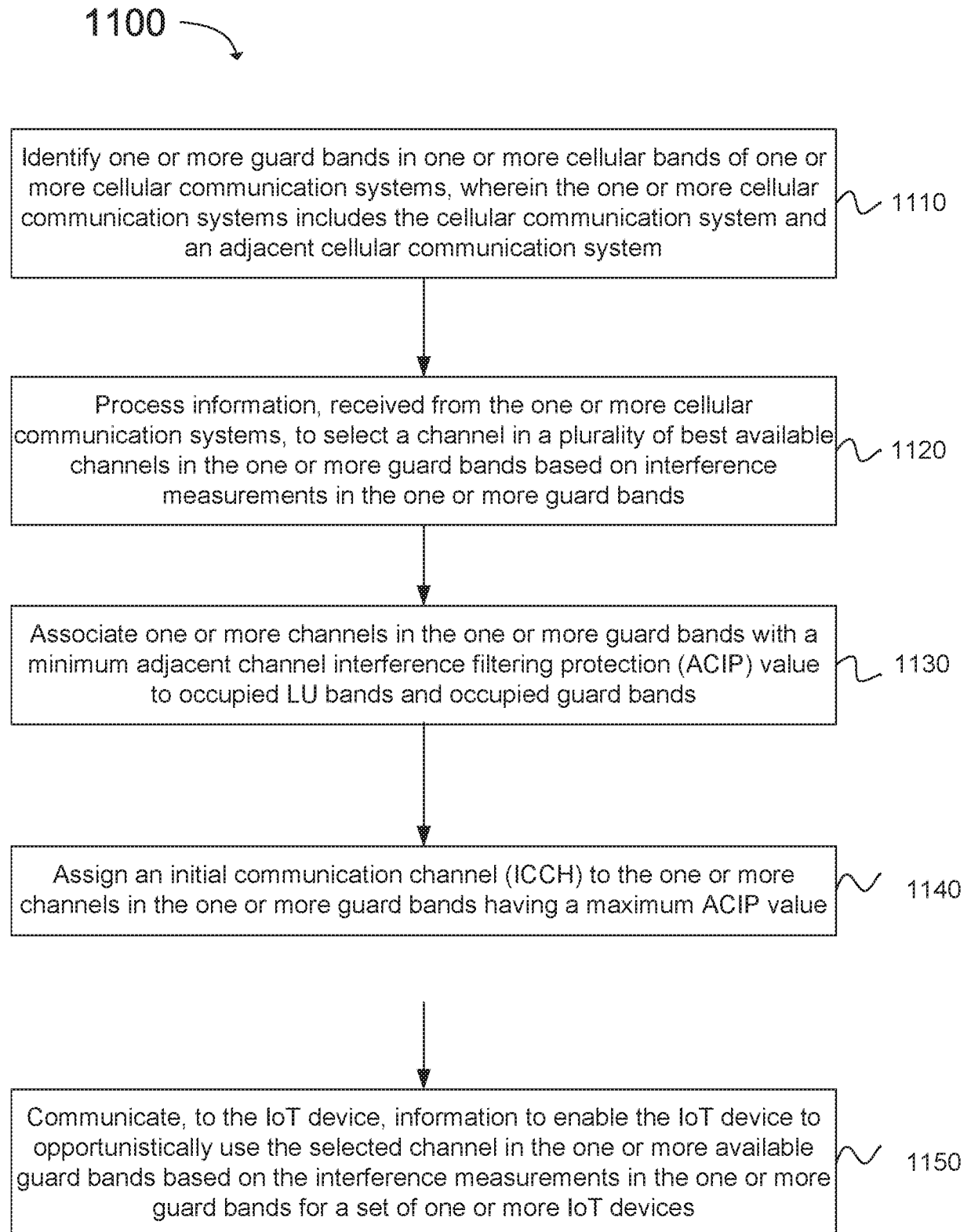


FIG. 11

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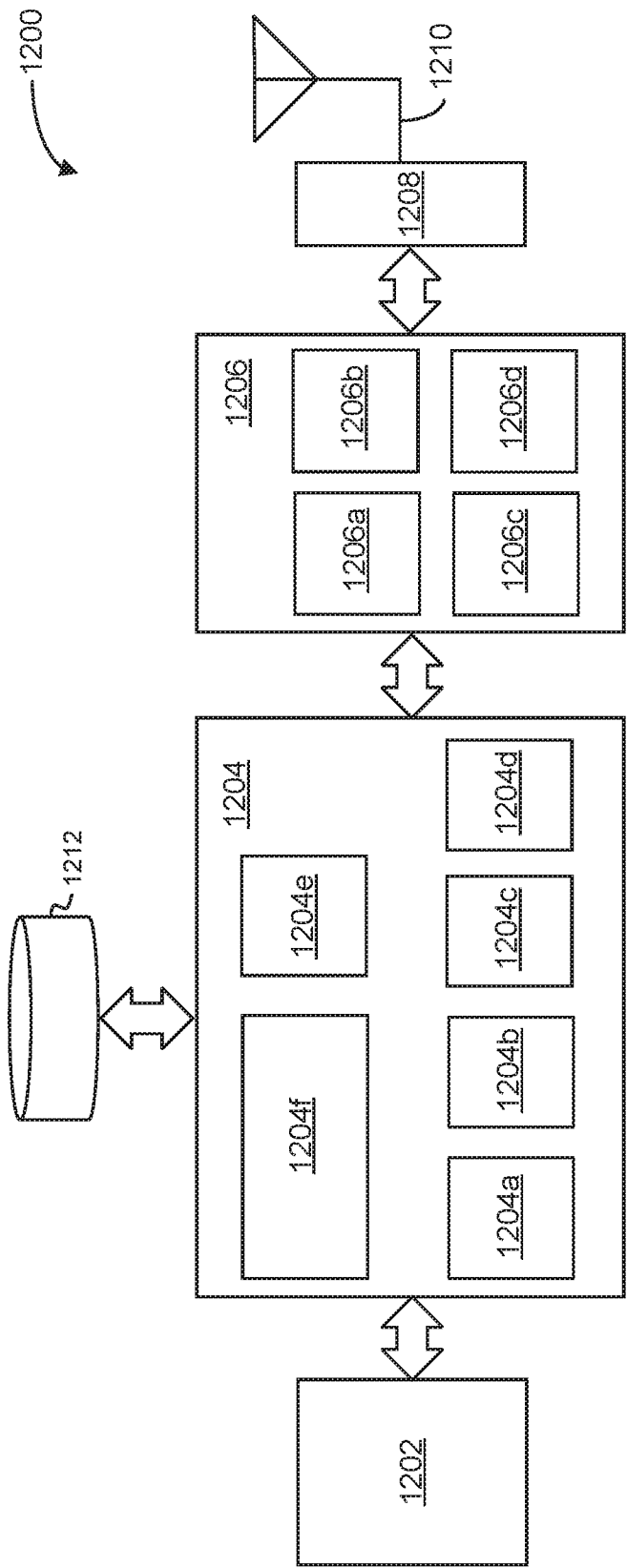


FIG. 12

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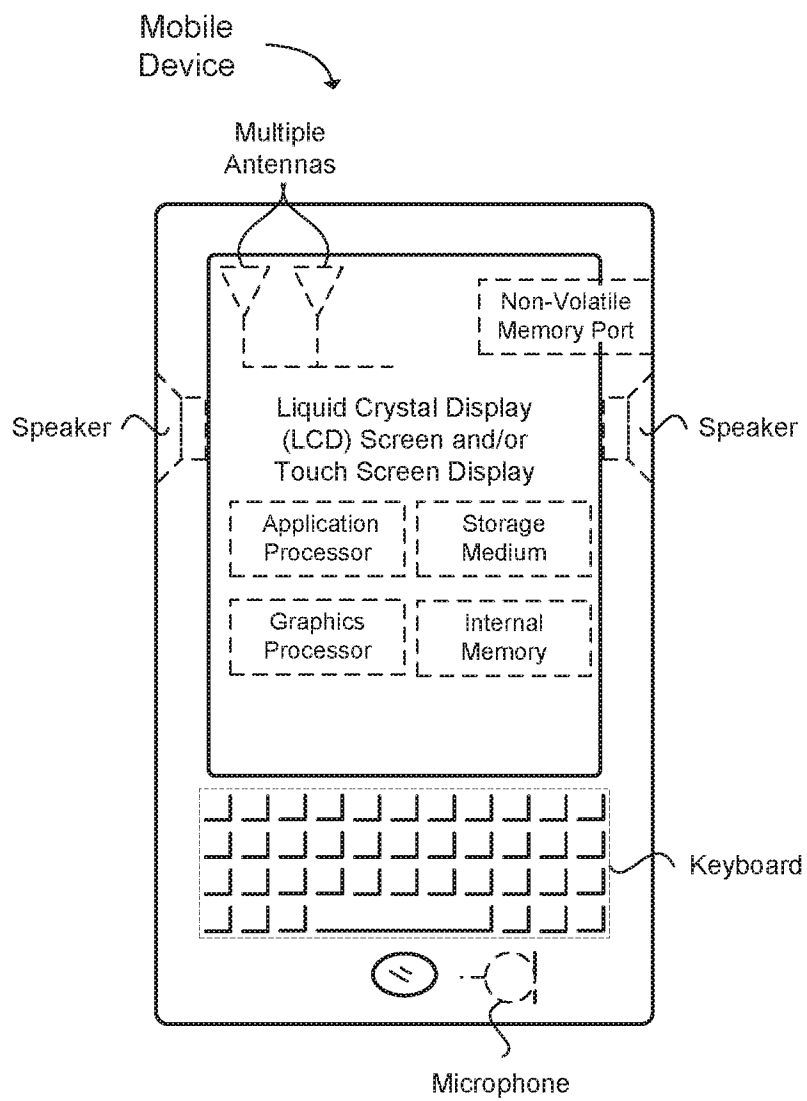
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FIG. 13

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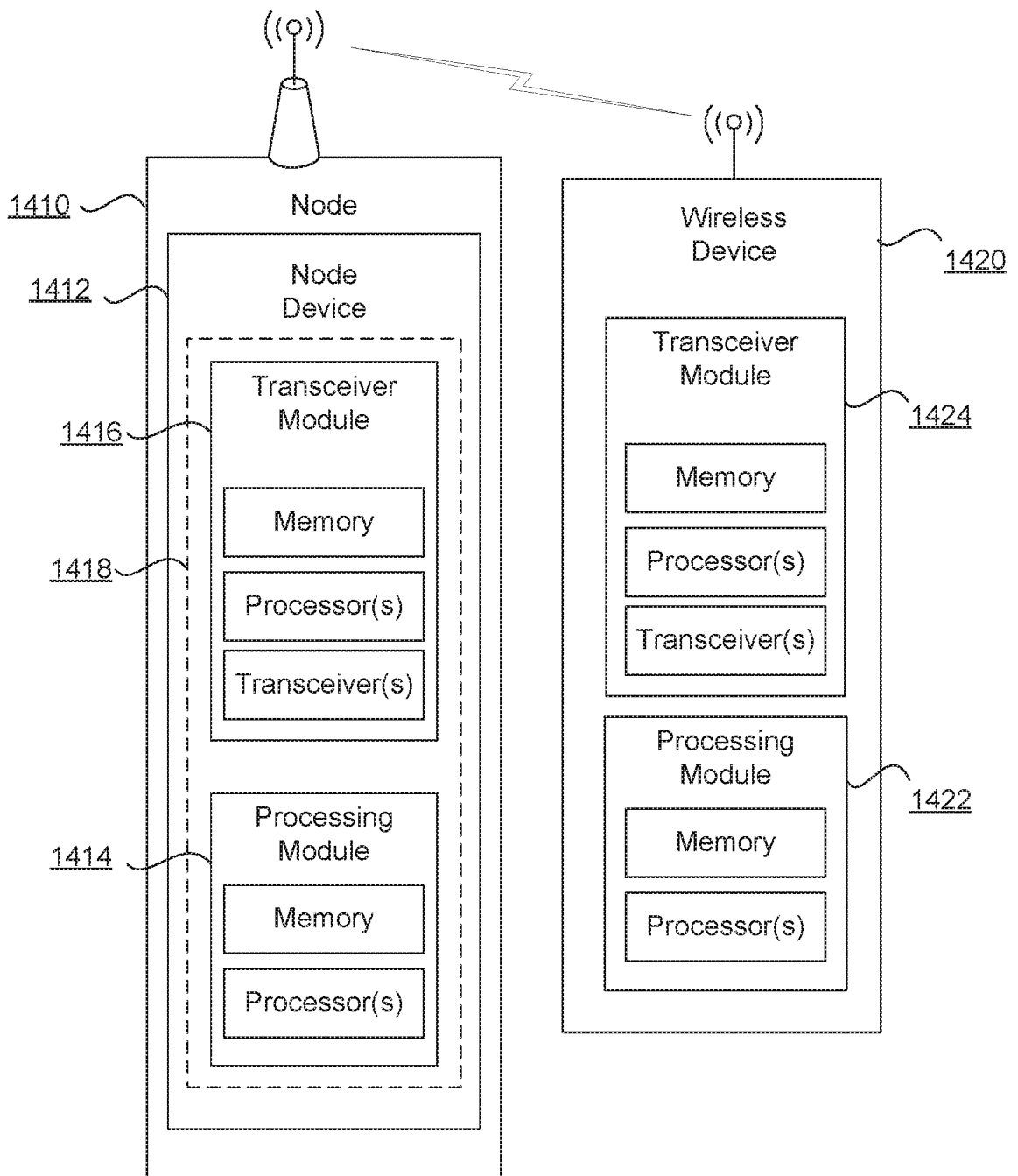
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FIG. 14

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/025774

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W72/08

ADD. H04W72/04 H04W16/14 H04W48/10

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

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2009/139789 A1 (QUALCOMM INC [US]; BHATTAD KAPIL [US]; PALANKI RAVI [US]) 19 November 2009 (2009-11-19) paragraph [0049] - paragraph [0067]; figures 4, 8 ----- -/--	1-8, 12-20, 23-28 9-11,21, 22,29,30



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

23 November 2016

Date of mailing of the international search report

05/12/2016

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No

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