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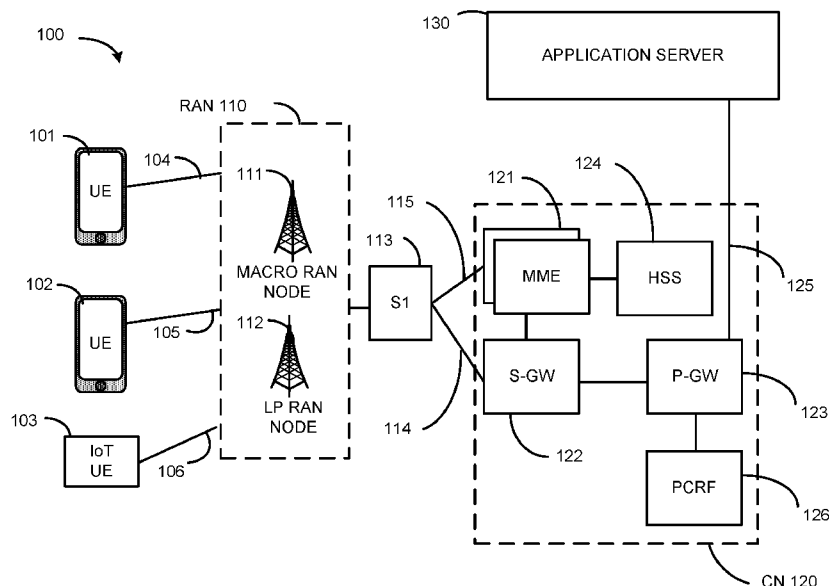


Fig. 1

(57) Abstract: Channel estimation parameters that are determined based on Narrowband Secondary Synchronization Signals (NSSS) that are transmitted in a subframe prior to a Narrowband Physical Broadcast Channel (NPBCH) subframe may be used to enhance channel estimation for the NPBCH subframe. By improving the channel estimation of the NPBCH, the block error rate (BLER) for a given channel signal-to-noise ratio (SNR) may be improved.

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CHANNEL ESTIMATION ENHANCEMENT FOR NARROWBAND INTERNET OF THINGS (NB-IOT) PHYSICAL BROADCAST CHANNEL (NPBCH)

RELATED APPLICATIONS

5 The present application claims the benefit of U.S. Provisional Patent Application No. 62/378,049, which was filed on August 22, 2016, the contents of which are hereby incorporated by reference as though fully set forth herein.

BACKGROUND

10 Narrowband Internet-of-Things (NB-IoT) refers to a Third Generation Partnership Project standard for the development of wireless technologies that are able to support enhanced network coverage and a large number of low cost, low power consumption and low delay sensitivity devices. In particular, to meet the coverage enhancement requirement, NB-IoT protocols apply a repetition scheme in which a transmitter may repeatedly transmit the same data block to the receiver for a number of times in a sequence of subframes. On the receiving
15 end, the user equipment (UE) receives and accumulates multiple copies of the same (repeated) data block, which allows the UE to more easily demodulate/decode the transmitted information.

 Even using repetition schemes, in certain conditions, the block error rate (BLER) that is received by an NB-IoT UE may be above acceptable levels. For example, when transmitting the NB-IoT Master Information Block (N-MIB) over the NB-IoT Physical Broadcast Channel
20 (NPBCH), the maximum allowed repetition level may be 64 repetitions. Depending on channel conditions, this may not be sufficient to communicate the N-MIB. Accordingly, it is desirable to improve transmissions over the NPBCH, such as transmission of the N-MIB, without increasing the maximum repetition amount.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Embodiments described herein will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals may designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

 Fig. 1 illustrates an architecture of a system of a network in accordance with some
30 embodiments;

 Figs. 2A-2C are diagrams illustrating an example transmission/reception sequence for an NB-IoT system;

 Fig. 3 is a flow chart illustrating an example process for performing NPBCH channel state estimation;

35 Fig. 4 illustrates example components of a device in accordance with some embodiments;

Fig. 5 illustrates example interfaces of baseband circuitry in accordance with some embodiments; and

Fig. 6 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments is defined by the appended claims and their equivalents.

Techniques described herein relate to improvements in channel estimation techniques for the NPBCH. In one embodiment, channel estimation parameters that are determined based on narrowband secondary synchronization signals (NSSS) that are transmitted in a subframe prior to the NPBCH may be used to enhance channel estimation for NPBCH. By improving the channel estimation of the NPBCH, the block error rate (BLER) for a given channel signal-to-noise ratio (SNR) may be improved. Advantageously, the techniques described herein may improve NPBCH reception without requiring modification to the NPBCH transmission or modification to the NPBCH reception hardware.

Fig. 1 illustrates an architecture of a system 100 of a network in accordance with some embodiments. The system 100 is shown to include user equipment (UE) 101, UE 102, and 103. The UEs 101 and 102 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface. UE 103 is particularly illustrated as an IoT UE, such as an IoT sensor device. IoT UE 103 may be, for example, an NB-IoT device that receives data via the NPBCH.

The UEs 101-103 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 110 — the RAN 110 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs 101-103 utilize connections 104-106, respectively, each of which comprises a physical communications interface or layer

(discussed in further detail below); in this example, the connections 104-106 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like. Connection 106 may particularly use 3GPP NB-IoT protocols.

The RAN 110 can include one or more access nodes that enable the connections 104-106. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). The RAN 110 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 111, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 112. In some embodiments, a RAN node may be implemented as or include one or more Remote Radio Heads (RRHs).

Any of the RAN nodes 111 and 112 can terminate the air interface protocol and can be the first point of contact for the UEs 101-103. In some embodiments, any of the RAN nodes 111 and 112 can fulfill various logical functions for the RAN 110 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

In accordance with some embodiments, the UEs 101-103 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes 111 and 112 over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 111 and 112 to the UEs 101-103, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a

time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element (RE). Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs 101-103. The physical downlink control channel (PDCCH) may carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 101-103 about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE within a cell) may be performed at any of the RAN nodes 111 and 112 based on channel quality information fed back from any of the UEs 101-103. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 101-103. In NB-IoT, the corresponding channels are referred to as the Narrowband PDSCH (NPDSCH) and the Narrowband PDCCH (NPDCCH).

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

Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using

one or more enhanced the control channel elements (ECCEs). Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an enhanced resource element groups (EREGs). An ECCE may have other numbers of EREGs in some situations.

The RAN 110 is shown to be communicatively coupled to a core network (CN) 120 —
5 via an S1 interface 113. In embodiments, the CN 120 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment the S1 interface 113 is split into two parts: the S1-U interface 114, which carries traffic data between the RAN nodes 111 and 112 and the serving gateway (S-GW) 122, and the S1-mobility management entity (MME) interface 115, which is a signaling interface between the RAN nodes
10 111 and 112 and MMEs 121.

In this embodiment, the CN 120 comprises the MMEs 121, the S-GW 122, the Packet Data Network (PDN) Gateway (P-GW) 123, and a home subscriber server (HSS) 124. The MMEs 121 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 121 may manage mobility aspects in
15 access such as gateway selection and tracking area list management. The HSS 124 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN 120 may comprise one or several HSSs 124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 124 can provide support for
20 routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

The S-GW 122 may terminate the S1 interface 113 towards the RAN 110, and routes data packets between the RAN 110 and the CN 120. In addition, the S-GW 122 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-
25 3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

The P-GW 123 may terminate an SGi interface toward a PDN. The P-GW 123 may route data packets between the EPC network 123 and external networks such as a network including the application server 130 (alternatively referred to as application function (AF)) via an Internet
30 Protocol (IP) interface 125. Generally, the application server 130 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW 123 is shown to be communicatively coupled to an application server 130 via an IP communications interface 125. The application server 130 can also be configured to support one or more communication

services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101-103 via the CN 120.

The P-GW 123 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 126 is the policy and charging control element of the CN 120. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 126 may be communicatively coupled to the application server 130 via the P-GW 123. The application server 130 may signal the PCRF 126 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 126 may provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server 130.

Figs. 2A-2C are diagrams illustrating an example transmission/reception sequence for an NB-IoT system. In general, in order to maintain synchronization and to manage the different types of information that is carried between the radio nodes and the UEs, a defined frame and subframe structure is used. As illustrated, a frame may have an overall length of 10 milliseconds (ms), and may be divided into ten subframes. In Fig. 2A, four frames (40 subframes) are illustrated.

Different subframes may be used to transmit different types of uplink or downlink information. As is particularly illustrated in Fig. 2A, each frame may include an NPBCH subframe and every other frame may include a NSSS subframe. The NSSS subframes may immediately precede a NPBCH subframe. The NSSS may be used by the NB-IoT UE to perform cell search, which includes time and frequency synchronization, and cell identity detection.

Fig. 2B is a diagram illustrating a resource grid for the NSSS in additional detail. Each square block in Fig. 2B represents a resource element (RE). Each RE may correspond to an Orthogonal Frequency-Division Multiplexing (OFDM) symbol, which carry one or more bits of information. In Fig. 2B, the frequency domain is represented on the vertical axes and the time domain on the horizontal axes. Each column in Fig. 2B may represent a particular carrier bandwidth in the frequency domain and one OFDM symbol duration in time domain. The total carrier bandwidth may be divided into a number of OFDM sub-carriers (In Fig. 2B, it is divided into 12 OFDM sub-carriers). Each sub-carrier may represent one RE over one OFDM symbol duration. In Fig. 2B, there are 14 OFDM symbols (in time) in one subframe.

As is particularly shown in Fig. 2B, some of the REs may be Long Term Evolution (LTE) Cell-Specific Reference Signal (CRS) REs and other of the REs may be LTE Physical Data Control Channel (PDCCH) REs. These REs may correspond to legacy, non-NB-IoT REs. Starting at the fourth OFDM symbol (i.e., occupying the last 11 OFDM symbols of the subframe and including 12 sub-carriers), however, many of the REs are NSSS REs, which, as mentioned, may be used to perform time and frequency synchronization. For in-band mode, on REs used by LTE CRS, the NSSS may be punctured by LTE CRS (i.e., the LTE CRS symbols that are in the last 11 OFDM symbols). When receiving an NSSS subframe, UE 103 may use the NSSS REs to calculate a number of channel estimation parameters, such as frequency offset information and multi-path distortion related parameters. The calculated channel parameters may be used to optimize the decoding and/or demodulation. The NSSS subframes may be transmitted in the tenth subframe (subframe nine using zero based counting) of alternate radio frames, which results in a period of 20 ms.

Fig. 2C is a diagram illustrating a NPBCH subframe in additional detail. As shown, the REs in the NPBCH subframe include LTE CRS REs, LTE PDCCH REs, Narrowband Reference Signal (NRS) Port 0 REs, and NRS Port 1 REs. The NRS may be used to assist a UE in finding a suitable cell for attachment. For example, in order to find a suitable cell, UE 103 may first measures the received power and quality of the NRS, and compare these values to cell specific thresholds, to determine if UE 103 is in the coverage of that cell. Demodulation may be based on NRS, which allows UE 103 to decode the NPBCH without knowledge of the LTE Physical Resource Block (PRB).

As is further shown in Fig. 2C, the majority of the REs in the NPBCH subframe may be used to transmit the NPBCH. The NPBCH may be used, for example, to signal the NB-IoT Master Information Block (N-MIB). The NPBCH may be transmitted in subframe zero of every radio frame, resulting in a period of 10 ms.

For NB-IoT networks, only one physical resource block (PRB) may be used for transmission. As shown in Fig. 2C, the number of NRS antenna ports may be two at maximum. This means that there are at most 16 NRS REs available in each NPBCH subframe. For a worse case, when there is only one NRS antenna port, there would be only 8 NRS REs available for the UE to perform channel estimation. On the other hand, the target SNR for extreme coverage enhancement may be about -12dB. It can be difficult for the receiver to conduct accurate channel estimation for NPBCH based on these limited NRS resources when the SNR level is very low.

According to the existing NB-IoT protocols, the repetition level is fixed at 64 times of one N-MIB, which carries the most important information, such as System Frame Number. This

N-MIB will be broadcasted through the NB-IoT Physical Broadcast Channel (NPBCH). In general, the signal-to-noise ratio (SNR) requirement is set to a level corresponding to NPBCH block error rate (BLER) of 1%. It has been found that, for existing NB-IoT system configuration settings, to achieve NPBCH BLER = 1%, the SNR level should be no less than -9dB. However, as a requirement of coverage enhancement in NB-IoT networks, the target SNR level may be about -12dB for NB-IoT Physical Control Channel (NPDCCH), which results in BLER of 1%. Normally, the NPBCH transmission should be more robust than NPDCCH. This means that, to achieve the same BLER=1%, NPBCH should require a lower SNR level than NPDCCH.

As discussed in the previous paragraph, the SNR level (approximately -9dB) for NPBCH to achieve BLER=1%, is about 3dB larger than the SNR level (approximately -12dB) needed for NPDCCH to achieve BLER=1%. This SNR gap implies a coverage constraint associated with the system information acquisition if, for example, the system is working under a channel condition where SNR is about -12dB. To improve the robustness of NPDCCH/NPDSCH transmission, in various channel conditions, various repetition levels are applied. For example, the repetition level of an NPDCCH transmission can be a few hundred times for the extreme coverage enhancement. An issue with NPBCH transmission, however, is that the maximum repetition level is fixed at 64 times over a 640 ms transmission time interval (TTI), regardless of coverage conditions. In addition, since the N-MIB data block conveyed by the NPBCH may be varied from one TTI to another, without a long term assumption about the stability of the N-MIB TTI, the UE cannot assume that multiple N-MIB TTIs can be reliably combined to improve performance.

Consistent with techniques described herein, the receiver at UE 103 may initially derive the channel state information associated with the NSSS subframe, and then make use of this information for channel estimation of the NPBCH subframe that is next to (time-wise) of the NSSS subframe. In this manner, channel estimation can be improved and BLER performance at UE 103 may be improved.

Fig. 3 is a flow chart illustrating an example process 300 for performing NPBCH channel state estimation. Process 300 may be performed by UE 103.

As illustrated, process 300 may include estimating the channel state information of an NSSS subframe (block 310). The determined channel state estimation parameters may include parameters describing an amount of frequency offset and multi-path fading that is currently associated with the UE.

Process 300 may further include estimating the channel state information for NPBCH based on the NSSS channel state information (block 320). For example, in one embodiment, the channel parameters estimated in block 310 may be used for the NPBCH subframe. Alternatively

or additionally, the channel parameters estimated in block 310 may be used as a factor in estimating the channel parameters for the NPBCH subframe. For example, certain channel parameters may be used from the NSSS subframe and other channel parameters, which may be directly calculated for the NPBCH subframe, may also be used. Alternatively or additionally,
5 both the NSSS and NRS REs may be jointly used to estimate the channel parameters.

In one implementation, the channel state information that is determined in block 310 and/or block 320 may be based on using the EPA-5Hz (Extended Pedestrian A) and/or the ETU-1Hz (Extended Typical Urban) NB-IoT channel models.

In some embodiments, the estimation of the channel state information based on the
10 NSSS channel state information may only be performed at every other frame. For example, as shown in Fig. 2A, an NSSS subframe may immediately precede a NPBCH subframe at every other frame. Accordingly, the estimation of the channel state information based on the NSSS channel state information may only be performed when the NSSS channel state information immediately precedes the NPBCH subframe.

15 Process 300 may further include demodulating and/or decoding the NPBCH using the estimated channel state information for the NPBCH subframe (block 330). Because the NSSS subframe is received close-in-time to the NPBCH subframe, the channel state information estimated for the NSSS subframe is likely to still apply to the NPBCH subframe. In particular, the mobility state for NB-IoT devices tends to be low. With low mobility, channel conditions are
20 likely to be somewhat constant in time. Additionally, because the number of NSSS REs is large, it can be relatively easier, compared with the NPBCH NRS, to mitigate the detrimental impact of additive white Gaussian noise (AWGN) when SNR very low, such as -12dB. Further, for non-anchor NB-IoT transmission, the NPSS/NSSS/NPBCH may be transmitted on the anchor PRB, and the NPDCCH and NPDSCH can be transmitted on a non-anchor PRB. In this case, it
25 may be not feasible for the receiver to conduct “cross-subframe” channel estimation based on NRS in NPBCH, NPDCCH and/or NPDSCH.

Fig. 4 illustrates example components of a device 400 in accordance with some embodiments. In some embodiments, the device 400 may include application circuitry 402, baseband circuitry 404, Radio Frequency (RF) circuitry 406, front-end module (FEM) circuitry
30 408, one or more antennas 410, and power management circuitry (PMC) 412 coupled together at least as shown. The components of the illustrated device 400 may be included in a UE or a RAN node. In some embodiments, the device 400 may include less elements (e.g., a RAN node may not utilize application circuitry 402, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 400 may include additional elements
35 such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface.

In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

The application circuitry 402 may include one or more application processors. For example, the application circuitry 402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device 400. In some embodiments, processors of application circuitry 402 may process IP data packets received from an EPC.

The baseband circuitry 404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 404 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 406 and to generate baseband signals for a transmit signal path of the RF circuitry 406. Baseband processing circuitry 404 may interface with the application circuitry 402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 406. For example, in some embodiments, the baseband circuitry 404 may include a third generation (3G) baseband processor 404A, a fourth generation (4G) baseband processor 404B, a fifth generation (5G) baseband processor 404C, or other baseband processor(s) 404D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry 404 (e.g., one or more of baseband processors 404A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 406. In other embodiments, some or all of the functionality of baseband processors 404A-D may be included in modules stored in the memory 404G and executed via a Central Processing Unit (CPU) 404E. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 404 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 404 may include convolution, tail-biting convolution, turbo, Viterbi, or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry 404 may include one or more audio digital signal processor(s) (DSP) 404F. The audio DSP(s) 404F may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably
5 combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 404 and the application circuitry 402 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 404 may provide for communication
10 compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 404 is configured to support radio communications of more than one
15 wireless protocol may be referred to as multi-mode baseband circuitry.

Baseband circuitry 404 may also include an interface to RF circuitry 406.

RF circuitry 406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 406 may include switches, filters, amplifiers, etc. to facilitate the communication with the
20 wireless network. RF circuitry 406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 408 and provide baseband signals to the baseband circuitry 404. RF circuitry 406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 404 and provide RF output signals to the FEM circuitry 408 for transmission.

In some embodiments, the receive signal path of the RF circuitry 406 may include mixer circuitry 406a, amplifier circuitry 406b and filter circuitry 406c. In some embodiments, the transmit signal path of the RF circuitry 406 may include filter circuitry 406c and mixer circuitry 406a. RF circuitry 406 may also include synthesizer circuitry 406d for synthesizing a frequency for use by the mixer circuitry 406a of the receive signal path and the transmit signal path. In
30 some embodiments, the mixer circuitry 406a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 408 based on the synthesized frequency provided by synthesizer circuitry 406d. The amplifier circuitry 406b may be configured to amplify the down-converted signals and the filter circuitry 406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the
35 down-converted signals to generate output baseband signals. Output baseband signals may be

provided to the baseband circuitry 404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

5 In some embodiments, the mixer circuitry 406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 406d to generate RF output signals for the FEM circuitry 408. The baseband signals may be provided by the baseband circuitry 404 and may be filtered by filter circuitry 406c.

10 In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley
15 image rejection). In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may be configured for super-heterodyne operation.

20 In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the
25 baseband circuitry 404 may include a digital baseband interface to communicate with the RF circuitry 406.

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

30 In some embodiments, the synthesizer circuitry 406d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry 406d may be configured to synthesize an output frequency for use by the mixer circuitry 406a of the RF circuitry 406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 406d may be a fractional $N/N+1$ synthesizer.

5 In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 404 or the applications processor 402 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 402.

10 Synthesizer circuitry 406d of the RF circuitry 406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example
15 embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

20 In some embodiments, synthesizer circuitry 406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each
25 other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 406 may include an IQ/polar converter.

FEM circuitry 408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 410, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry
30 406 for further processing. FEM circuitry 408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 406 for transmission by one or more of the one or more antennas 410. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 406, solely in the FEM 408, or in both the RF circuitry 406 and the FEM 408.

In some embodiments, the FEM circuitry 408 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 406). The transmit signal path of the FEM circuitry 408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 410).

In some embodiments, the PMC 412 may manage power provided to the baseband circuitry 404. In particular, the PMC 412 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 412 may often be included when the device 400 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 412 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

While Fig. 4 shows the PMC 412 coupled only with the baseband circuitry 404. However, in other embodiments, the PMC 412 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 402, RF circuitry 406, or FEM 408.

In some embodiments, the PMC 412 may control, or otherwise be part of, various power saving mechanisms of the device 400. For example, if the device 400 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device 400 may power down for brief intervals of time and thus save power.

If there is no data traffic activity for an extended period of time, then the device 400 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device 400 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device 400 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

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

Processors of the application circuitry 402 and processors of the baseband circuitry 404 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 404, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 404 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY) layer of a UE/RAN node, described in further detail below.

Fig. 5 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry 404 of Fig. 4 may comprise processors 404A-404E and a memory 404G utilized by said processors. Each of the processors 404A-404E may include a memory interface, 504A-704E, respectively, to send/receive data to/from the memory 404G.

The baseband circuitry 404 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 512 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 404), an application circuitry interface 514 (e.g., an interface to send/receive data to/from the application circuitry 402 of Fig. 4), an RF circuitry interface 516 (e.g., an interface to send/receive data to/from RF circuitry 406 of Fig. 4), a wireless hardware connectivity interface 518 (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 520 (e.g., an interface to send/receive power or control signals to/from the PMC 412).

Fig. 6 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Fig. 6 shows a diagrammatic representation of hardware resources 600 including one or more processors (or processor cores) 610, one or more memory/storage devices 620, and one or more communication resources 630, each of which may be communicatively coupled via a bus 640. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 602 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 600

The processors 610 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC),
5 another processor, or any suitable combination thereof) may include, for example, a processor 612 and a processor 614.

The memory/storage devices 620 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 620 may include, but are not limited to any type of volatile or non-volatile memory such as dynamic random access memory
10 (DRAM), static random-access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

The communication resources 630 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 604
15 or one or more databases 606 via a network 608. For example, the communication resources 630 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, NFC components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

Instructions 650 may comprise software, a program, an application, an applet, an app, or
20 other executable code for causing at least any of the processors 610 to perform any one or more of the methodologies discussed herein. The instructions 650 may reside, completely or partially, within at least one of the processors 610 (e.g., within the processor's cache memory), the memory/storage devices 620, or any suitable combination thereof. Furthermore, any portion of the instructions 650 may be transferred to the hardware resources 600 from any combination of
25 the peripheral devices 604 or the databases 606. Accordingly, the memory of processors 610, the memory/storage devices 620, the peripheral devices 604, and the databases 606 are examples of computer-readable and machine-readable media.

A number of examples, relating to implementations of the techniques described above, will next be given.

30 In a first example, a baseband apparatus for User Equipment (UE) may comprise a radio frequency (RF) interface; and one or more processors to: process a Narrowband Secondary Synchronization Signal (NSSS) subframe, received via the RF interface, associated with a Narrowband Internet of Things (NB-IoT) transmission to obtain channel state information describing a radio channel over which the NSSS subframe was transmitted; determine, based on
35 the channel state information for the NSSS subframe, channel state information for a

subsequently received Narrowband Physical Broadcast Channel (NPBCH) subframe; and demodulate or decode the NPBCH subframe based on the determined channel state information for the NPBCH.

5 In example 2, the subject matter of example 1, wherein processing the NSSS subframe to determine the channel state information for the NPBCH subframe is only performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

In example 3, the subject matter of example 2, or any of the preceding examples, wherein processing the NSSS subframe to determine the channel state information for the NPBCH subframe is performed every other frame.

10 In a fourth example, a UE apparatus may comprise a computer-readable medium containing processing instructions; and one or more processors, to execute the processing instructions to: process Narrowband Secondary Synchronization Signal (NSSS) resource elements associated with a Narrowband Internet of Things (NB-IoT) transmission; determine, based on NSSS resource elements, channel state information for a Narrowband Physical
15 Broadcast Channel (NPBCH) subframe; and demodulate or decode the NPBCH subframe based on the determined channel state information.

In example 5, the subject matter of example 4, or any of the preceding examples, wherein the NSSS resource elements are received in a subframe immediately preceding the NPBCH subframe.

20 In example 6, the subject matter of examples 1 or 4, or any of the preceding examples, wherein the channel state information for the NPBCH subframe is determined based both on the NSSS resource elements and on Narrowband Reference Signal (NRS) resource elements.

In example 7, the subject matter of examples 1 or 4, or any of the preceding examples, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-
25 IoT channel models.

In example 8, the subject matter of examples 1 or 4, or any of the preceding examples, wherein the channel state information includes channel state parameters relating to frequency offsets or multi-path distortion.

In a ninth example, a baseband apparatus for a UE may comprise: a radio frequency (RF)
30 interface; and one or more processors to: process a Narrowband Secondary Synchronization Signal (NSSS) subframe, received via the RF interface and associated with a Narrowband Internet of Things (NB-IoT) transmission, to obtain channel state information describing a radio channel over which the NSSS subframe was transmitted; and demodulate or decode a subsequently received Narrowband Physical Broadcast Channel (NPBCH) subframe, received
35 via the RF interface, based on the determined channel state information.

In example 10, the subject matter of example 9, or any of the preceding examples, wherein demodulating or decoding the NPBCH subframe, based on the channel state information determined from the NSSS subframe, is performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

5 In example 11, the subject matter of example 10, or any of the preceding examples, wherein demodulating or decoding the NPBCH subframe, based on the channel state information determined from the NSSS subframe, is performed every other frame.

10 In example 12, the subject matter of example 9, or any of the preceding examples, wherein the NSSS resource elements are received in a subframe immediately preceding the NPBCH subframe.

In example 13, the subject matter of example 9, or any of the preceding examples, wherein the channel state information for the NPBCH subframe is further determined based on Narrowband Reference Signal (NRS) resource elements received in the NPBCH subframe.

15 In example 14, the subject matter of example 9, or any of the preceding examples, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

In example 15, the subject matter of example 9, or any of the preceding examples, wherein the channel state information includes channel state parameters relating to frequency offsets or multi-path distortion.

20 In a 16th example, a UE may comprise: a computer-readable medium containing processing instructions; and one or more processors to execute the processing instructions to: process a Narrowband Secondary Synchronization Signal (NSSS) subframe, associated with a Narrowband Internet of Things (NB-IoT) transmission, to obtain channel state information describing a radio channel over which the NSSS subframe was transmitted; and demodulate or
25 decode a subsequently received Narrowband Physical Broadcast Channel (NPBCH) subframe based on the determined channel state information.

30 In example 17, the subject matter of example 16, or any of the preceding examples, wherein demodulating or decoding the NPBCH subframe, based on the channel state information determined from the NSSS subframe, is performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

In example 18, the subject matter of example 16, or any of the preceding examples, wherein demodulating or decoding the NPBCH subframe, based on the channel state information determined from the NSSS subframe, is performed every other frame.

In example 19, the subject matter of example 16, or any of the preceding examples, wherein the NSSS resource elements are received in a subframe immediately preceding the NPBCH subframe.

5 In example 20, the subject matter of example 16, or any of the preceding examples, wherein the channel state information for the NPBCH subframe is further determined based on Narrowband Reference Signal (NRS) resource elements received in the NPBCH subframe.

In example 21, the subject matter of example 16, or any of the preceding examples, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

10 In a 22nd example, a method, implemented by a UE, may comprise processing a Narrowband Secondary Synchronization Signal (NSSS) subframe, received via the RF interface, associated with a Narrowband Internet of Things (NB-IoT) transmission to obtain channel state information describing a radio channel over which the NSSS subframe was transmitted; determining, based on the channel state information for the NSSS subframe, channel state
15 information for a subsequently received Narrowband Physical Broadcast Channel (NPBCH) subframe; and demodulating or decoding the NPBCH subframe based on the determined channel state information for the NPBCH.

In example 23, the subject matter of example 22, or any of the preceding examples, wherein using the NSSS subframe to determine the channel state information for the NPBCH
20 subframe is only performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

In example 24, the subject matter of example 22, or any of the preceding examples, wherein using the NSSS subframe to determine the channel state information for the NPBCH subframe is performed every other frame.

25 In example 25, the subject matter of example 22, or any of the preceding examples, wherein the channel state information for the NPBCH subframe is determined based both on the NSSS resource elements and on Narrowband Reference Signal (NRS) resource elements.

In example 26, the subject matter of example 22, or any of the preceding examples, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.
30

In example 27, the subject matter of example 22, or any of the preceding examples, wherein the channel state information includes channel state parameters relating to frequency offsets or multi-path distortion.

In a 28th example, User Equipment may comprise: means for processing a Narrowband
35 Secondary Synchronization Signal (NSSS) subframe, received via the RF interface, associated

with a Narrowband Internet of Things (NB-IoT) transmission to obtain channel state information describing a radio channel over which the NSSS subframe was transmitted; means for determining, based on the channel state information for the NSSS subframe, channel state information for a subsequently received Narrowband Physical Broadcast Channel (NPBCH) subframe; and means for demodulating or decoding the NPBCH subframe based on the determined channel state information for the NPBCH.

In example 29, the subject matter of example 28, or any of the preceding examples, wherein using the NSSS subframe to determine the channel state information for the NPBCH subframe is only performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

In example 30, the subject matter of example 28, or any of the preceding examples, wherein using the NSSS subframe to determine the channel state information for the NPBCH subframe is performed every other frame.

In example 31, the subject matter of example 28, or any of the preceding examples, wherein the channel state information for the NPBCH subframe is determined based both on the NSSS resource elements and on Narrowband Reference Signal (NRS) resource elements.

In example 32, the subject matter of example 28, or any of the preceding examples, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

In example 33, the subject matter of example 28, or any of the preceding examples, wherein the channel state information includes channel state parameters relating to frequency offsets or multi-path distortion.

In the preceding specification, various embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without departing from the broader scope as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

For example, while series of signals and/or operations have been described with regard to Fig. 3, the order of the signals/operations may be modified in other implementations. Further, non-dependent signals may be performed in parallel.

It will be apparent that example aspects, as described above, may be implemented in many different forms of software, firmware, and hardware in the implementations illustrated in the figures. The actual software code or specialized control hardware used to implement these aspects should not be construed as limiting. Thus, the operation and behavior of the aspects were

described without reference to the specific software code—it being understood that software and control hardware could be designed to implement the aspects based on the description herein.

Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to be limiting. In fact, many
5 of these features may be combined in ways not specifically recited in the claims and/or disclosed in the specification.

No element, act, or instruction used in the present application should be construed as critical or essential unless explicitly described as such. An instance of the use of the term "and," as used herein, does not necessarily preclude the interpretation that the phrase "and/or" was
10 intended in that instance. Similarly, an instance of the use of the term "or," as used herein, does not necessarily preclude the interpretation that the phrase "and/or" was intended in that instance. Also, as used herein, the article "a" is intended to include one or more items, and may be used interchangeably with the phrase "one or more." Where only one item is intended, the terms "one," "single," "only," or similar language is used.

WHAT IS CLAIMED IS:

1. A baseband apparatus for User Equipment (UE), comprising:
a radio frequency (RF) interface; and
one or more processors to:

5 process a Narrowband Secondary Synchronization Signal (NSSS) subframe,
received via the RF interface, associated with a Narrowband Internet of Things (NB-IoT)
transmission to obtain channel state information describing a radio channel over which the
NSSS subframe was transmitted;
determine, based on the channel state information for the NSSS subframe,
10 channel state information for a subsequently received Narrowband Physical Broadcast Channel
(NPBCH) subframe; and
demodulate or decode the NPBCH subframe based on the determined channel
state information for the NPBCH.

15 2. The apparatus of claim 1, wherein processing the NSSS subframe to determine
the channel state information for the NPBCH subframe is only performed when the NPBCH
subframe is received as a next subframe relative to the NSSS subframe.

20 3. The apparatus of claim 2, wherein processing the NSSS subframe to determine
the channel state information for the NPBCH subframe is performed every other frame.

4. User Equipment (UE) apparatus comprising:
a computer-readable medium containing processing instructions; and
one or more processors, to execute the processing instructions to:

25 process Narrowband Secondary Synchronization Signal (NSSS) resource
elements associated with a Narrowband Internet of Things (NB-IoT) transmission;

determine, based on NSSS resource elements, channel state information for a Narrowband Physical Broadcast Channel (NPBCH) subframe; and
demodulate or decode the NPBCH subframe based on the determined channel state information.

5

5. The apparatus of claim 4, wherein the NSSS resource elements are received in a subframe immediately preceding the NPBCH subframe.

6. The apparatus of claim 1 or 4, wherein the channel state information for the
10 NPBCH subframe is determined based both on the NSSS resource elements and on Narrowband Reference Signal (NRS) resource elements.

7. The apparatus of claim 1 or 4, wherein the channel state information is
determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

15

8. The apparatus of claim 1 or 4, wherein the channel state information includes channel state parameters relating to frequency offsets or multi-path distortion.

9. A baseband apparatus for User Equipment (UE), comprising:

20 a radio frequency (RF) interface; and

one or more processors to:

process a Narrowband Secondary Synchronization Signal (NSSS) subframe,
received via the RF interface and associated with a Narrowband Internet of Things (NB-IoT)
transmission, to obtain channel state information describing a radio channel over which the
25 NSSS subframe was transmitted; and

demodulate or decode a subsequently received Narrowband Physical Broadcast

Channel (NPBCH) subframe, received via the RF interface, based on the determined channel state information.

10. The apparatus of claim 9, wherein demodulating or decoding the NPBCH
5 subframe, based on the channel state information determined from the NSSS subframe, is performed when the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

11. The apparatus of claim 10, wherein demodulating or decoding the NPBCH
10 subframe, based on the channel state information determined from the NSSS subframe, is performed every other frame.

12. The apparatus of claim 9, wherein the NSSS resource elements are received in a
subframe immediately preceding the NPBCH subframe.
15

13. The apparatus of claim 9, wherein the channel state information for the NPBCH
subframe is further determined based on Narrowband Reference Signal (NRS) resource elements received in the NPBCH subframe.

20 14. The apparatus of claim 9, wherein the channel state information is determined using the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

15. The apparatus of claim 9, wherein the channel state information includes channel
state parameters relating to frequency offsets or multi-path distortion.
25

16. A User Equipment (UE) comprising:

a computer-readable medium containing processing instructions; and
one or more processors to execute the processing instructions to:

process a Narrowband Secondary Synchronization Signal (NSSS) subframe,
associated with a Narrowband Internet of Things (NB-IoT) transmission, to obtain channel state
5 information describing a radio channel over which the NSSS subframe was transmitted; and
demodulate or decode a subsequently received Narrowband Physical Broadcast
Channel (NPBCH) subframe based on the determined channel state information.

17. The UE of claim 16, wherein demodulating or decoding the NPBCH subframe,
10 based on the channel state information determined from the NSSS subframe, is performed when
the NPBCH subframe is received as a next subframe relative to the NSSS subframe.

18. The UE of claim 16, wherein demodulating or decoding the NPBCH subframe,
based on the channel state information determined from the NSSS subframe, is performed every
15 other frame.

19. The UE of claim 16, wherein the NSSS resource elements are received in a
subframe immediately preceding the NPBCH subframe.

20. The UE of claim 16, wherein the channel state information for the NPBCH
subframe is further determined based on Narrowband Reference Signal (NRS) resource elements
received in the NPBCH subframe.

21. The UE of claim 16, wherein the channel state information is determined using
25 the EPA-5Hz or the ETU-1Hz NB-IoT channel models.

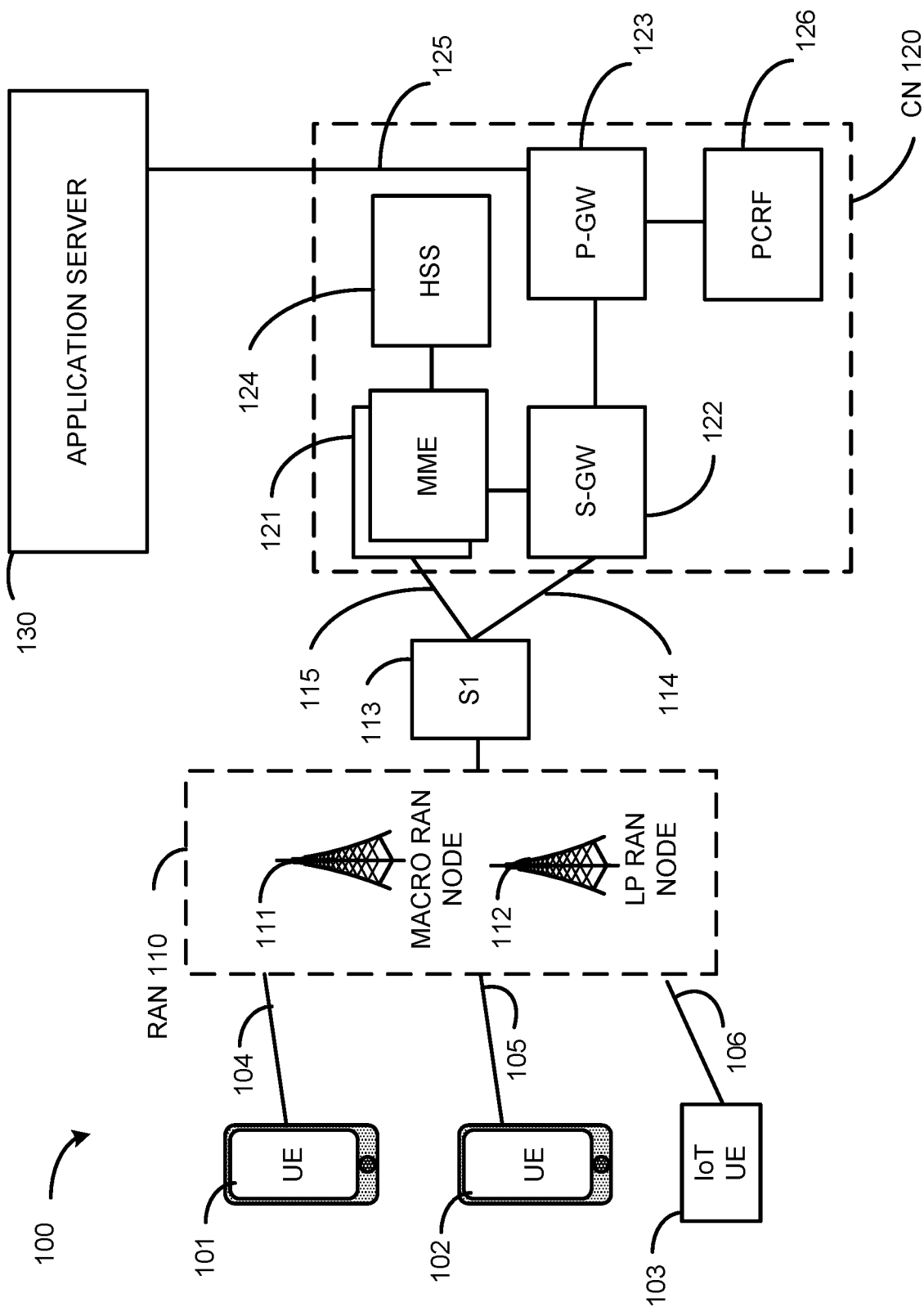


Fig. 1

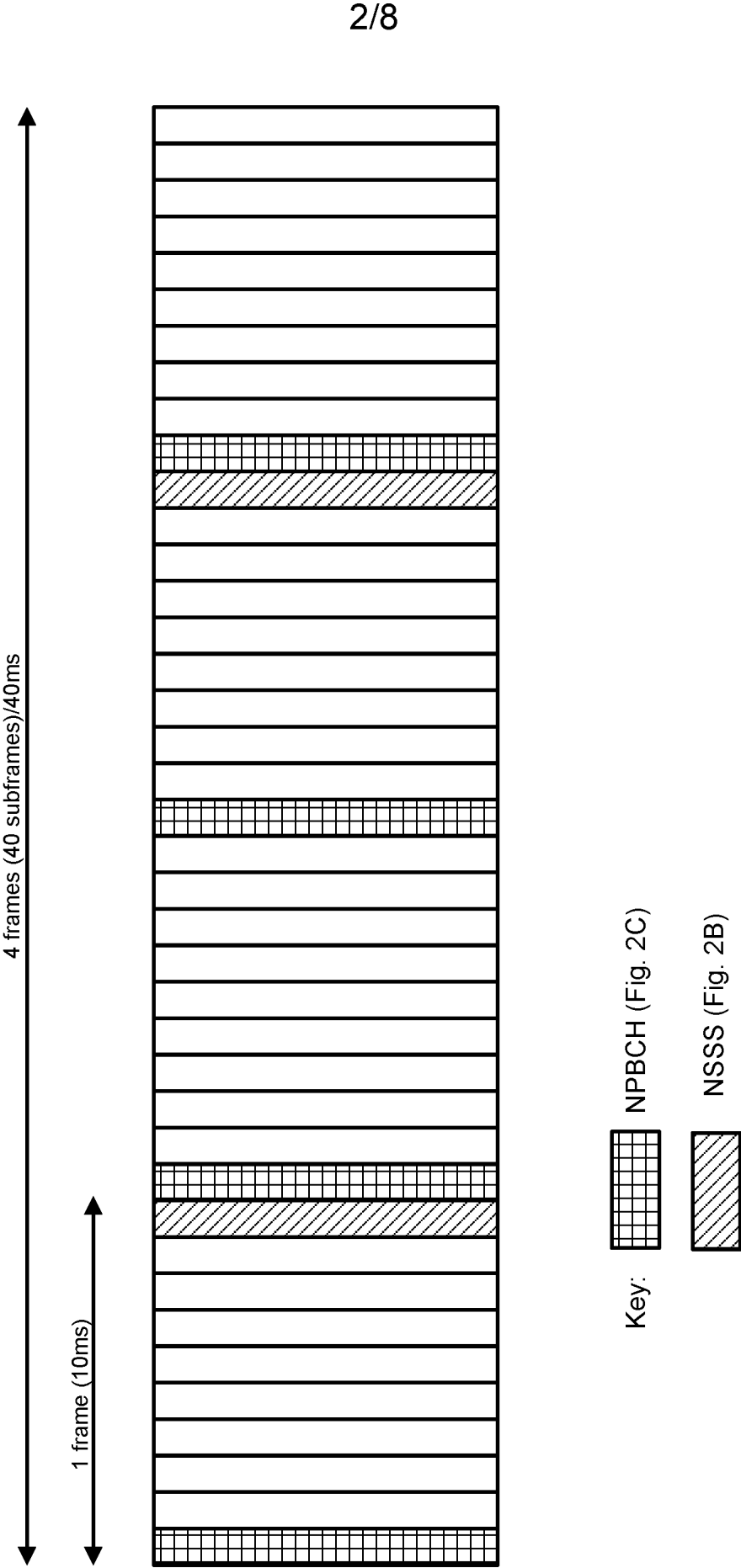


Fig. 2A

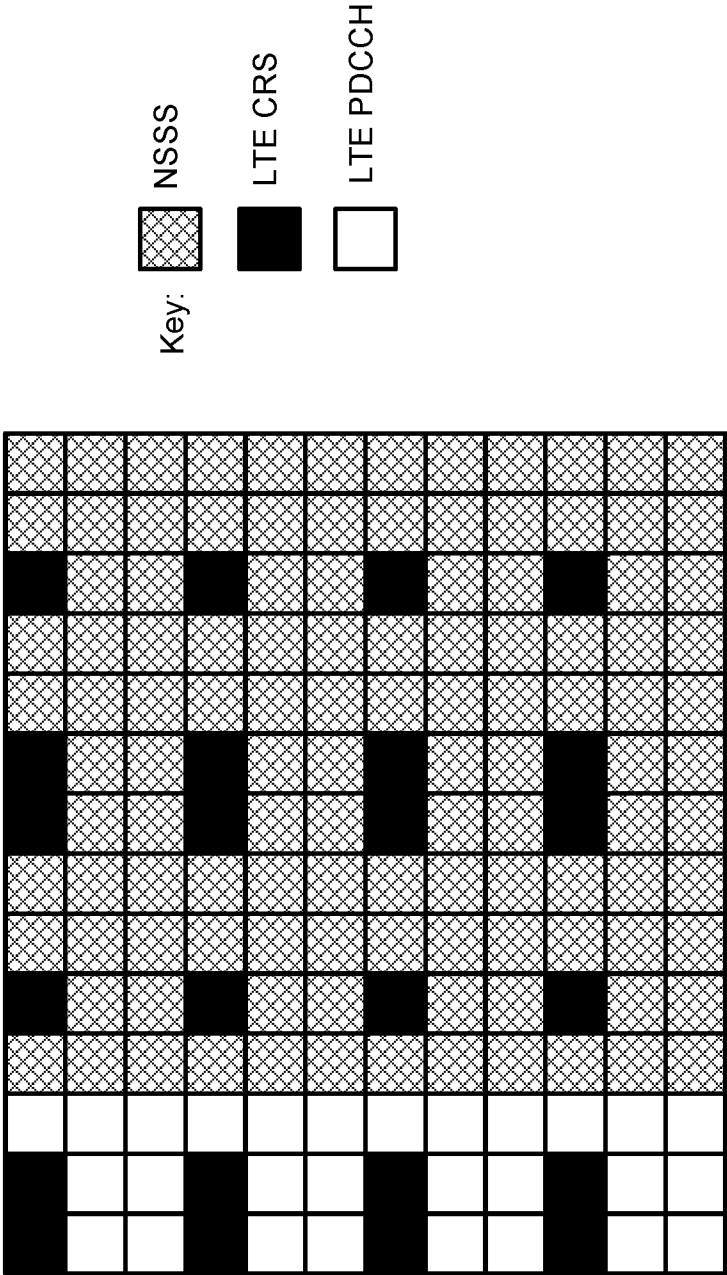


Fig. 2B

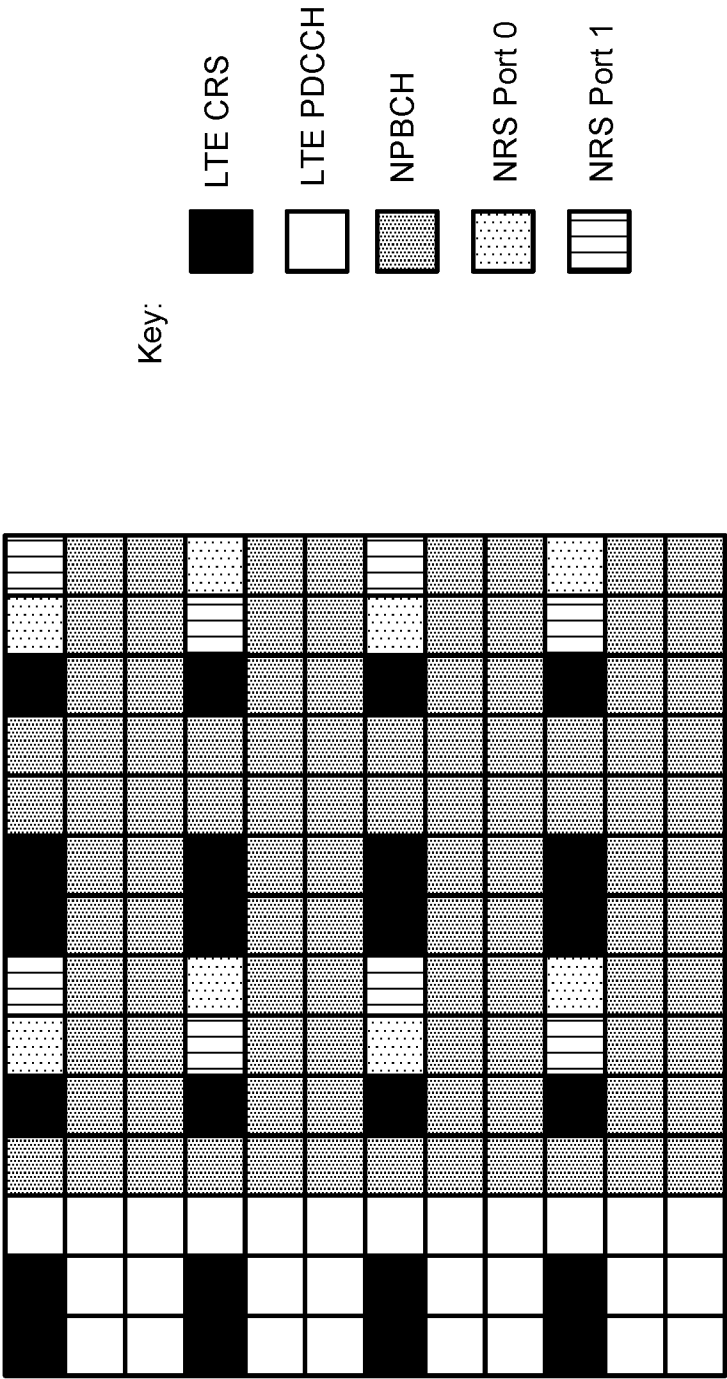
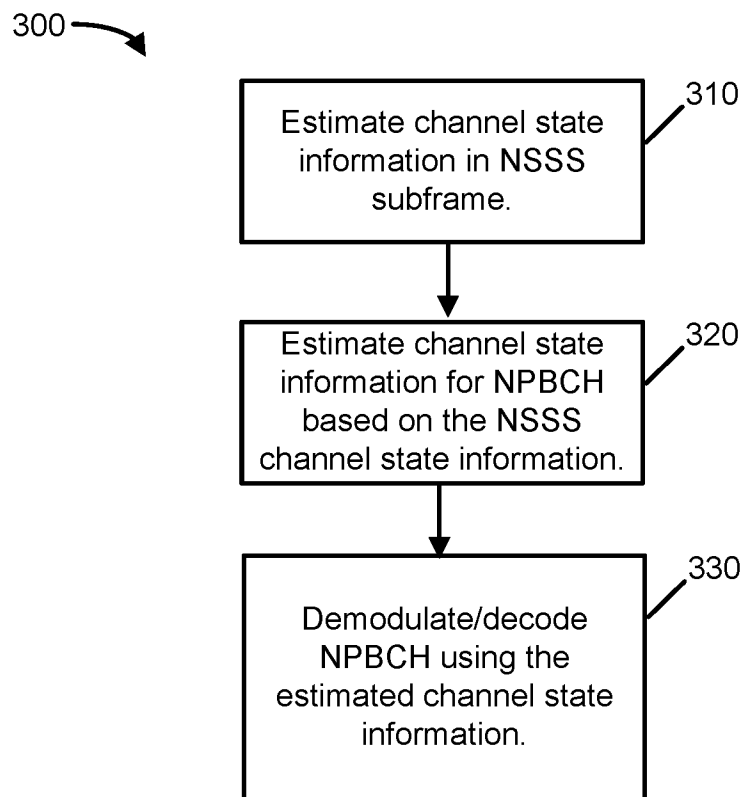


Fig. 2C

5/8

**Fig. 3**

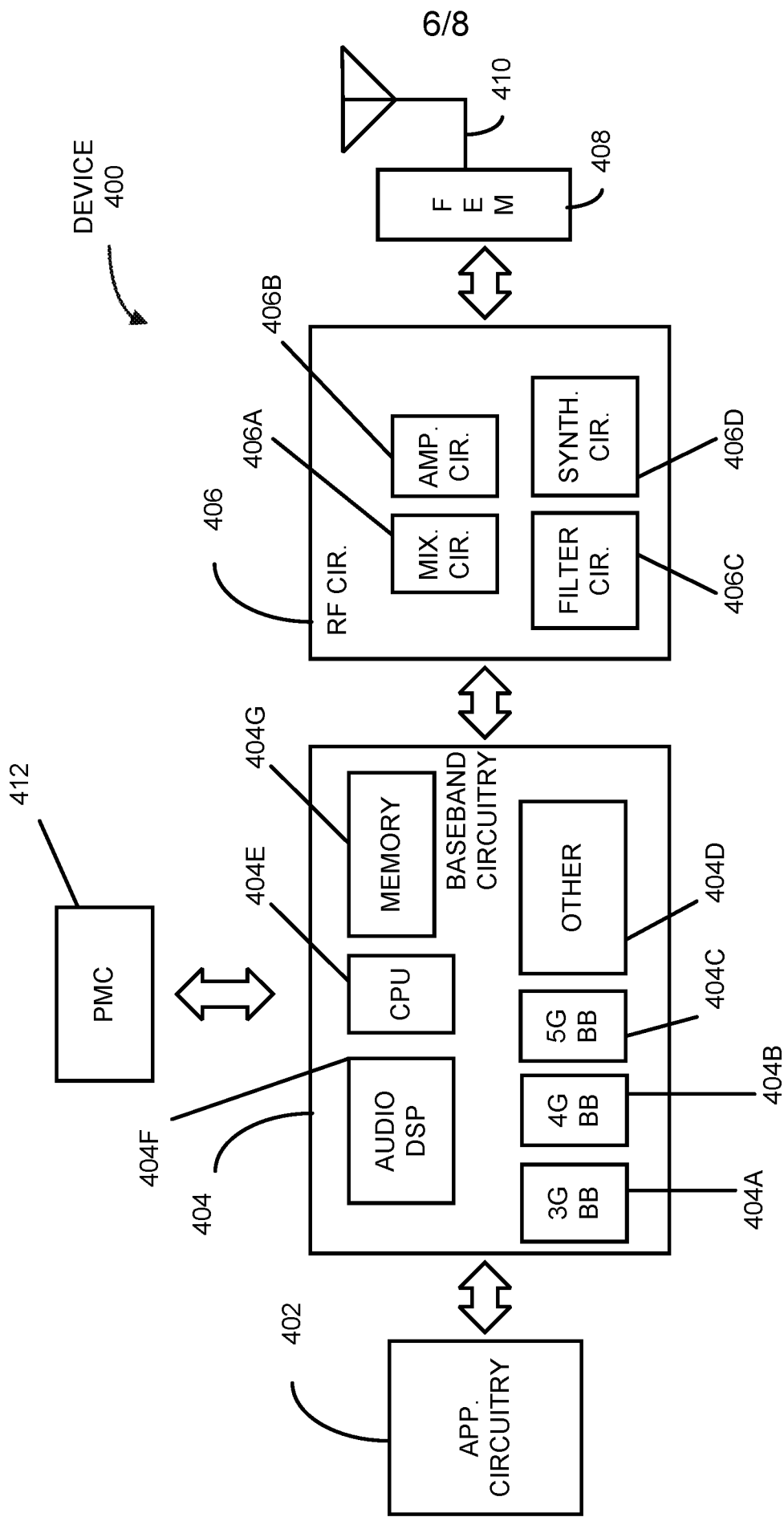


Fig. 4

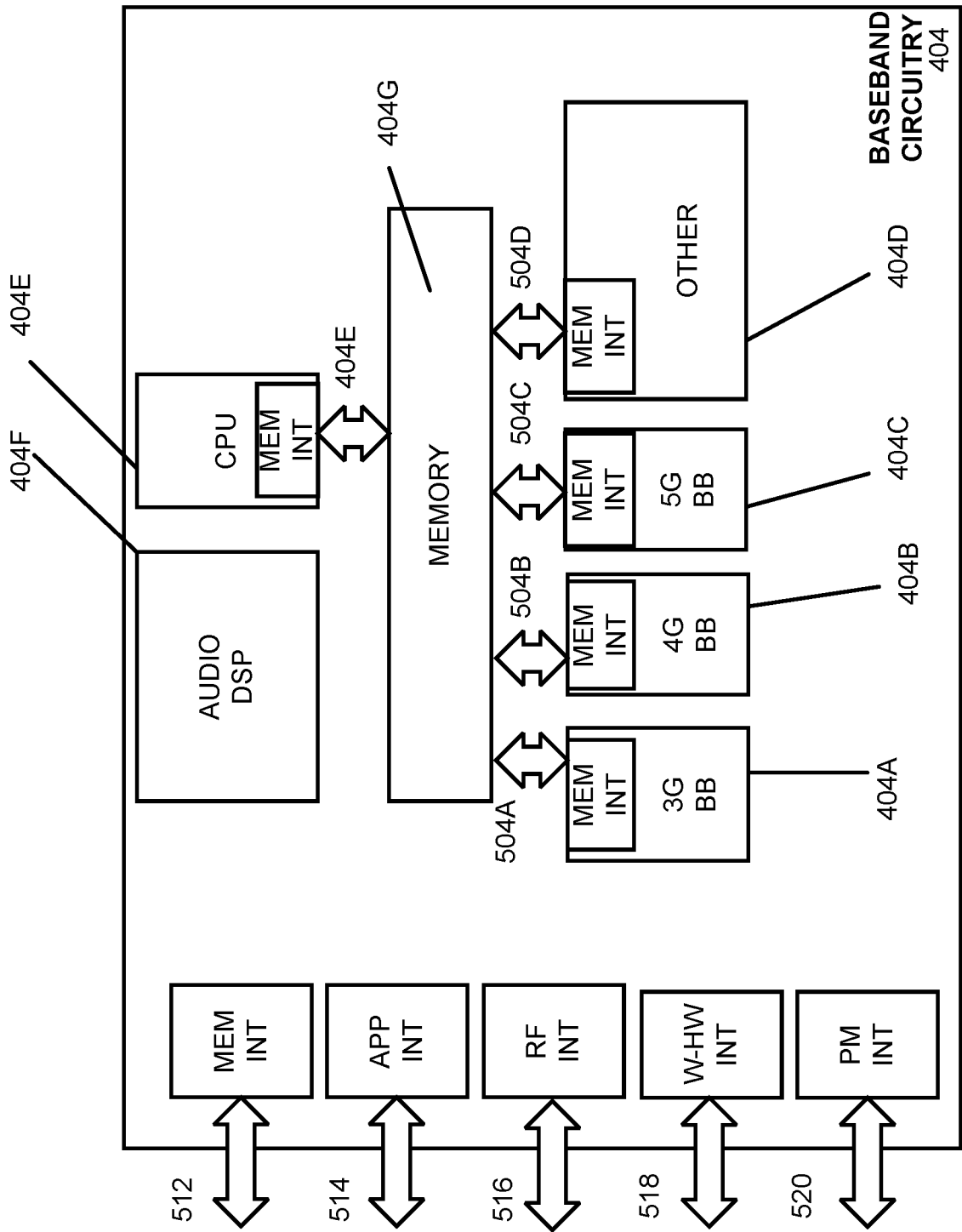


Fig. 5

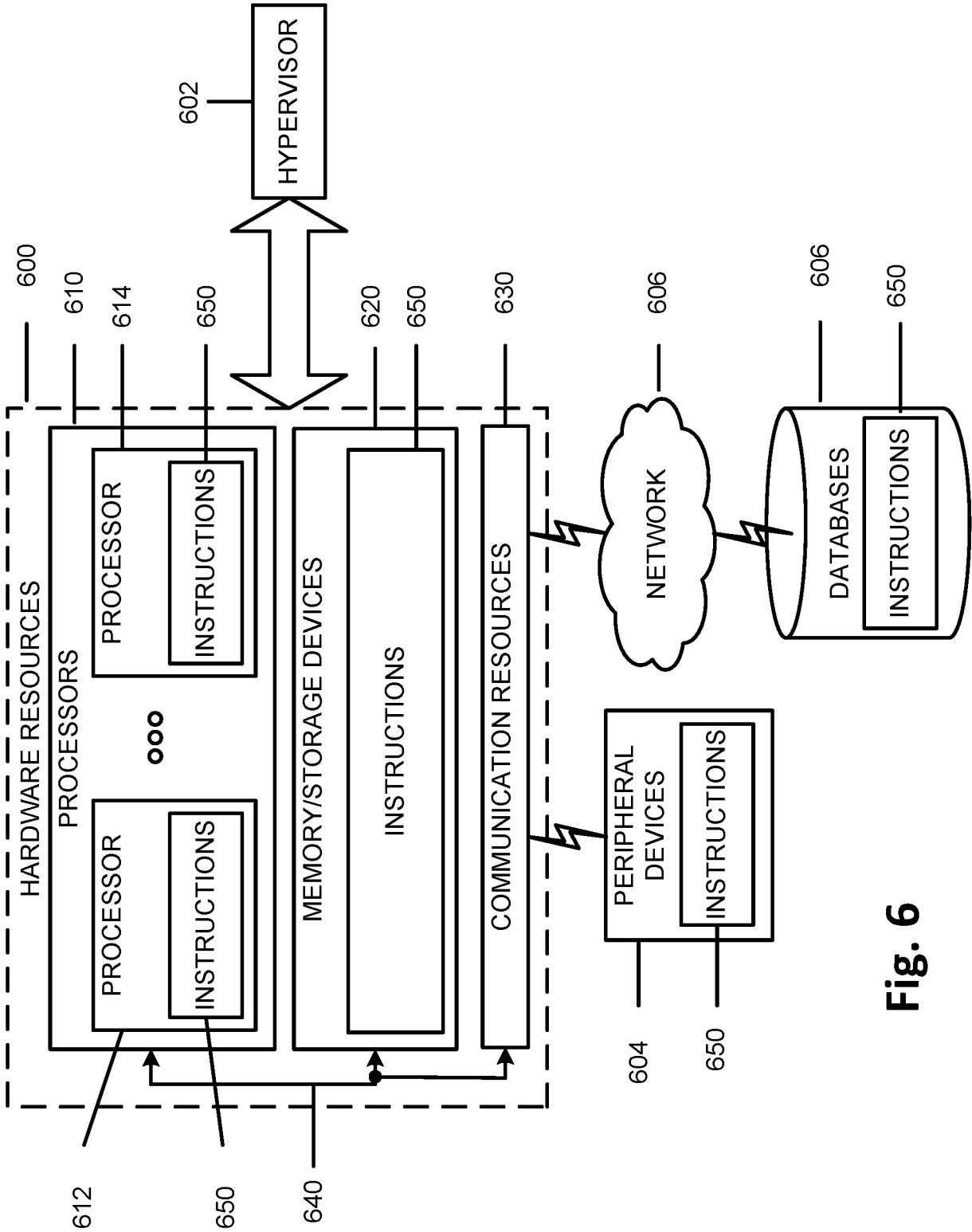


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/047669

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L5/00 H04L25/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SPREADTRUM COMMUNICATIONS: "Discussion on the reference signal design for NB-IoT", 3GPP DRAFT; R1-160161 DISCUSSION ON THE REFERENCE SIGNAL DESIGN FOR NB-IOT, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CED , vol. RAN WG1, no. Budapest, HU; 20160118 - 20160120 17 January 2016 (2016-01-17), XP051053480, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2016-01-17] section 2.1; figure 1 ----- -/-	1-21



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

17 October 2017

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/047669

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SPREADTRUM COMMUNICATIONS: "Performance evaluation of NB-PBCH", 3GPP DRAFT; R1-161963 PERFORMANCE EVALUATION OF NB-PBCH, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Sophia- Antipolis, France; 20160322 - 20160324 15 March 2016 (2016-03-15), XP051080920, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_AH/LTE_NB-IoT_1603/Docs/ [retrieved on 2016-03-15] section 2.1 and 2.2; figure 1	1-21
X	SPREADTRUM COMMUNICATIONS: "On the reference signal design for NB-IoT", 3GPP DRAFT; R1-161962 ON THE REFERENCE SIGNAL DESIGN FOR NB-IOT, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Sophia Antipolis, FRANCE; 20160322 - 20160324 15 March 2016 (2016-03-15), XP051080919, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_AH/LTE_NB-IoT_1603/Docs/ [retrieved on 2016-03-15] the whole document	1-21
X	SPREADTRUM COMMUNICATIONS: "Further discussion on the reference signal design for NB-IoT", 3GPP DRAFT; R1-160820 FURTHER DISCUSSION ON THE REFERENCE SIGNAL DESIGN FOR NB-IOT, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIP , vol. RAN WG1, no. Malta; 20160215 - 20160219 14 February 2016 (2016-02-14), XP051054146, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2016-02-14] section 2	1-21

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/047669

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2017/039739 A1 (INTEL IP CORP [US]) 9 March 2017 (2017-03-09) figure 2 -----	1-5, 9-12, 16-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/047669

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017039739 A1	09-03-2017	TW 201720200 A WO 2017039739 A1	01-06-2017 09-03-2017
