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(71) Applicant: INTEL IP CORPORATION [US/US]; 2200 Mission College Boulevard, Santa Clara, California 95054 (US).

(72) Inventors: BENDLIN, Ralf; 301 Arrowhead Trail, Cedar Park, TX 78613 (US). CHO, Joonyoung; 5917 NW Samuel Dr., Portland, Oregon 97229 (US). PHUYAL, Umesh; 20782 NW Longbow Ln., Beaverton, Oregon 97006 (US).

HE, Hong; 8F, Raycom Infotech Park A. No. 2, KeXueYuan South Road, HaiDian District, Beijing, 11 100190 (CN).

(74) Agent: ESCHWEILER, Thomas G.; Eschweiler & Potashnik, LLC, 629 Euclid Avenue, Suite 1000, Cleveland, Ohio 44114 (US).

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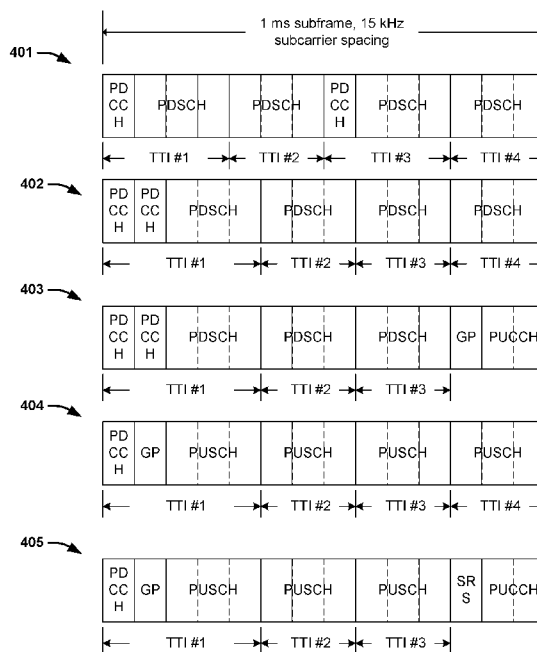


FIG. 4

(57) Abstract: An apparatus is configured to be employed within one or more user equipment (UE) devices. The apparatus comprises baseband circuitry, which includes one or more processors. The one or more processors are configured to determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels. The one or more processors are also configured to generate a mapping for one or more transport blocks of a transport channel based on the determined TTI and map the one or more transport blocks to the PHY layer based on the generated mapping.



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TRANSPORT CHANNEL TO PHYSICAL CHANNEL MAPPING WITH SCALABLE TRANSMISSION TIME INTERVALS

FIELD

[0001] The present disclosure relates to mobile communication and, more particularly to channel mapping techniques for mobile communications.

RELATED APPLICATIONS

[0002] This application claims the benefit of U.S. Provisional Application No. 62/336,464, filed May 13, 2016.

BACKGROUND

[0003] Mobile communication, including cellular communication, involves the transfer of data between mobile devices. The use of mobile communication is continuously increasing. Additionally, the bandwidth or data rate used and needed for mobile communications is continuously increasing.

[0004] One of the factors contributing to the data rate is the arrangement of data sent between mobile devices. Various data arrangements can degrade or limit data rate and degrade or limit reliability.

[0005] Techniques are needed to facilitate reliability and data rates for mobile communication.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a diagram illustrating an arrangement for mobile communications that facilitates transport channel to physical channel mapping with scalable or reduced transmission time intervals.

[0007] FIG. 2 is a diagram illustrating examples of subcarrier spacing for varied frequencies.

[0008] FIG. 3 is a diagram illustrating transport channel to PHY layer mappings in accordance with an embodiment.

[0009] FIG. 4 is a diagram illustrating transport channel to PHY layer mappings in accordance with an embodiment.

- [0010] FIG. 5 is a flow diagram illustrating a method of mapping transport channel transport blocks to physical layer symbols by a node in accordance with an embodiment.
- [0011] FIG. 6 is a diagram illustrating transport channel to PHY layer mappings using a queue and a transmission time interval of 0.5 ms in accordance with an embodiment.
- [0012] FIG. 7 is a diagram illustrating transport channel to PHY layer mappings using a queue and a transmission time interval of 0.25 ms in accordance with an embodiment.
- [0013] FIG. 8 is a diagram illustrating transport channel to PHY layer mappings using a queue and a transmission time interval of 0.125 in accordance with an embodiment.
- [0014] FIGS. 9A and 9B are diagrams illustrating transport channel to PHY layer mappings using a 17.5 subcarrier frequency in accordance with an embodiment.
- [0015] FIG. 10 illustrates an architecture of a system of a network in accordance with some embodiments.
- [0016] FIG. 11 illustrates example components of a device in accordance with some embodiments.
- [0017] FIG. 12 illustrates example interfaces of baseband circuitry in accordance with some embodiments.
- [0018] FIG. 13 is an illustration of a control plane protocol stack in accordance with some embodiments.
- [0019] FIG. 14 is an illustration of a user plane protocol stack in accordance with some embodiments.
- [0020] FIG. 15 illustrates components of a core network in accordance with some embodiments.
- [0021] FIG. 16 is a block diagram illustrating components, according to some example embodiments, of a system to support NFV.
- [0022] FIG. 17 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

- [0023] The present disclosure will now be described with reference to the attached drawing figures, wherein like reference numerals are used to refer to like elements throughout, and wherein the illustrated structures and devices are not necessarily drawn

to scale. As utilized herein, terms “component,” “system,” “interface,” and the like are intended to refer to a computer-related entity, hardware, software (e.g., in execution), and/or firmware. For example, a component can be a processor (e.g., a microprocessor, a controller, or other processing device), a process running on a processor, a controller, an object, an executable, a program, a storage device, a computer, a tablet PC, an electronic circuit and/or a mobile phone with a processing device. By way of illustration, an application running on a server and the server can also be a component. One or more components can reside within a process, and a component can be localized on one computer and/or distributed between two or more computers. A set of elements or a set of other components can be described herein, in which the term “set” can be interpreted as “one or more.”

[0024] Further, these components can execute from various computer readable storage media having various data structures stored thereon such as with a module, for example. The components can communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network, such as, the Internet, a local area network, a wide area network, or similar network with other systems via the signal).

[0025] As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, in which the electric or electronic circuitry can be operated by a software application or a firmware application executed by one or more processors. The one or more processors can be internal or external to the apparatus and can execute at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts; the electronic components can include one or more processors therein to execute software and/or firmware that confer(s), at least in part, the functionality of the electronic components.

[0026] Use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as

used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form. Furthermore, to the extent that the terms "including", "includes", "having", "has", "with", or variants thereof are used in either the detailed description and the claims, such terms are intended to be inclusive in a manner similar to the term "comprising".

[0027] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[0028] The Long-term Evolution (LTE) communications standard of the Third Generation Partnership Project (3GPP) defines numerologies, such as subcarrier spacings (7.5kHz and 15kHz), cyclic prefix (CP) lengths (normal and extended CP), transmission time interval (TTI) durations (1ms and 40ms), system bandwidths (1.4, 3, 5, 10, 15, 20MHz).

[0029] For the LTE standard, a subframe is defined as a time interval of $30,720 \times T_s$ = 1ms where T_s is the basic time unit of LTE and 32.55208 micro seconds. Due to this fixed time interval definition, all subframes are of length 1ms regardless of the numerology. Additionally, different numerologies result in a different number of symbols per subframe. For example, with 15kHz subcarrier spacing and normal CP, one subframe has 14 symbols in LTE whereas for the same subcarrier spacing with an extended CP, this number reduces to 12 to account for the longer CP per orthogonal frequency division multiplexing (OFDM) symbol. For smaller subcarrier spacings, which have longer OFDM symbol durations, the number of symbols per subframe is further reduced to six as is the case for 7.5kHz subcarrier spacing.

[0030] The subcarrier spacing is an important design parameter for orthogonal frequency-division multiple access (OFDMA) systems. It can mitigate against oscillator phase noise and Doppler spread. Further, since the subcarrier spacing is reciprocal to the OFDM symbol duration, it impacts the number of OFDM symbols per subframe (assuming the latter is a time interval of fixed length) as well as the CP duration if the

overhead induced from the CP is designed to be roughly constant. For instance, if the CP overhead is chosen to be x% of the useful symbol duration, increasing the subcarrier spacing would reduce the CP length.

[0031] For fifth generation (“5G”) new radio access technologies (NR), several subcarrier spacing are considered, such as:

[0032] Alt. 1: $f_0 = 15$ kHz subcarrier spacing

[0033] Alt. 2: $f_0 = 17.5$ kHz subcarrier spacing

[0034] In addition, derivative subcarrier spacings f_{sc} can be defined based on scaling laws and the following two alternatives are considered:

[0035] Alt. 1: $f_{sc} = f_0 * 2^m$, m is an integer

[0036] Alt. 2: $f_{sc} = f_0 * M$, M is an integer

[0037] Examples of alternative subcarrier spacing for Alt. 1 include $f_{sc} = 3.75/15/30/60/120/240/480$ kHz for $f_0 = 15$ kHz and $f_{sc} = 4.375/17.5/35/70/140/280/560$ kHz for $f_0 = 17.5$ kHz. Similarly, for Alt. 2, $f_{sc} = 3.75/15/30/60/75/90/105/120/150/180/240/300$ kHz $f_0 = 15$ kHz.

[0038] However, it is noted that only some numerologies result in a number of symbols per subframe that is a power of two. For example, for a subcarrier spacing $f_0 * 2^m$ with $f_0 = 17.5$ kHz and $m = 0$, a single subframe has 16 symbols whereas the other examples have 14 symbols per subframe. It is noted that dividing 14 by 2 results in a prime number whereas dividing 16 by a power of two yields a power of two.

[0039] For next-generation (5G) NR access technologies, TTI scalability is a feature. A transmission time interval (TTI) indicates inter-arrival time of transport blocks (TBs) on a given transport channel (TrCH). Data arrives in the physical layer (PHY) in the form of TBs once every TTI for the case of one TB per TTI per user equipment (UE). If N TBs are to be transmitted to a given UE in one TTI, N TBs arrive once per TTI. LTE defines $N=1$ and $N=2$. In other words, the TrCHs define the interface between the Medium Access (MAC) layer and the PHY and the PHY transmits data over the air interface via so-called physical channels.

[0040] For example, in the LTE downlink, the TrCH for user data transmission is called DL-SCH and the corresponding physical channel is the Physical Downlink Shared Channel (PDSCH). Similarly, in the LTE uplink, data arrives at the coding unit on the UL-SCH TrCH and is transmitted on the Physical Uplink Shared Channel (PUSCH). TTI scalability describes the technique to shorten or extend the inter-arrival

time of TBs on a given TrCH (e.g., DL-SCH or UL-SCH). TTI shortening is an important technology for ultra-reliable low latency communications (URLLC).

[0041] For a given numerology, TTI shortening also typically requires adaptations in the PHY. In LTE, for example, for the DL-SCH and UL-SCH, the TTI is defined as 1ms, i.e., the length of one subframe. A TB that arrives in the PHY once every 1ms (=1 subframe) is transmitted on the PDSCH (PUSCH respectively) once every 1ms (=1 subframe). Since for a given numerology the number of OFDM symbols per subframe does not change, shortening a TTI means shortening the mapping of PDSCH/PUSCH in the time domain. Consequently, instead of mapping PDSCH/PUSCH to one subframe (=14) symbols they are now mapped to less than 14 symbols. Since $14/2=7$ is prime, further reductions of the TTI duration (below 0.5ms) require asymmetric mappings of PDSCH/PUSCH to OFDM symbols. This is because 7 cannot be divided by two, i.e., one PDSCH would have to map to three symbols and the next one to four symbols to maintain the 14 symbols per subframe.

[0042] Various embodiments are provided that facilitate handling channel mapping of various cases of TTI, including those where the number of symbols per subframe (or fixed time interval) is not a power of two.

[0043] FIG. 1 is a diagram illustrating an arrangement 100 for mobile communications that facilitates transport channel to physical channel mapping with scalable or reduced transmission time intervals. The arrangement 100 and/or portions of the arrangement 100, can also be incorporated into an apparatus, device and the like.

[0044] Generally, data arrives at a physical (PHY) layer in the form of transport blocks (TB) on transport channels (TrCH). The arrangement 100 facilitates mobile communications by mapping transport blocks from a transport channel and using scalable and/or adjustable numerology, including transmission time intervals (TTI).

[0045] The term numerology can include subcarrier spacing, TTI, symbols per subframe and the like.

[0046] The arrangement 100 includes a user equipment (UE) device 102, a transceiver 106, and nodes 120. The nodes 120 include components/entities such as, but not limited to, a packet gateway (PGW), a secondary gateway (SGW), a mobility management entity (MME), a packet data network (PDN), UE devices, evolved Node Bs (eNodeB) or (eNB), access points (AP), base stations (BS) and the like. The nodes 120 can also include network (NW) nodes. The term network node refers to a node

operated by a network operator and may share information with other nodes, such as UE devices.

[0047] For illustrative purposes and ease of explanation, a node 124 is shown as an eNodeB.

[0048] The UE 102 includes the transceiver 106, a storage component 118, and control circuitry or controller 104. The storage component 118 includes a memory, storage element and the like and is configured to store information for the UE 102. The controller 104 is configured to perform various operations associated with the UE 102. The controller 104 can include logic, components, circuitry, one or more processors and the like. Further, the controller 104 can include and/or be part of baseband circuitry. The transceiver 106 includes transmitter functionality and receiver functionality and can utilize an interface, referred to as an over the air interface. Further, the transceiver 106 is associated with RF circuitry. The UE 102 also includes one or more antenna 108 for communications with the network entities 120.

[0049] The eNodeB 124 includes a transceiver, a storage component, and control circuitry or controller. The storage component includes a memory, storage element and the like and is configured to store information for the eNodeB 124. The controller is configured to perform various operations associated with the eNodeB 124. The controller can include logic, components, circuitry, one or more processors and the like. The transceiver 106 includes transmitter functionality and receiver functionality. The eNodeB 124 can also include one or more antenna for communications with the nodes 120 and/or other UEs.

[0050] The control circuitry 104 of the UE 102 is configured to map transport blocks of transport channels of the MAC layer to the PHY layer using scalable numerology. The PHY layer or physical channel uses a physical downlink shared channel (PDSCH) for downlink communications from the eNodeB 124 to the UE 102 and a physical uplink shared channel (PUSCH) for uplink communications to the eNodeB 124.

[0051] The control circuitry 104 is configured to adjust PHY layer parameters of the PHY layer to perform the mapping and, for example to shorten the TTI. The PHY layer parameters include TTI, OFDM symbol length, use of guard periods (GP), use of control channels, symbol length of physical channels, subframe spacing, slot duration, and the like. The PHY layer parameters can include and/or be part of the scalable numerology. Additional examples are provided below.

[0052] The control circuitry 104 is configured to adjust the PHY layer parameters, such as the TTI, based on communication characteristics. For example, the TTI can be reduced from 1 ms to 0.25 ms to improve reliability. The communication characteristics include latency, data rate, reliability and the like. The communication characteristics can be associated with a particular node, such as the eNodeB 124.

[0053] The mapping is performed by generating a mapping of the TBs to the PHY layer that includes guard periods (GP), control channels (CC), and the like. The mapping is based on the determined PHY layer parameters. The TBs are then mapped to the PHY layer based on the mapping.

[0054] In one example, the mapping is based on a first-in-first-out queue, where transport blocks are mapped to physical channels in the order received.

[0055] In another example, the mapping involves identifying and arranging a number of physical channels, inserting gaps and/or adjusting resource span time.

[0056] The transceiver 106 is configured to transmit or receive the PHY layer, including physical channels, subframe, and/or the like. The PHY layer parameter adjustment and/or mapping can be configured to achieve the communication characteristics, such as reducing latency of DL-SCH or UL-SCH transmissions.

[0057] If the number of symbols per subframe is a power of 2, the control circuitry 104 can be configured to reduce TTIs by reducing its original length by half. Thus, a subframe having a TTI of 1 can be reduced to 0.5 by reducing the number of symbols in half, such as by 16 to 8.

[0058] If the number of symbols per subframe is not a power of 2, the control circuitry 104 is configured to reduce TTIs by inserting gaps as shown below with regard to FIG. 2.

[0059] In another example, control channels are used as gaps to perform suitable mapping. The control channels can include a physical downlink control channel (PDCCH) symbol, so that a suitable mapping is obtained. FIG. 3 describes examples of suitable techniques to perform the mapping using control channel symbols.

[0060] It is appreciated that other nodes, including the eNodeB 124, can be configured to perform channel mapping as shown by the UE 102.

[0061] The below figures and embodiments describe additional techniques to generate the mapping and map the transport blocks to the PHY layer. Further, it is appreciated that the below figures and embodiments can be incorporated into the UE

102 and/or the arrangement 100. Further, it is also appreciated that suitable variations of the described techniques are contemplated.

[0062] FIG. 2 is a diagram illustrating examples 200 of subcarrier spacing for varied frequencies. The examples 200 are provided for illustrated purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the examples 200. Further, it is appreciated that embodiments are not limited to the example values provided.

[0063] The diagram depicts a 1 ms subframe from left to right and includes a 0.5 ms slot for a PHY layer. The diagram shows a first example 201, where its numerology includes a subcarrier spacing or derivative subcarrier spacing f_{sc} of 15 kHz. The diagram also shows a second example 202, where its numerology includes a subcarrier spacing or derivative subcarrier spacing f_{sc} of 17.5 kHz. OFDM symbols are shown and have a fixed symbol length.

[0064] For the first example 201, there are 14 OFDM symbols per subframe and 7 OFDM symbols per slot. Thus, in this example, the slot length is 7 symbols.

[0065] For the second example 202, there are 16 OFDM symbols per subframe and 8 OFDM symbols per slot. Thus, in this example, the slot length is 8 symbols.

[0066] If the number of symbols per subframe is a power of two, the TTIs can be shortened by reducing an original length of the TTI by half. Thus, an original TTI of length 16, can be reduced to 8; an original TTI of length 8, can be reduced to 4 and so on.

[0067] In the second example 202, the number of symbols per subframe is 16 OFDM symbols. Thus, an original TTI of 16 symbols (1 ms) can be reduced by half, to 8 symbols (0.5 ms). Thus, the reduced TTI is 8 symbols.

[0068] In the first example 201, the number of symbols per subframe is 14, which is not a power of two. Thus, reducing the TTI from its original length includes modifying PHY layer parameters and generating a mapping, including inserting gaps, guard periods, control channels, and the like.

[0069] FIG. 3 is a diagram illustrating transport channel to PHY layer mappings 300 in accordance with an embodiment. The mappings 300 are provided for illustrated purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the shown mappings.

[0070] The mappings 300 are based on a subframe length of 1 ms, 15 kHz subcarrier spacing, and 14 OFDM symbols per subframe. It is appreciated that other numerologies can be utilized.

[0071] Generally, transport blocks of the transport channel are mapped to physical channels of the PHY layer. In this example, it is assumed that transport channels, such as downlink shared channel (DL-SCH) and uplink shared channel (UL-SCH), and PHY layer channels, such as physical downlink shared channels (PDSCH) and physical uplink shared channels (PUSCH) have lengths of equal duration. Further, a resource time span for the PHY layer channels is set to 3 OFDM symbols.

[0072] The number of OFDM symbols in the subframe is not a power of two, thus TTI reductions cannot be simply halved from original TTIs. Thus, transport blocks are mapped to an integer number of physical channels. Symbols not used by or assigned to the physical channels can be used for other purposes and referred to as gaps. The gaps include control channels, guard periods (GP) and the like. The gaps can be inserted into the subframe at its beginning, end, and elsewhere in between as shown in the below examples.

[0073] A first mapping 301 uses 4 PDSCHs, each assigned a TTI and length of 3 symbols. The 4 PDSCHs are for TBs using DL-SCHs. A physical downlink control channel (PDCCH) is inserted at a beginning and a second PDCCH is inserted in a middle of the subframe.

[0074] A second mapping 302 uses 4 PDSCHs for 4 TBs. The 4 PDSCHs are arranged consecutively and two PDCCHs are inserted at a beginning of the subframe.

[0075] A third mapping 303 uses 3 PDSCHs for 3 TBs. Thus, there are 5 unused symbols. In this example, two PDCCHs are inserted at a beginning of the subframe and a guard period (GP) and physical uplink control channel (PUCCH) are inserted at an end of the subframe as shown.

[0076] A fourth mapping 304 uses 4 physical uplink shared channels (PUSCH), which are arranged consecutively. A PDCCH and GP are inserted at a beginning of the subframe.

[0077] A fifth mapping 305 uses 3 PUSCH, instead of 4. A PDCCH and GP are inserted at a beginning of the subframe. Additionally, a sounding reference signal (SRS) and PUCCH are attached at an end of the subframe.

[0078] Thus, the mappings 300 involve identifying and arranging a number of physical channels (PDSCH and/or PUSCH) to accommodate the transport blocks and inserting gaps.

[0079] FIG. 4 is a diagram illustrating transport channel to PHY layer mappings 400 in accordance with an embodiment. The mappings 400 are provided for illustrated purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the shown mappings.

[0080] The mappings 400 are based on a subframe length of 1 ms, 15 kHz subcarrier spacing, and 14 OFDM symbols per subframe. It is appreciated that other numerologies can be utilized. A resource span time for each of the TTIs is variable, in this example.

[0081] Generally, transport blocks of the transport channel are mapped to physical channels of the PHY layer. In this example, it is assumed that transport channels, such as downlink shared channel (DL-SCH) and uplink shared channel (UL-SCH) have, and PHY layer channels, such as physical downlink shared channels (PDSCH) and physical uplink shared channels (PUSCH) have lengths of equal duration. A single DL-SCH can map to a single PDSCH, however a single DL-SCH can map 59 a single PDSCH whether a transport channel and physical channel have equal durations or not.

[0082] The transport blocks are mapped to an integer number of physical channels. Symbols not used by or assigned to the physical channels can be used for other purposes and referred to as gaps. The gaps include control channels, guard periods (GP) and the like. The gaps can be inserted into the subframe at its beginning, end, and elsewhere in between as shown in the below examples.

[0083] The TTI resource times are variable and are not limited to only including PDSCH and PUSCH.

[0084] A first mapping 401 uses 4 PDSCHs, each assigned a TTI and length of 3 symbols. The 4 PDSCHs are for TBs using DL-SCHs. A physical downlink control channel (PDCCH) is inserted at a beginning and a second PDCCH is inserted in a middle of the subframe. Here, TTI resource times have been selected to include the PDCCHs. Thus, TTI #1 has a length of 4 OFDM symbols and includes the first PDCCH, the TTI #2 has a length of 3 OFDM symbols, the TTI #3 has a length of 4 OFDM symbols and includes the second PDCCH, and the TTI #4 has a length of 3 OFDM symbols.

[0085] A second mapping 402 uses 4 PDSCHs for 4 TBs. The 4 PDSCHs are arranged consecutively and two PDCCHs are inserted at a beginning of the subframe. The TTI #1 has a length of 5 OFDM symbols and includes the first PDCCH and the second PDCCH, the TTI #2 has a length of 3 OFDM symbols, the TTI #3 has a length of 3 OFDM symbols, and the TTI #4 has a length of 3 OFDM symbols.

[0086] A third mapping 403 uses 3 PDSCHs for 3 TBs. In this example, two PDCCHs are inserted at a beginning of the subframe and a guard period (GP) and physical uplink control channel (PUCCH) are inserted at an end of the subframe as shown. The TTI #1 has a length of 5 OFDM symbols and includes the first PDCCH and the second PDCCH, the TTI #2 has a length of 3 OFDM symbols, and the TTI #3 has a length of 3 OFDM symbols. It is noted that a TTI is not used for the GP and PUCCH.

[0087] A fourth mapping 404 uses 4 physical uplink shared channels (PUSCH), which are arranged consecutively. A PDCCH and GP are inserted at a beginning of the subframe. The TTI #1 has a length of 5 OFDM symbols and includes the PDCCH and the GP, the TTI #2 has a length of 3 OFDM symbols, the TTI #3 has a length of 3 OFDM symbols, and the TTI #4 has a length of 3 OFDM symbols.

[0088] A fifth mapping 405 uses 3 PUSCH. A PDCCH and GP are inserted at a beginning of the subframe. Additionally, a sounding reference signal (SRS) and PUCCH are attached at an end of the subframe. The TTI #1 has a length of 5 OFDM symbols and includes the first PDCCH and the second PDCCH, the TTI #2 has a length of 3 OFDM symbols, and the TTI #3 has a length of 3 OFDM symbols. It is noted that a TTI is not used for the GP and PUCCH.

[0089] Thus, the mappings 400 involve identifying and arranging a number of physical channels (PDSCH and/or PUSCH), inserting gaps and adjusting resource span time.

[0090] FIG. 5 is a flow diagram illustrating a method 500 of mapping transport channel transport blocks to physical layer symbols in accordance with an embodiment. The mapping is done with adjustable numerologies or PHY layer parameters, such as TTI.

[0091] The method 500 can be understood and utilized with reference to the arrangement 100 and variations thereof, described above. The method can be performed by a node that is a type of node including, but not limited to, a UE device, eNodeB, AP, BS, and the like. In one example, the node is the UE device 102, shown

above. Further, the blocks can be performed by a transmitter and/or circuitry of the node.

[0092] Physical layer symbols are arranged by a node or circuitry of the node into one or more groups of symbols at block 502. The symbols can be OFDM symbols. The one or more groups may have an unequal or equal numbers of symbols. The one or more groups each include one or more consecutive symbols. In one example, the physical layer symbols comprise a subframe. The one or more groups can be referred to as PHY groups.

[0093] There are PHY layer parameters associated with the symbols. These parameters can be adjusted and/or selected based on communication characteristics.

[0094] One or more groups of the PHY groups are selected by the node or circuitry of the node to map transport channel transport blocks at block 504. One or more of the PHY groups may remain unselected and/or unused. The unselected groups can be unselected for reasons including, but not limited to its symbols being required for reference signals and/or control channels.

[0095] The node or circuitry of the node maps the transport blocks to the selected groups at block 506. The resource time span for a given transport block and its mapped to group can be identical or different, including a different TTI.

[0096] In one example, the number of symbols within each group varies and the time span of the groups the TTI of the transport block can be different. In another example, the number of symbols in a group is 7, the subframe duration includes two 0.5 ms TTIs, and the time span and the TTI can be identical.

[0097] The node maps the transport blocks to symbols of the selected groups at block 508. In one example, information from each block is consecutively mapped to symbols of the associated, selected group. The node can also include gaps, control channels and the like in the physical layer symbols.

[0098] The node transmits the symbols at block 508. The transmitted symbols are of the selected PHY groups and include data from the TBs. A transceiver and/or RF circuitry can be utilized.

[0099] While the methods described within this disclosure are illustrated in and described herein as a series of acts or events, it will be appreciated that the illustrated ordering of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. In addition, not all illustrated

acts may be required to implement one or more aspects or embodiments of the description herein. Further, one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases.

[00100] Figs. 6, 7 and 8 illustrate mappings that utilize a first-in-first-out (FIFO) type of queue. Thus, a first transport block is passed and mapped from the MAC layer to the PHY layer first and is transmitted by the PHY layer first. Generally, the number of transport blocks arriving to the PHY layer from the MAC layer on a transport channel during one subframe should be less than or equal to $K \cdot M$, where K is the number of supportable transport block per physical channel and M is the number of physical channels per subframe. Thus, after one subframe, the queue is empty. Further, the next K transport blocks may not or should not arrive until the previous transport blocks have been scheduled. As a result, there can be TTIs where there may not be any data due to the above constraints.

[00101] FIG. 6 is a diagram illustrating transport channel to PHY layer mappings 600 using a queue and a transmission time interval of 0.5 ms in accordance with an embodiment. The mappings 600 are provided for illustrative purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the shown mappings.

[00102] A MAC layer is shown passing transport blocks to a PHY layer. The PHY layer maps and transmits associated physical data channels in order.

[00103] In one example, the physical channels have equal TTI lengths and in another, the physical channels can have varied TTI lengths.

[00104] The mappings 600 utilize transport blocks and physical data channels having TTIs of equal length and without gaps. The mappings 600 utilize a first-in-first-out (FIFO) type of queue. Thus, a first transport block is passed and mapped from the MAC layer to the PHY layer first and is transmitted by the PHY layer first.

[00105] The mappings 600 are based on a subframe length of 1 ms, 15 kHz subcarrier spacing, and 14 OFDM symbols per subframe. It is appreciated that other numerologies can be utilized. A TTI for the subframe is 0.5 ms.

[00106] In this example, the transport blocks are provided as DL-SCH and the physical channels or physical data channels are provided as PDSCH.

[00107] The mappings 600 include a first mapping 601 and a second mapping 602. The first mapping 601 is shown in an upper portion of the diagram and the second mapping 602 is shown in a lower portion of the diagram.

[00108] The first mapping 601, illustrates a first DL-SCH passed to the PHY layer in a first TTI and a second DL-SCH passed to the PHY layer in a second TTI. The first and second DL-SCH are mapped to first and second PDSCHs having lengths of 6 OFDM symbols. A gap or unused symbol is inserted at the beginning of each TTI.

[00109] The second mapping 602, illustrates a first DL-SCH passed to the PHY layer in the first TTI and a second DL-SCH passed to the PHY layer in the second TTI. The first DL-SCH is mapped to a first PDSCH having lengths of 4 OFDM symbols. A gap or unused symbol is inserted at the beginning of the first slot and two gaps are appended at the end of the first PDSCH. The second DL-SCH is mapped to a second PDSCH having lengths of 4 OFDM symbols. A gap or unused symbol is inserted at the beginning of the first slot and two gaps are appended at the end of the second PDSCH.

[00110] FIG. 7 is a diagram illustrating transport channel to PHY layer mappings 700 using a queue and a transmission time interval of 0.25 ms in accordance with an embodiment. The mappings 700 are provided for illustrative purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the mappings.

[00111] A MAC layer is shown passing transport blocks to a PHY layer. The PHY layer maps and transmits associated physical data channels in order.

[00112] The mappings 700 utilize transport blocks and physical data channels having TTIs of equal length and without gaps. The mappings 700 utilize a first-in-first-out (FIFO) type of queue. Thus, a first transport block is passed and mapped from the MAC layer to the PHY layer first and is transmitted by the PHY layer first.

[00113] The mappings 700 are based on a subframe length of 1 ms, 15 kHz subcarrier spacing, and 14 OFDM symbols per subframe. It is appreciated that other numerologies can be utilized. Here, the PHY layer TTI for the subframe is set to 0.25 ms.

[00114] In this example, the transport blocks are provided as DL-SCH and the physical channels or physical data channels are provided as PDSCH.

[00115] The mappings 700 include a first mapping 701 and a second mapping 702. The first mapping 701 is shown in an upper portion of the diagram and the second mapping 702 is shown in a lower portion of the diagram.

[00116] The first mapping 701, illustrates a first DL-SCH passed in a first TTI, a second DL-SCH passed to the PHY layer in a second TTI, a third DL-SCH passed to the PHY layer in a third TTI, and a fourth DL-SCH passed to the PHY layer in a fourth

TTI. The terms first, second, ... TTI here also refers to a group of consecutive symbols of the physical layer. The first, second, and third DL-SCH are mapped to first, second and third PDSCHs as shown. A gap or unused symbol is inserted at the beginning of each slot. There is an incremental delay in mapping the DL-SCHs increasing from 1 symbol, to 1.5 symbols, to 2 symbols. Thus, a delay shown at 703 in mapping for the fourth DL-SCH does not allow the fourth DL-SCH to be mapped to a PDSCH. Thus, the fourth DL-SCH is delayed, blocked, or resent by the MAC layer. This mapping accommodates 3 transport blocks.

[00117] The second mapping 702, illustrates a first DL-SCH passed in a first TTI, a second DL-SCH passed to the PHY layer in a second TTI, and a third DL-SCH passed to the PHY layer in a third TTI. The first, second, and third DL-SCH are mapped to first, second and third PDSCHs as shown. This mapping accommodates 3 transport blocks, so all of the transport blocks are mapped.

[00118] FIG. 8 is a diagram illustrating transport channel to PHY layer mappings 800 using a queue and a transmission time interval of 0.125 in accordance with an embodiment. The mappings 800 are provided for illustrative purposes and to facilitate understanding. It is appreciated that the arrangement 100 and variations thereof can be utilized with the mappings.

[00119] A MAC layer is shown passing transport blocks to a PHY layer. The PHY layer maps and transmits associated physical data channels in order.

[00120] The mappings 800 utilize transport blocks and physical data channels having TTIs of equal length and without gaps. The mappings 800 utilize a first-in-first-out (FIFO) type of queue. Thus, a first transport block is passed and mapped from the MAC layer to the PHY layer first and is transmitted by the PHY layer first.

[00121] The mappings 800 are based on a subframe length of 1 ms, 15 kHz subcarrier spacing, and 14 OFDM symbols per subframe. It is appreciated that other numerologies can be utilized. The PHY layer TTI for the subframe is set to 0.125 ms.

[00122] The transport blocks are provided as DL-SCH and the physical channels or physical data channels are provided as PDSCH.

[00123] The mappings 800 include a first mapping 801 and a second mapping 802. The first mapping 801 is shown in an upper portion of the diagram and the second mapping 802 is shown in a lower portion of the diagram.

[00124] The first mapping 801, illustrates a number of DL-SCHs passed to the PHY layer and mapped to PDSCHs. It can be seen that this mapping supports 7 transport blocks. Transport blocks after 803 are not able to be mapped within the subframe.

[00125] The second mapping 802 only utilizes 6 transport blocks, shown as DL-SCHs. Thus, at 804, no more transport blocks are mapped to the subframe.

[00126] Figs. 9A and 9B are diagrams illustrating transport channel to PHY layer mappings 900 using a 17.5 subcarrier frequency in accordance with an embodiment. The mappings 900 are provided for illustrated purposes and to facilitate understanding and include the mappings 900a shown in FIG. 9A and the mappings 900b, shown in FIG. 9B. It is appreciated that the arrangement 100 and variations thereof can be utilized with the shown mappings.

[00127] The mappings 900 are based on a subframe length of 1 ms, 17.5 kHz subcarrier spacing, and 16 OFDM symbols per subframe. The subframe includes a power of 2 OFDM symbols. As a result, evenly splitting the TTIs is possible. However, non-data symbols can be present, thus some of the OFDM symbols may not be used for TTI.

[00128] Generally, transport blocks of the transport channel are mapped to physical channels of the PHY layer. In this example, it is assumed that transport channels, such as downlink shared channel (DL-SCH) and uplink shared channel (UL-SCH), and PHY layer channels, such as physical downlink shared channels (PDSCH) and physical uplink shared channels (PUSCH) have lengths of equal duration.

[00129] The transport blocks are mapped to an integer number of physical channels. Symbols not used by or assigned to the physical channels are used for other purposes and referred to as gaps. The gaps include control channels, guard periods (GP) and the like. The gaps can be inserted into the subframe at its beginning, end, and elsewhere in between as shown in the below examples.

[00130] A first mapping 901 evenly divides the subframe into 4 TTIs or groups, each having 4 symbols. The TTIs each include a PDCCH of length 1 and a PDSCH of length 3 symbols. The TTIs or resource time spans are extended to include the non data symbols, the PDCCH.

[00131] A second mapping 902 incorporates non data symbols/channels including a downlink reference signal (DL RS), GP and a PUCCH. Thus, the mapping 902 uses only 3 TTIs or groups. The final 4 symbols incorporate a DL RS, GP and a PUCCH.

[00132] A second mapping 902 incorporates non data symbols/channels including a downlink reference signal (DL RS), GP and a PUCCH. Thus, the mapping 902 uses only 3 TTIs or groups. The final 4 symbols incorporate a DL RS, GP and a PUCCH.

[00133] A third mapping 903 incorporates non data symbols/channels including a GP, SRS and a PUCCH. Thus, the mapping 903 uses only 3 TTIs or groups. The final 4 symbols incorporate the GP, SRS and the PUCCH.

[00134] A fourth mapping 904 incorporates non data symbols/channels including a first SRS, a second SRS and a PUCCH. Thus, the mapping 904 uses 3 TTIs or groups. The final 4 symbols incorporate the first SRS, the second SRS and the PUCCH.

[00135] A fifth mapping 905 utilizes smaller TTIs or groups, which in this example are at lengths of 0.125. The TTIs only include data channels of PDSCH or PUSCH. The control channels and GP are not within the TTIs or groups. non data symbols/channels including a first SRS, a second SRS and a PUCCH. Thus, the mapping 904 uses 3 TTIs or groups. The final 4 symbols incorporate the first SRS, the second SRS and the PUCCH.

[00136] A sixth mapping 906 uses overlapping TTIs or groups. Here, a the TTI #1 includes a first four symbols of the subframe. The TTI #2 includes the first eight symbols, which includes the first four symbols of the subframe. The last 4 symbols are used for a GP, a SRS and a PUCCH.

[00137] A seventh mapping 907 also uses overlapping TTIs or groups. The TTI #1 includes a first four symbols of the subframe. The TTI #2 includes the first eight symbols, which includes the first four symbols of the subframe. The last 4 symbols are used for a first SRS, a second SRS and a PUCCH.

[00138] FIG. 10 illustrates an architecture of a system 1000 of a network in accordance with some embodiments. The system 1000 is shown to include a user equipment (UE) 1001 and a UE 1002. The UEs 1001 and 1002 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.

[00139] In some embodiments, any of the UEs 1001 and 1002 can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize

technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[00140] The UEs 1001 and 1002 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 1010 — the RAN 1010 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 1001 and 1002 utilize connections 1003 and 1004, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 1003 and 1004 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

[00141] In this embodiment, the UEs 1001 and 1002 may further directly exchange communication data via a ProSe interface 1005. The ProSe interface 1005 may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[00142] The UE 1002 is shown to be configured to access an access point (AP) 1006 via connection 1007. The connection 1007 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 1006 would comprise a wireless fidelity (WiFi®) router. In this example, the AP 1006 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[00143] The RAN 1010 can include one or more access nodes that enable the connections 1003 and 1004. 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 1010 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 1011, 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 1012.

[00144] Any of the RAN nodes 1011 and 1012 can terminate the air interface protocol and can be the first point of contact for the UEs 1001 and 1002. In some embodiments, any of the RAN nodes 1011 and 1012 can fulfill various logical functions for the RAN 1010 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.

[00145] In accordance with some embodiments, the UEs 1001 and 1002 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes 1011 and 1012 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.

[00146] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 1011 and 1012 to the UEs 1001 and 1002, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest

time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[00147] The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs 1001 and 1002. 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 1001 and 1002 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 1002 within a cell) may be performed at any of the RAN nodes 1011 and 1012 based on channel quality information fed back from any of the UEs 1001 and 1002. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1001 and 1002.

[00148] 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, $L=1, 2, 4, \text{ or } 8$).

[00149] 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.

[00150] The RAN 1010 is shown to be communicatively coupled to a core network (CN) 1020—via an S1 interface 1013. In embodiments, the CN 1020 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 1013 is split into two parts: the S1-U interface 1014, which carries traffic data between the RAN nodes 1011 and 1012 and the serving gateway (S-GW) 1022, and the S1-mobility management entity (MME) interface 1015, which is a signaling interface between the RAN nodes 1011 and 1012 and MMEs 1021.

[00151] In this embodiment, the CN 1020 comprises the MMEs 1021, the S-GW 1022, the Packet Data Network (PDN) Gateway (P-GW) 1023, and a home subscriber server (HSS) 1024. The MMEs 1021 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 1021 may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS 1024 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN 1020 may comprise one or several HSSs 1024, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1024 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[00152] The S-GW 1022 may terminate the S1 interface 1013 towards the RAN 1010, and routes data packets between the RAN 1010 and the CN 1020. In addition, the S-GW 1022 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

[00153] The P-GW 1023 may terminate an SGi interface toward a PDN. The P-GW 1023 may route data packets between the EPC network 1023 and external networks such as a network including the application server 1030 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 1025. Generally, the application server 1030 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 1023 is shown to be

communicatively coupled to an application server 1030 via an IP communications interface 1025. The application server 1030 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 1001 and 1002 via the CN 1020.

[00154] The P-GW 1023 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 1026 is the policy and charging control element of the CN 1020. 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 1026 may be communicatively coupled to the application server 1030 via the P-GW 1023. The application server 1030 may signal the PCRF 1026 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 1026 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 1030.

[00155] FIG. 11 illustrates example components of a device 1100 in accordance with some embodiments. In some embodiments, the device 1100 may include application circuitry 1102, baseband circuitry 1104, Radio Frequency (RF) circuitry 1106, front-end module (FEM) circuitry 1108, one or more antennas 1110, and power management circuitry (PMC) 1112 coupled together at least as shown. The components of the illustrated device 1100 may be included in a UE or a RAN node. In some embodiments, the device 1100 may include less elements (e.g., a RAN node may not utilize application circuitry 1102, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 1100 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

[00156] The application circuitry 1102 may include one or more application processors. For example, the application circuitry 1102 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 1100. In some embodiments, processors of application circuitry 1102 may process IP data packets received from an EPC.

[00157] The baseband circuitry 1104 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1104 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 1106 and to generate baseband signals for a transmit signal path of the RF circuitry 1106. Baseband processing circuitry 1104 may interface with the application circuitry 1102 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1106. For example, in some embodiments, the baseband circuitry 1104 may include a third generation (3G) baseband processor 1104A, a fourth generation (4G) baseband processor 1104B, a fifth generation (5G) baseband processor 1104C, or other baseband processor(s) 1104D 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 1104 (e.g., one or more of baseband processors 1104A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1106. In other embodiments, some or all of the functionality of baseband processors 1104A-D may be included in modules stored in the memory 1104G and executed via a Central Processing Unit (CPU) 1104E. 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 1104 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1104 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.

[00158] In some embodiments, the baseband circuitry 1104 may include one or more audio digital signal processor(s) (DSP) 1104F. The audio DSP(s) 1104F may be include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1104 and the application circuitry 1102 may be implemented together such as, for example, on a system on a chip (SOC).

[00159] In some embodiments, the baseband circuitry 1104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1104 may support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00160] RF circuitry 1106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1108 and provide baseband signals to the baseband circuitry 1104. RF circuitry 1106 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1104 and provide RF output signals to the FEM circuitry 1108 for transmission.

[00161] In some embodiments, the receive signal path of the RF circuitry 1106 may include mixer circuitry 1106a, amplifier circuitry 1106b and filter circuitry 1106c. In some embodiments, the transmit signal path of the RF circuitry 1106 may include filter circuitry 1106c and mixer circuitry 1106a. RF circuitry 1106 may also include synthesizer circuitry 1106d for synthesizing a frequency for use by the mixer circuitry 1106a of the receive signal path and the transmit signal path. In some embodiments,

the mixer circuitry 1106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1108 based on the synthesized frequency provided by synthesizer circuitry 1106d. The amplifier circuitry 1106b may be configured to amplify the down-converted signals and the filter circuitry 1106c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1104 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 1106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00162] In some embodiments, the mixer circuitry 1106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1106d to generate RF output signals for the FEM circuitry 1108. The baseband signals may be provided by the baseband circuitry 1104 and may be filtered by filter circuitry 1106c.

[00163] In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a of the transmit signal path may be configured for super-heterodyne operation.

[00164] 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 1106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1104 may include a digital baseband interface to communicate with the RF circuitry 1106.

[00165] 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.

[00166] In some embodiments, the synthesizer circuitry 1106d 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 1106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00167] The synthesizer circuitry 1106d may be configured to synthesize an output frequency for use by the mixer circuitry 1106a of the RF circuitry 1106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1106d may be a fractional $N/N+1$ synthesizer.

[00168] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 1104 or the applications processor 1102 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1102.

[00169] Synthesizer circuitry 1106d of the RF circuitry 1106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may 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 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.

[00170] In some embodiments, synthesizer circuitry 1106d 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 other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 1106 may include an IQ/polar converter.

[00171] FEM circuitry 1108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1110, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1106 for further processing. FEM circuitry 1108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1106 for transmission by one or more of the one or more antennas 1110. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1106, solely in the FEM 1108, or in both the RF circuitry 1106 and the FEM 1108.

[00172] In some embodiments, the FEM circuitry 1108 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 1106). The transmit signal path of the FEM circuitry 1108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1110).

[00173] In some embodiments, the PMC 1112 may manage power provided to the baseband circuitry 1104. In particular, the PMC 1112 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 1112 may often be included when the device 1100 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 1112 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[00174] While FIG. 11 shows the PMC 1112 coupled only with the baseband circuitry 1104. However, in other embodiments, the PMC 1112 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 1102, RF circuitry 1106, or FEM 1108.

[00175] In some embodiments, the PMC 1112 may control, or otherwise be part of, various power saving mechanisms of the device 1100. For example, if the device 1100 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 1100 may power down for brief intervals of time and thus save power.

[00176] If there is no data traffic activity for an extended period of time, then the device 1100 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 1100 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 1100 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00177] 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.

[00178] Processors of the application circuitry 1102 and processors of the baseband circuitry 1104 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1104, alone or in combination, may be used to execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1102 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.

[00179] FIG. 12 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry 1104 of FIG. 11 may comprise processors 1104A-1104E and a memory 1104G utilized by said

processors. Each of the processors 1104A-1104E may include a memory interface, 1204A-1204E, respectively, to send/receive data to/from the memory 1104G.

[00180] The baseband circuitry 1104 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 1212 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 1104), an application circuitry interface 1214 (e.g., an interface to send/receive data to/from the application circuitry 1102 of FIG. 11), an RF circuitry interface 1216 (e.g., an interface to send/receive data to/from RF circuitry 1106 of FIG. 11), a wireless hardware connectivity interface 1218 (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 1220 (e.g., an interface to send/receive power or control signals to/from the PMC 1112).

[00181] FIG. 13 is an illustration of a control plane protocol stack in accordance with some embodiments. In this embodiment, a control plane 1300 is shown as a communications protocol stack between the UE 1001 (or alternatively, the UE 1002), the RAN node 1011 (or alternatively, the RAN node 1012), and the MME 1021.

[00182] The PHY layer 1301 may transmit or receive information used by the MAC layer 1302 over one or more air interfaces. The PHY layer 1301 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC layer 1305. The PHY layer 1301 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and Multiple Input Multiple Output (MIMO) antenna processing.

[00183] The MAC layer 1302 may perform mapping between logical channels and transport channels, multiplexing of MAC service data units (SDUs) from one or more logical channels onto transport blocks (TB) to be delivered to PHY via transport channels, de-multiplexing MAC SDUs to one or more logical channels from transport blocks (TB) delivered from the PHY via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), and logical channel prioritization.

[00184] The RLC layer 1303 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC layer 1303 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC layer 1303 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[00185] The PDCP layer 1304 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[00186] The main services and functions of the RRC layer 1305 may include broadcast of system information (e.g., included in Master Information Blocks (MIBs) or System Information Blocks (SIBs) related to the non-access stratum (NAS)), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting. Said MIBs and SIBs may comprise one or more information elements (IEs), which may each comprise individual data fields or data structures.

[00187] The UE 1001 and the RAN node 1011 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange control plane data via a protocol stack comprising the PHY layer 1301, the MAC layer 1302, the RLC layer 1303, the PDCP layer 1304, and the RRC layer 1305.

[00188] The non-access stratum (NAS) protocols 1306 form the highest stratum of the control plane between the UE 1001 and the MME 1021. The NAS protocols 1306

support the mobility of the UE 1001 and the session management procedures to establish and maintain IP connectivity between the UE 1001 and the P-GW 1023.

[00189] The S1 Application Protocol (S1-AP) layer 1315 may support the functions of the S1 interface and comprise Elementary Procedures (EPs). An EP is a unit of interaction between the RAN node 1011 and the CN 1020. The S1-AP layer services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[00190] The Stream Control Transmission Protocol (SCTP) layer (alternatively referred to as the SCTP/IP layer) 1314 may ensure reliable delivery of signaling messages between the RAN node 1011 and the MME 1021 based, in part, on the IP protocol, supported by the IP layer 1313. The L2 layer 1312 and the L1 layer 1311 may refer to communication links (e.g., wired or wireless) used by the RAN node and the MME to exchange information.

[00191] The RAN node 1011 and the MME 1021 may utilize an S1-MME interface to exchange control plane data via a protocol stack comprising the L1 layer 1311, the L2 layer 1312, the IP layer 1313, the SCTP layer 1314, and the S1-AP layer 1315.

[00192] FIG. 14 is an illustration of a user plane protocol stack in accordance with some embodiments. In this embodiment, a user plane 1400 is shown as a communications protocol stack between the UE 1001 (or alternatively, the UE 1002), the RAN node 1011 (or alternatively, the RAN node 1012), the S-GW 1022, and the P-GW 1023. The user plane 1400 may utilize at least some of the same protocol layers as the control plane 1300. For example, the UE 1001 and the RAN node 1011 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange user plane data via a protocol stack comprising the PHY layer 1301, the MAC layer 1302, the RLC layer 1303, the PDCP layer 1304.

[00193] The General Packet Radio Service (GPRS) Tunneling Protocol for the user plane (GTP-U) layer 1404 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP and IP security (UDP/IP) layer 1403 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 1011 and the S-GW

1022 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising the L1 layer 1311, the L2 layer 1312, the UDP/IP layer 1403, and the GTP-U layer 1404. The S-GW 1022 and the P-GW 1023 may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising the L1 layer 1311, the L2 layer 1312, the UDP/IP layer 1403, and the GTP-U layer 1404. As discussed above with respect to FIG. 13, NAS protocols support the mobility of the UE 1001 and the session management procedures to establish and maintain IP connectivity between the UE 1001 and the P-GW 1023.

[00194] FIG. 15 illustrates components of a core network in accordance with some embodiments. The components of the CN 1020 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In some embodiments, Network Functions Virtualization (NFV) is utilized to virtualize any or all of the above described network node functions via executable instructions stored in one or more computer readable storage mediums (described in further detail below). A logical instantiation of the CN 1020 may be referred to as a network slice 1501. A logical instantiation of a portion of the CN 1020 may be referred to as a network sub-slice 1502 (e.g., the network sub-slice 1502 is shown to include the PGW 1023 and the PCRF 1026).

[00195] NFV architectures and infrastructures may be used to virtualize one or more network functions, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[00196] FIG. 16 is a block diagram illustrating components, according to some example embodiments, of a system 1600 to support NFV. The system 1600 is illustrated as including a virtualized infrastructure manager (VIM) 1602, a network function virtualization infrastructure (NFVI) 1604, a VNF manager (VNFM) 1606, virtualized network functions (VNFs) 1608, an element manager (EM) 1610, an NFV Orchestrator (NFVO) 1612, and a network manager (NM) 1614.

[00197] The VIM 1602 manages the resources of the NFVI 1604. The NFVI 1604 can include physical or virtual resources and applications (including hypervisors) used to execute the system 1600. The VIM 1602 may manage the life cycle of virtual resources with the NFVI 1604 (e.g., creation, maintenance, and tear down of virtual machines

(VMs) associated with one or more physical resources), track VM instances, track performance, fault and security of VM instances and associated physical resources, and expose VM instances and associated physical resources to other management systems.

[00198] The VNFM 1606 may manage the VNFs 1608. The VNFs 1608 may be used to execute EPC components/functions. The VNFM 1606 may manage the life cycle of the VNFs 1608 and track performance, fault and security of the virtual aspects of VNFs 1608. The EM 1610 may track the performance, fault and security of the functional aspects of VNFs 1608. The tracking data from the VNFM 1606 and the EM 1610 may comprise, for example, performance measurement (PM) data used by the VIM 1602 or the NFVI 1604. Both the VNFM 1606 and the EM 1610 can scale up/down the quantity of VNFs of the system 1600.

[00199] The NFVO 1612 may coordinate, authorize, release and engage resources of the NFVI 1604 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 1614 may provide a package of end-user functions with the responsibility for the management of a network, which may include network elements with VNFs, non-virtualized network functions, or both (management of the VNFs may occur via the EM 1610).

[00200] FIG. 17 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. 17 shows a diagrammatic representation of hardware resources 1700 including one or more processors (or processor cores) 1710, one or more memory/storage devices 1720, and one or more communication resources 1730, each of which may be communicatively coupled via a bus 1740. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 1702 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 1700

[00201] The processors 1710 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency

integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 1712 and a processor 1714.

[00202] The memory/storage devices 1720 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1720 may include, but are not limited to any type of volatile or non-volatile memory such as dynamic random access memory (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.

[00203] The communication resources 1730 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 1704 or one or more databases 1706 via a network 1708. For example, the communication resources 1730 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.

[00204] Instructions 1750 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1710 to perform any one or more of the methodologies discussed herein. The instructions 1750 may reside, completely or partially, within at least one of the processors 1710 (e.g., within the processor's cache memory), the memory/storage devices 1720, or any suitable combination thereof. Furthermore, any portion of the instructions 1750 may be transferred to the hardware resources 1700 from any combination of the peripheral devices 1704 or the databases 1706. Accordingly, the memory of processors 1710, the memory/storage devices 1720, the peripheral devices 1704, and the databases 1706 are examples of computer-readable and machine-readable media.

[00205]

[00206] Examples herein can include subject matter such as a method, means for performing acts or blocks of the method, at least one machine-readable medium including executable instructions that, when performed by a machine (e.g., a processor with memory or the like) cause the machine to perform acts of the method or of an apparatus or system for concurrent communication using multiple communication technologies according to embodiments and examples described.

[00207] Example 1 is an apparatus configured to be employed within one or more user equipment (UE) devices. The apparatus comprises baseband circuitry, which

includes one or more processors. The one or more processors are configured to determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels. The one or more processors are also configured to generate a mapping for one or more transport blocks of a transport channel based on the determined TTI and map the one or more transport blocks to the PHY layer based on the generated mapping.

[00208] Example 2 includes the subject matter of Example 1, including or omitting optional elements, where the baseband circuitry further includes a radio frequency (RF) circuitry interface to send transmission data to RF circuitry, the transmission data generated based on the generated mapping.

[00209] Example 3 includes the subject matter of any of Examples 1-2, including or omitting optional elements, where the determined TTI is varied for each of the one or more transport blocks.

[00210] Example 4 includes the subject matter of any of Examples 1-3, including or omitting optional elements, where the mapping identifies one of a physical downlink shared channel (PDSCH) and a physical uplink shared channel (PUSCH) for each of the one or more transport blocks.

[00211] Example 5 includes the subject matter of any of Examples 1-4, including or omitting optional elements, where the one or more transport blocks include a downlink shared channel (DL-SCH) of the transport channel of a medium access (MAC) layer.

[00212] Example 6 includes the subject matter of any of Examples 1-5, including or omitting optional elements, where the determined TTI is reduced from an original TTI.

[00213] Example 7 includes the subject matter of any of Examples 1-6, including or omitting optional elements, where the determined TTI is less than a subframe duration of 1 milli-second (ms).

[00214] Example 8 includes the subject matter of any of Examples 1-7, including or omitting optional elements, where the mapping includes one or more gaps inserted in a subframe.

[00215] Example 9 includes the subject matter of any of Examples 1-8, including or omitting optional elements, where the mapping includes one or more groups of orthogonal frequency division multiplexing (OFDM) symbols.

[00216] Example 10 includes the subject matter of any of Examples 1-9, including or omitting optional elements, where each of the one or more groups is matched with one of the one or more transport blocks.

[00217] Example 11 includes the subject matter of any of Examples 1-10, including or omitting optional elements, where the mapping utilizes a first-in-first-out (FIFO) queue to map the one or more transport blocks to one or more physical channels.

[00218] Example 12 includes the subject matter of any of Examples 1-11, including or omitting optional elements, where the communication characteristics comprise one or more of latency, reliability and data rate.

[00219] Example 13 is an apparatus configured to be employed within an evolved Node B (eNodeB). The apparatus comprises baseband circuitry, which includes one or more processors. The one or more processors are configured to determine physical (PHY) layer parameters of a PHY layer based on communication characteristics, wherein the numerology includes a transmission time interval (TTI) and wherein the communication characteristics include reliability. The physical layer comprises physical channels. The one or more processors are also configured to generate a mapping for one or more transport blocks based on the determined PHY layer parameters and map the one or more transport blocks to a subframe of the PHY layer.

[00220] Example 14 includes the subject matter of Example 13, including or omitting optional elements, where the baseband circuitry further includes a radio frequency (RF) circuitry interface to send transmission data to RF circuitry, the transmission data generated based on the subframe.

[00221] Example 15 includes the subject matter of any of Examples 13-14, including or omitting optional elements, where the mapping includes arranging one or more physical channels, inserting gaps and adjusting resource span times.

[00222] Example 16 includes the subject matter of any of Examples 13-15, including or omitting optional elements, where the PHY layer uses a subcarrier frequency of 15 kHz.

[00223] Example 17 includes the subject matter of any of Examples 13-16, including or omitting optional elements, where the communication characteristics further include latency.

[00224] Example 18 is one or more computer-readable media having instructions. When executed, the instructions cause one or more nodes to generate a mapping for one or more transport blocks of a transport channel based on the determined TTI, map the one or more transport blocks to one or more physical channels of the PHY layer based on the generated mapping, and transmit the physical channels using the determined TTI.

[00225] Example 19 includes the subject matter of Example 18, including or omitting optional elements, where the instructions further cause the one or more nodes to map each transport block of the one or more transport blocks to a group of consecutive orthogonal frequency division multiplexing (OFDM) symbols.

[00226] Example 20 includes the subject matter of any of Examples 18-19, including or omitting optional elements, where the instructions further cause the one or more nodes to insert a physical downlink control channel (PDCCH) into a subframe of the PHY layer based on the mapping.

[00227] Example 21 includes the subject matter of any of Examples 18-20, including or omitting optional elements, where the instructions further cause the one or more nodes to insert a physical uplink control channel (PUCCH) into a subframe of the PHY layer based on the mapping, wherein the subframe has a length greater than the determined TTI.

[00228] Example 22 is an apparatus configured to be employed within one or more user equipment (UE) devices. The apparatus includes a means to determine one or more physical (PHY) layer parameters based on communication characteristics, a means to generate a mapping for a plurality of transport blocks from a transport channel to a plurality of physical channels of a PHY layer based on the determined one or more PHY layer parameters, a means to map the plurality of transport blocks to the plurality of physical channels based on the generated mapping, and a means to transmit the plurality of physical channels.

[00229] Example 23 includes the subject matter of Example 22, including or omitting optional elements, further comprising a means to determine an inter-arrival time for the transport blocks.

[00230] Example 24 includes the subject matter of any of Examples 22-23, including or omitting optional elements, where the one or more PHY layer parameters include a transmission time interval (TTI) for the plurality of physical channels.

[00231] Example 25 is an apparatus configured to be employed within an access point (AP). The apparatus comprises baseband circuitry, which includes one or more processors. The one or more processors are configured to determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels. The one or more processors are also configured to generate a mapping for one or more transport blocks of a transport

channel based on the determined TTI and map the one or more transport blocks to the PHY layer based on the generated mapping.

[00232] Example 26 includes the subject matter of Example 25, including or omitting optional elements, where the baseband circuitry further includes a radio frequency (RF) circuitry interface to send transmission data to RF circuitry, the transmission data generated based on the generated mapping.

[00233] The above description of illustrated embodiments of the subject disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are possible that are considered within the scope of such embodiments and examples, as those skilled in the relevant art can recognize.

[00234] In this regard, while the disclosed subject matter has been described in connection with various embodiments and corresponding figures, where applicable, it is to be understood that other similar embodiments can be used or modifications and additions can be made to the described embodiments for performing the same, similar, alternative, or substitute function of the disclosed subject matter without deviating therefrom. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

[00235] In particular regard to the various functions performed by the above described components or structures (assemblies, devices, circuits, systems, *etc.*), the terms (including a reference to a "means") used to describe such components are intended to correspond, unless otherwise indicated, to any component or structure which performs the specified function of the described component (*e.g.*, that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations of the invention. In addition, while a particular feature may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

CLAIMS

What is claimed is:

1. An apparatus configured to be employed within one or more user equipment (UE) devices, the apparatus comprising baseband circuitry, including:
 - one or more processors configured to:
 - determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels;
 - generate a mapping for one or more transport blocks of a transport channel based on the determined TTI; and
 - map the one or more transport blocks to the PHY layer based on the generated mapping.
2. The apparatus of claim 1, wherein the baseband circuitry further includes a radio frequency (RF) circuitry interface to send transmission data to RF circuitry, the transmission data generated based on the generated mapping.
3. The apparatus of claim 1, wherein the determined TTI is varied for each of the one or more transport blocks.
4. The apparatus of claim 1, wherein the mapping identifies one of a physical downlink shared channel (PDSCH) and a physical uplink shared channel (PUSCH) for each of the one or more transport blocks.
5. The apparatus of claim 1, wherein the one or more transport blocks include a downlink shared channel (DL-SCH) of the transport channel of a medium access (MAC) layer.
6. The apparatus of claim 1, wherein the determined TTI is reduced from an original TTI.
7. The apparatus of claim 1, wherein the determined TTI is less than a subframe duration of 1 milli-second (ms).

8. The apparatus of any one of claims 1-7, wherein the mapping includes one or more gaps inserted in a subframe.
9. The apparatus of any one of claims 1-7, wherein the mapping includes one or more groups of orthogonal frequency division multiplexing (OFDM) symbols.
10. The apparatus of claim 9, wherein each of the one or more groups is matched with one of the one or more transport blocks.
11. The apparatus of any one of claims 1-7, wherein the mapping utilizes a first-in-first-out (FIFO) queue to map the one or more transport blocks to one or more physical channels.
12. The apparatus of any one of claims 1-7, wherein the communication characteristics comprise one or more of latency, reliability and data rate.

13. An apparatus configured to be employed within an evolved Node B (eNodeB), the apparatus comprising baseband circuitry, including:
- one or more processors configured to:
 - determine physical (PHY) layer parameters of a PHY layer based on communication characteristics, wherein the numerology includes a transmission time interval (TTI) and wherein the communication characteristics include reliability and the PHY layer comprises physical channels;
 - generate a mapping for one or more transport blocks based on the determined PHY layer parameters; and
 - map the one or more transport blocks to a subframe of the PHY layer.
14. The apparatus of claim 13, wherein the baseband circuitry further includes a radio frequency (RF) circuitry interface to send transmission data to RF circuitry, the transmission data generated based on the subframe.
15. The apparatus of claim 13, wherein the mapping includes arranging one or more physical channels, inserting gaps and adjusting resource span times.
16. The apparatus of claim 13, wherein the PHY layer uses a subcarrier frequency of 15 kHz.
17. The apparatus of any one of claims 13-16, wherein the communication characteristics further include latency.

18. One or more computer-readable media having instructions that, when executed, cause a user equipment (UE) device to:

determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels;

generate a mapping for one or more transport blocks of a transport channel based on the determined TTI;

map the one or more transport blocks to one or more physical channels of the PHY layer based on the generated mapping; and

transmit the physical channels using the determined TTI.

19. The computer-readable media of claim 18, comprising one or more computer-readable media having instructions that, when executed, further cause the UE device to:

map each transport block of the one or more transport blocks to a group of consecutive orthogonal frequency division multiplexing (OFDM) symbols.

20. The computer-readable media of claim 18, comprising one or more computer-readable media having instructions that, when executed, further cause the UE device to:

insert a physical downlink control channel (PDCCH) into a subframe of the PHY layer based on the mapping.

21. The computer-readable media of claim 18, comprising one or more computer-readable media having instructions that, when executed, further cause the UE device to:

insert a physical uplink control channel (PUCCH) into a subframe of the PHY layer based on the mapping, wherein the subframe has a length greater than the determined TTI.

22. An apparatus configured to be employed within one or more user equipment (UE) devices, the apparatus comprising:
- a means to determine one or more physical (PHY) layer parameters based on communication characteristics;
 - a means to generate a mapping for a plurality of transport blocks from a transport channel to a plurality of physical channels of a PHY layer based on the determined one or more PHY layer parameters;
 - a means to map the plurality of transport blocks to the plurality of physical channels based on the generated mapping; and
 - a means to transmit the plurality of physical channels.
23. The apparatus of claim 22, further comprising:
- a means to determine an inter-arrival time for the transport blocks.
24. The apparatus of claim 22, wherein the one or more PHY layer parameters include a transmission time interval (TTI) for the plurality of physical channels.
25. An apparatus configured to be employed within an access point (AP), the apparatus comprising baseband circuitry, including:
- one or more processors configured to:
 - determine a transmission time interval (TTI) for a physical (PHY) layer based on communication characteristics, the PHY layer comprising physical channels;
 - generate a mapping for one or more transport blocks of a transport channel based on the determined TTI; and
 - map the one or more transport blocks to the PHY layer based on the generated mapping.

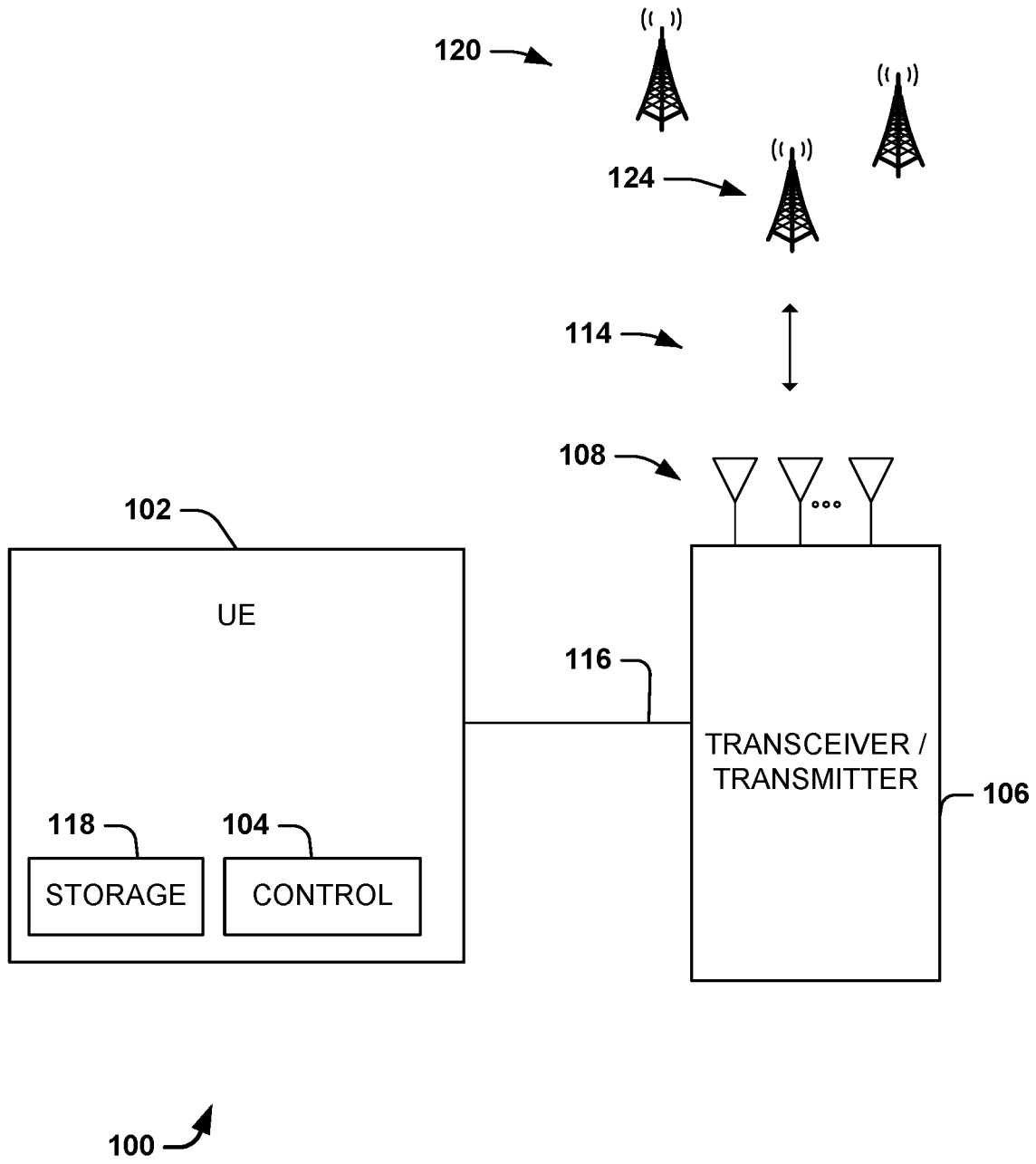
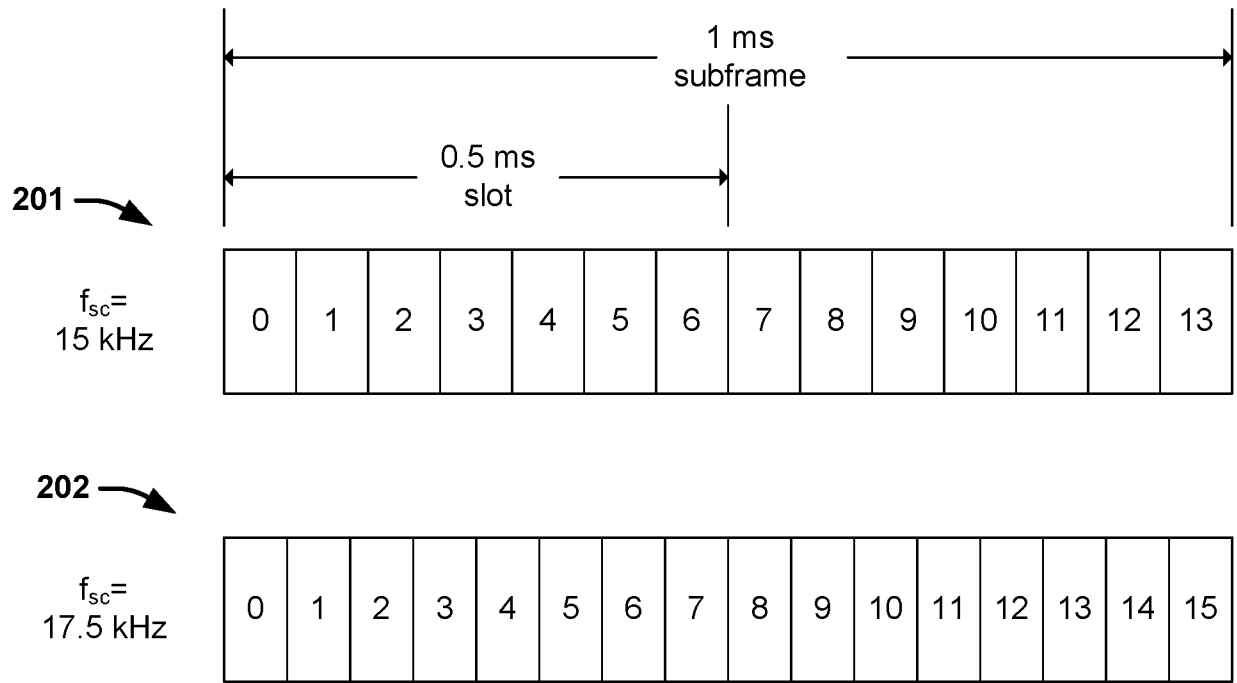
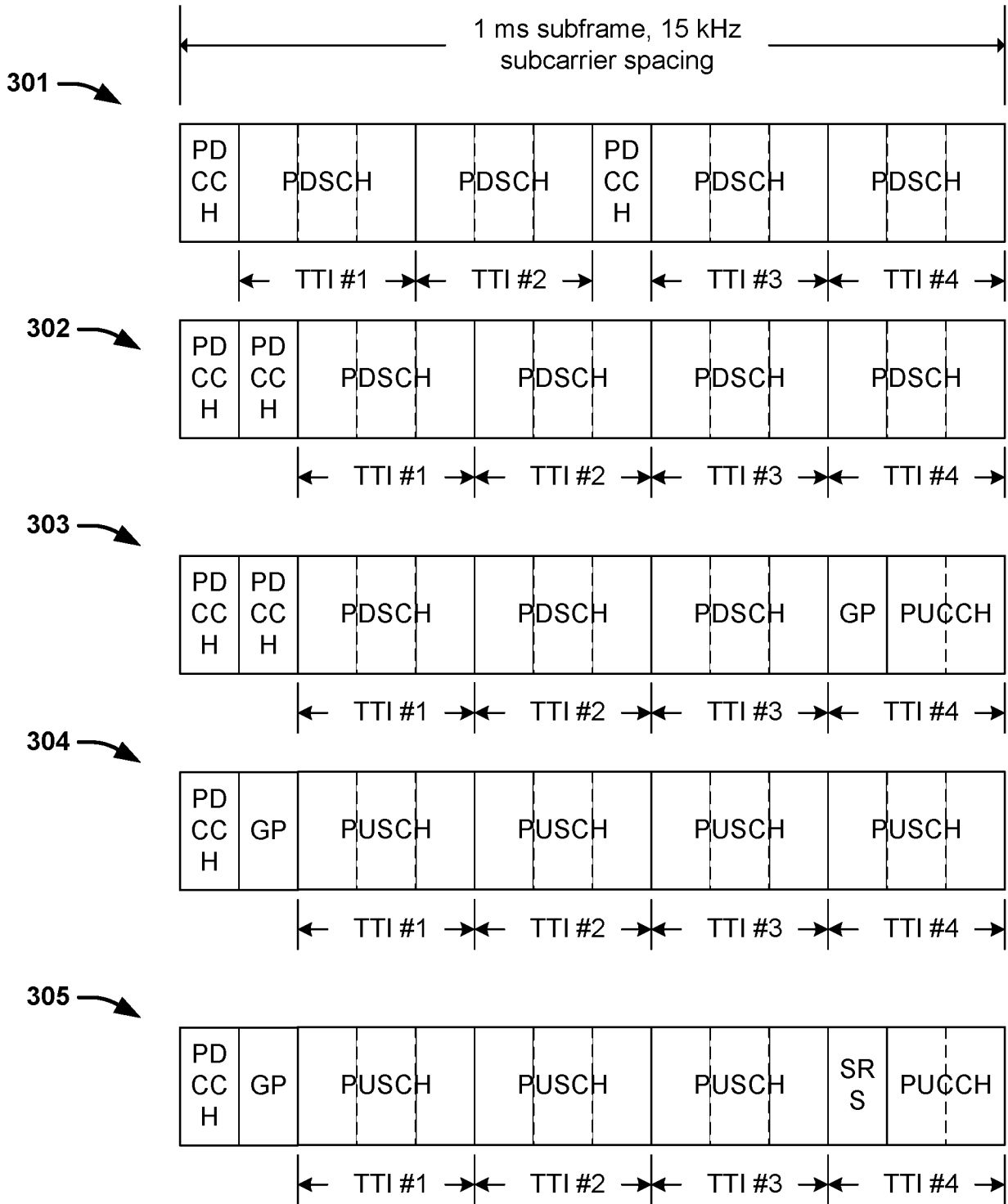


FIG. 1



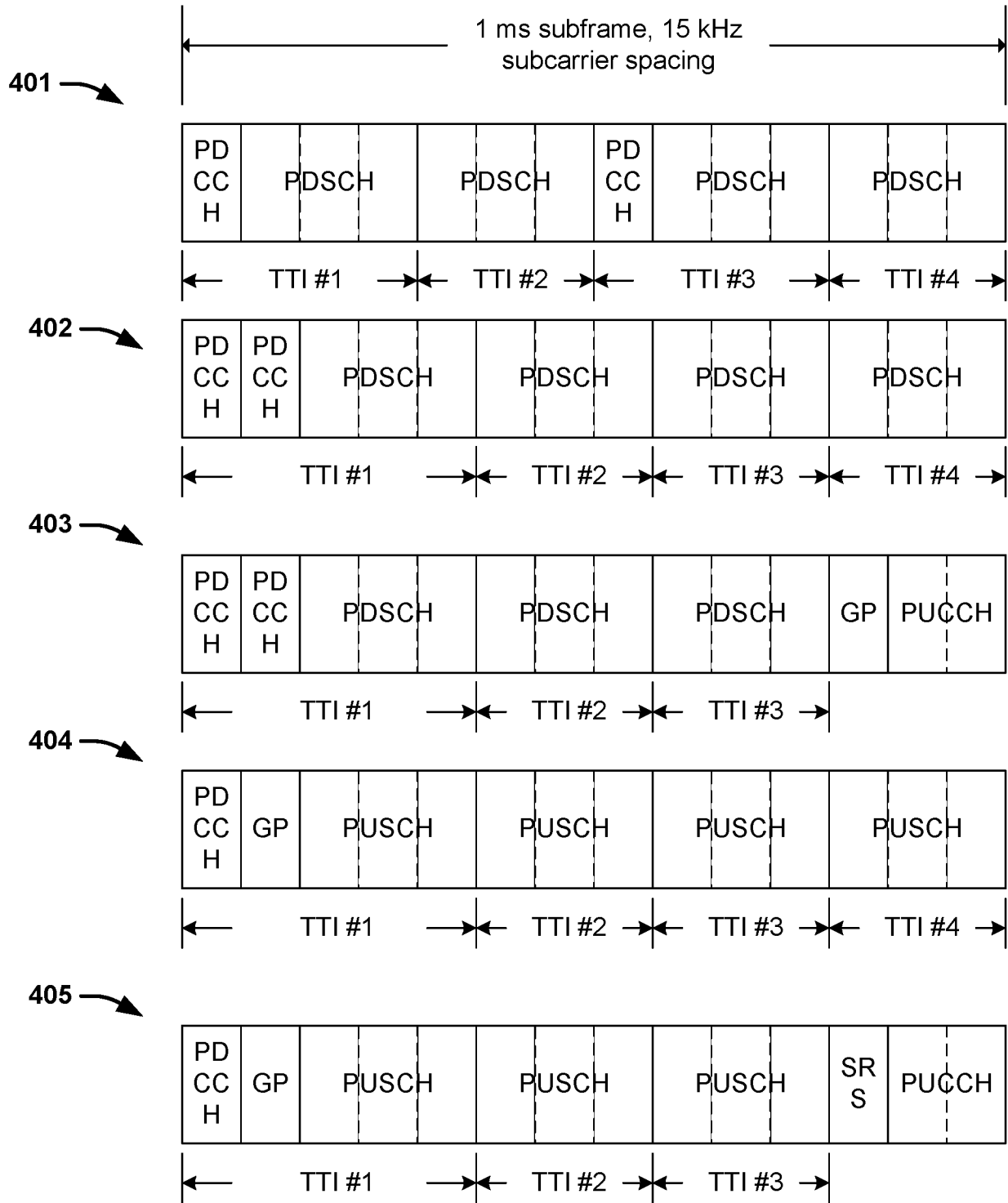
200 ↗

FIG. 2



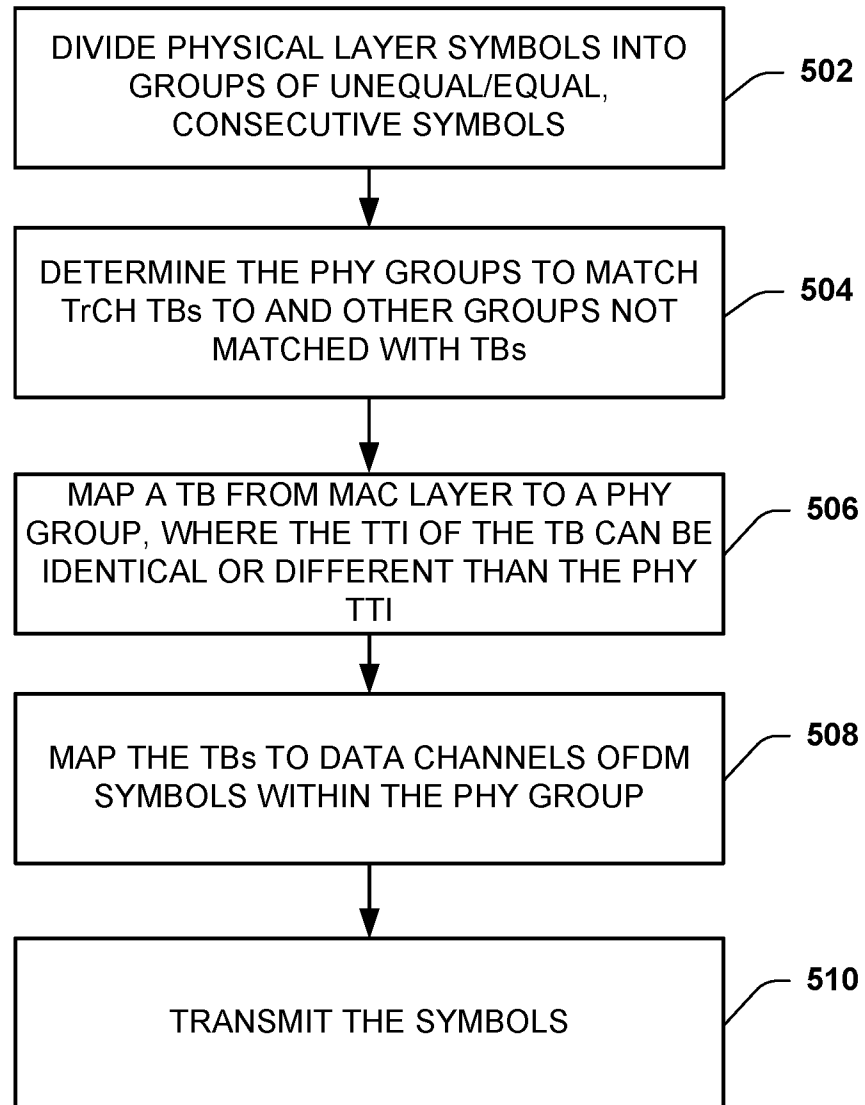
300 ↗

FIG. 3



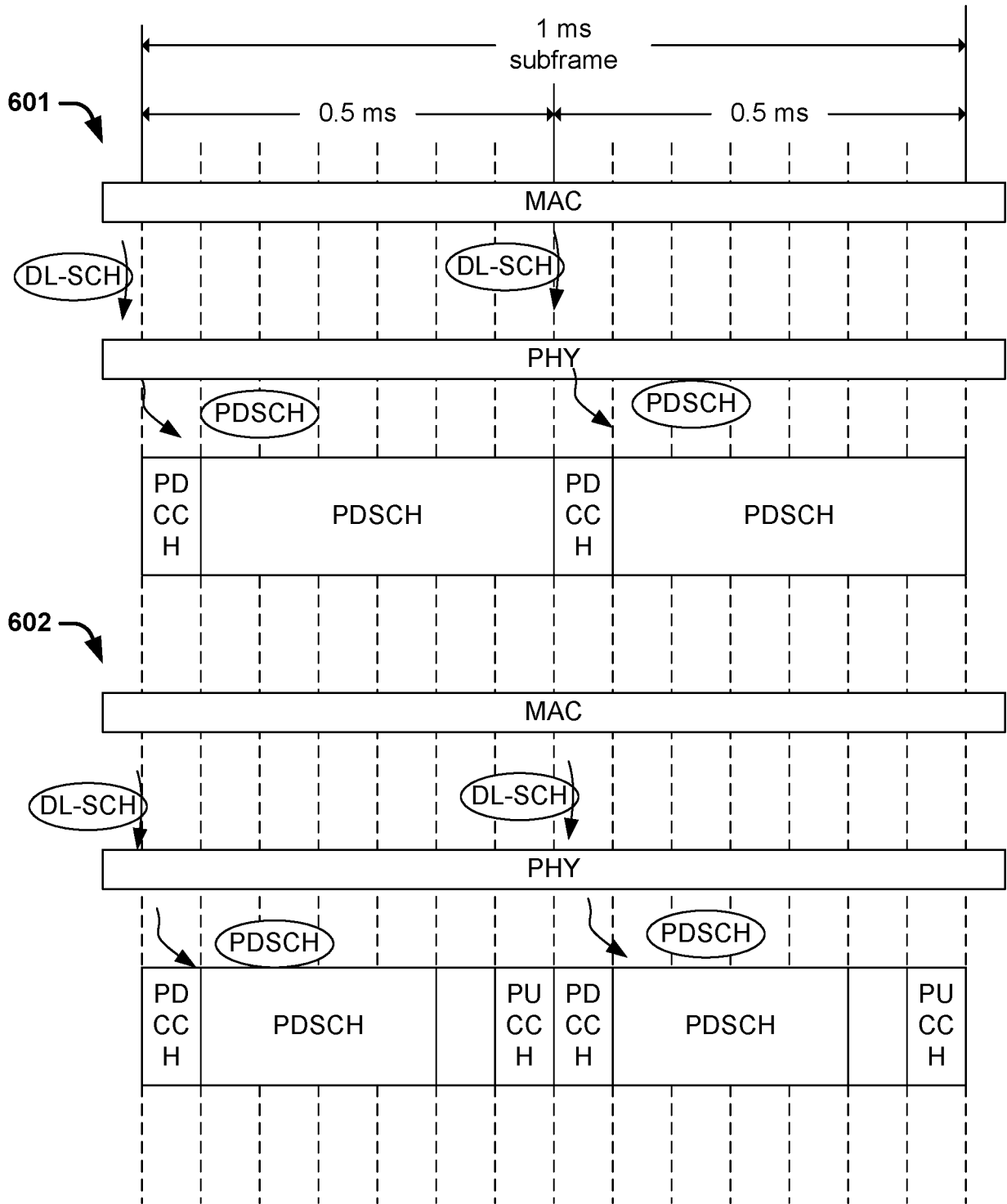
400 ↗

FIG. 4



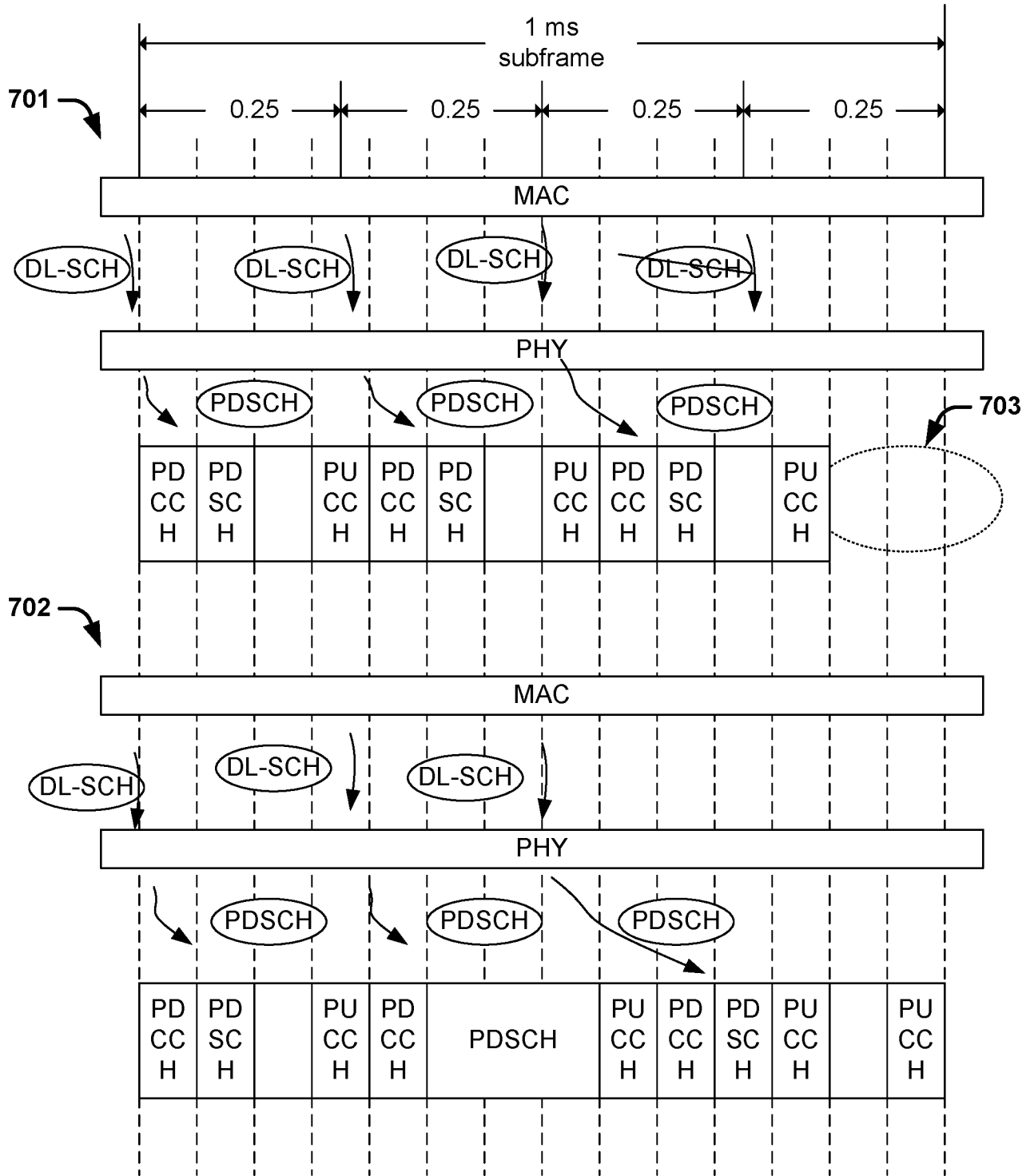
500 ↗

Fig. 5



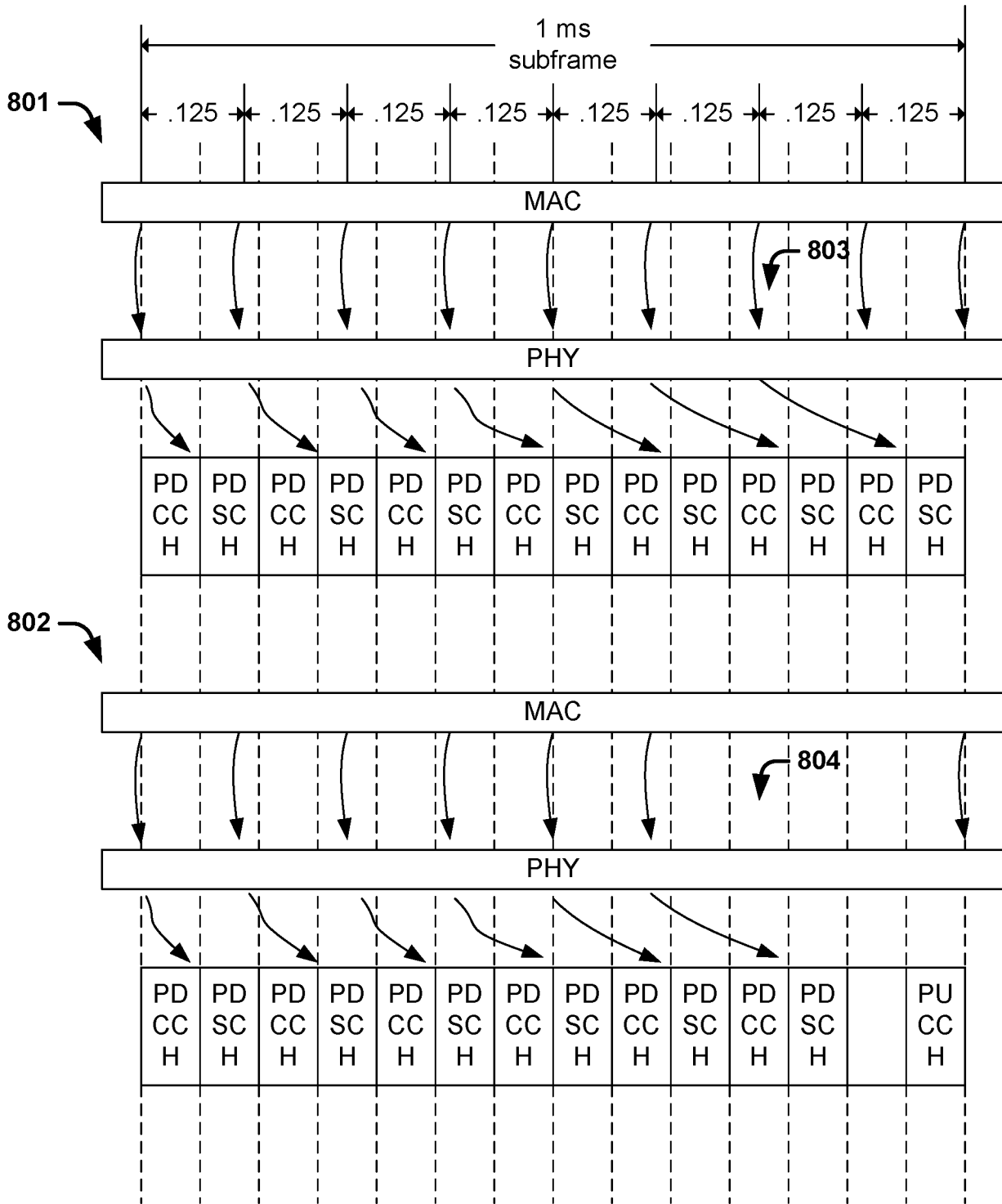
600 ↗

FIG. 6



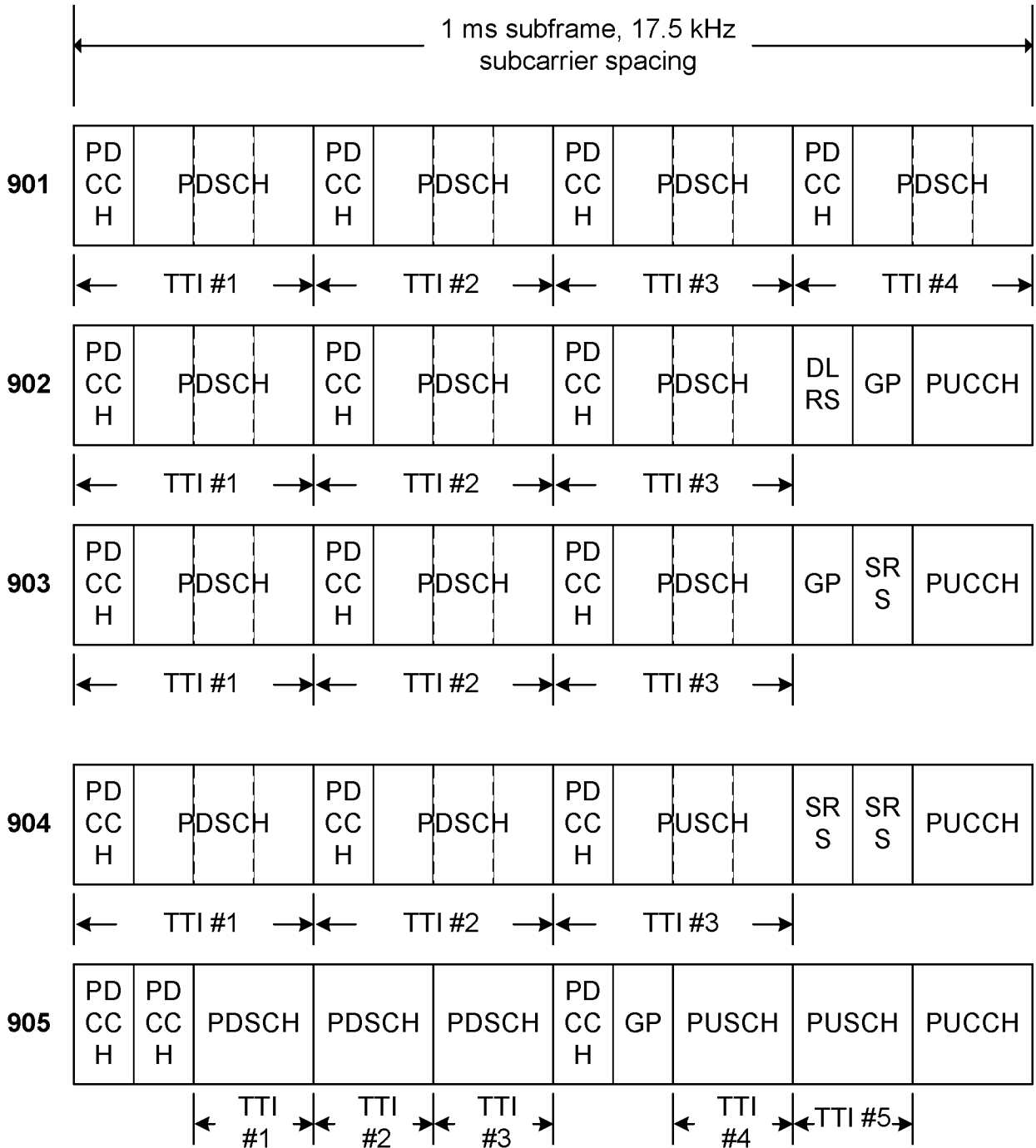
700 ↗

FIG. 7



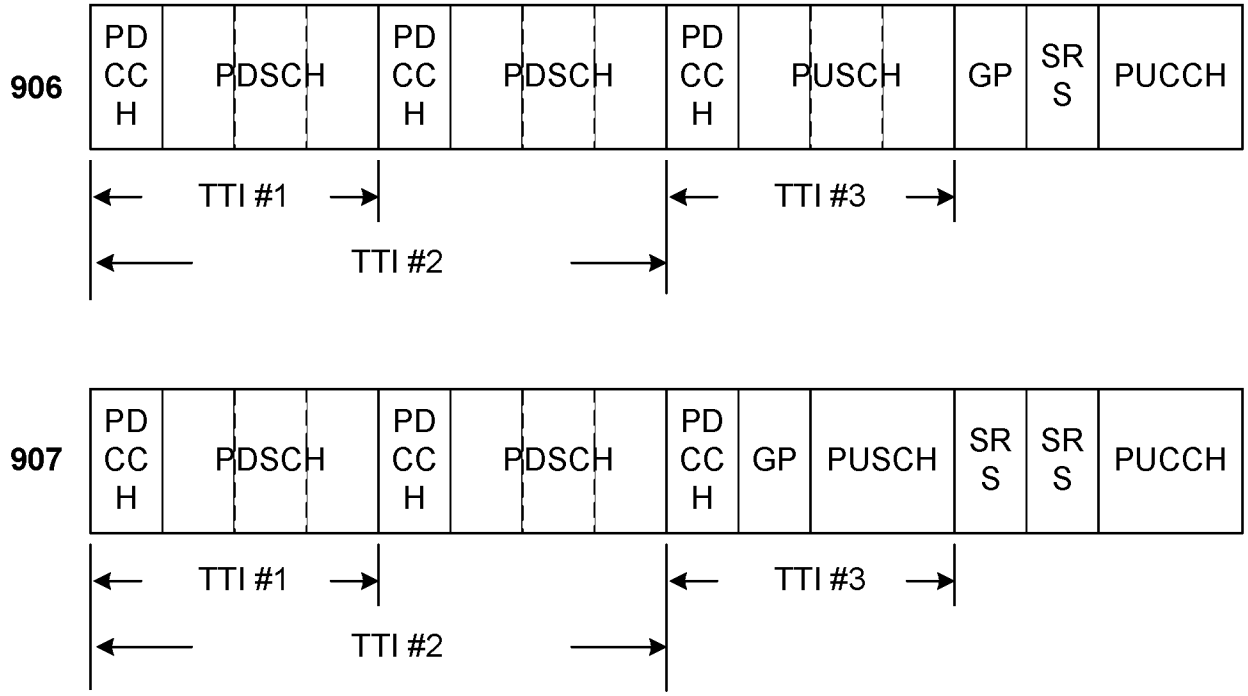
800 ↗

FIG. 8



900a ↗

FIG. 9A



900b ↗

FIG. 9B

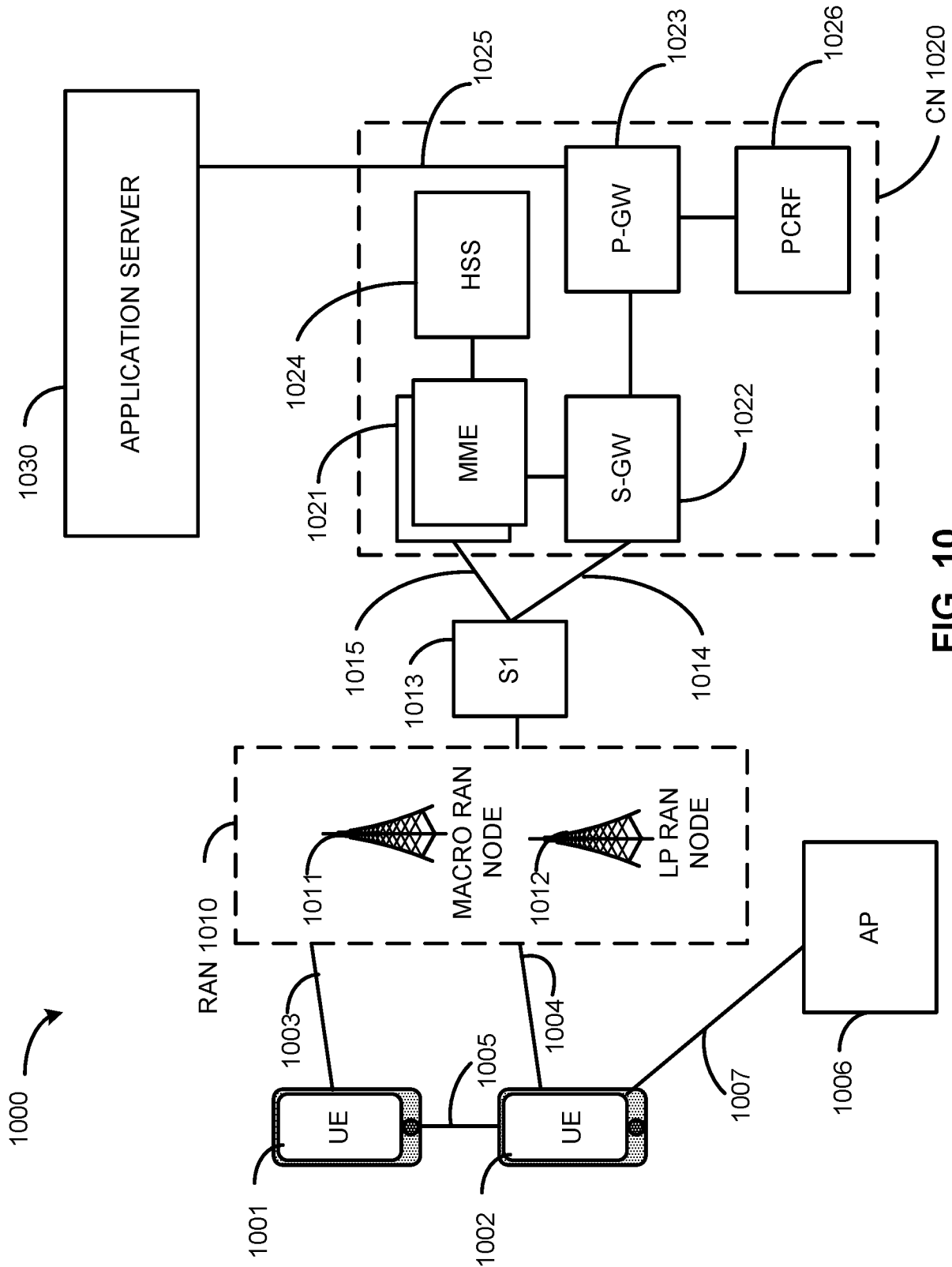


FIG. 10

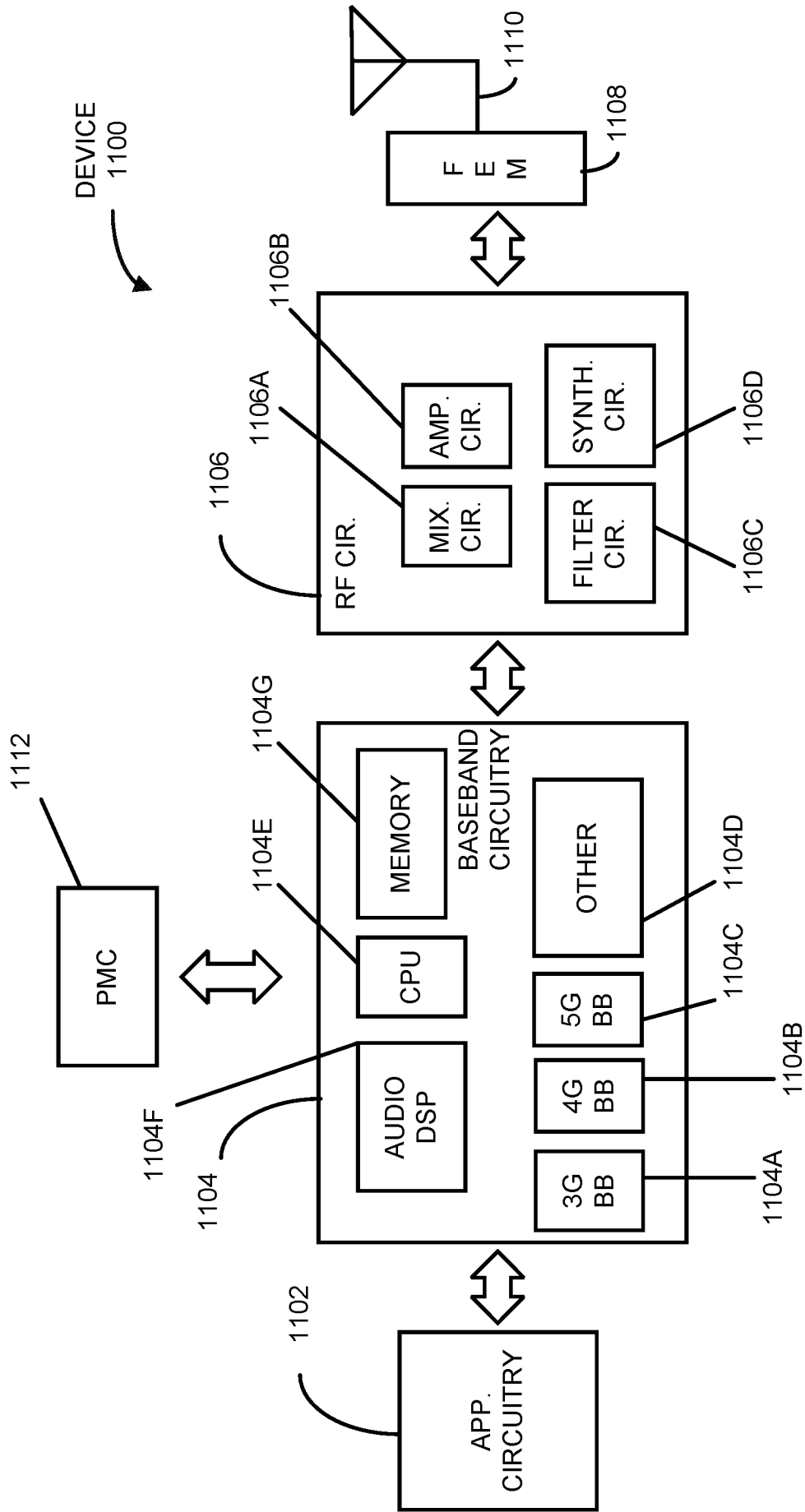


FIG. 11

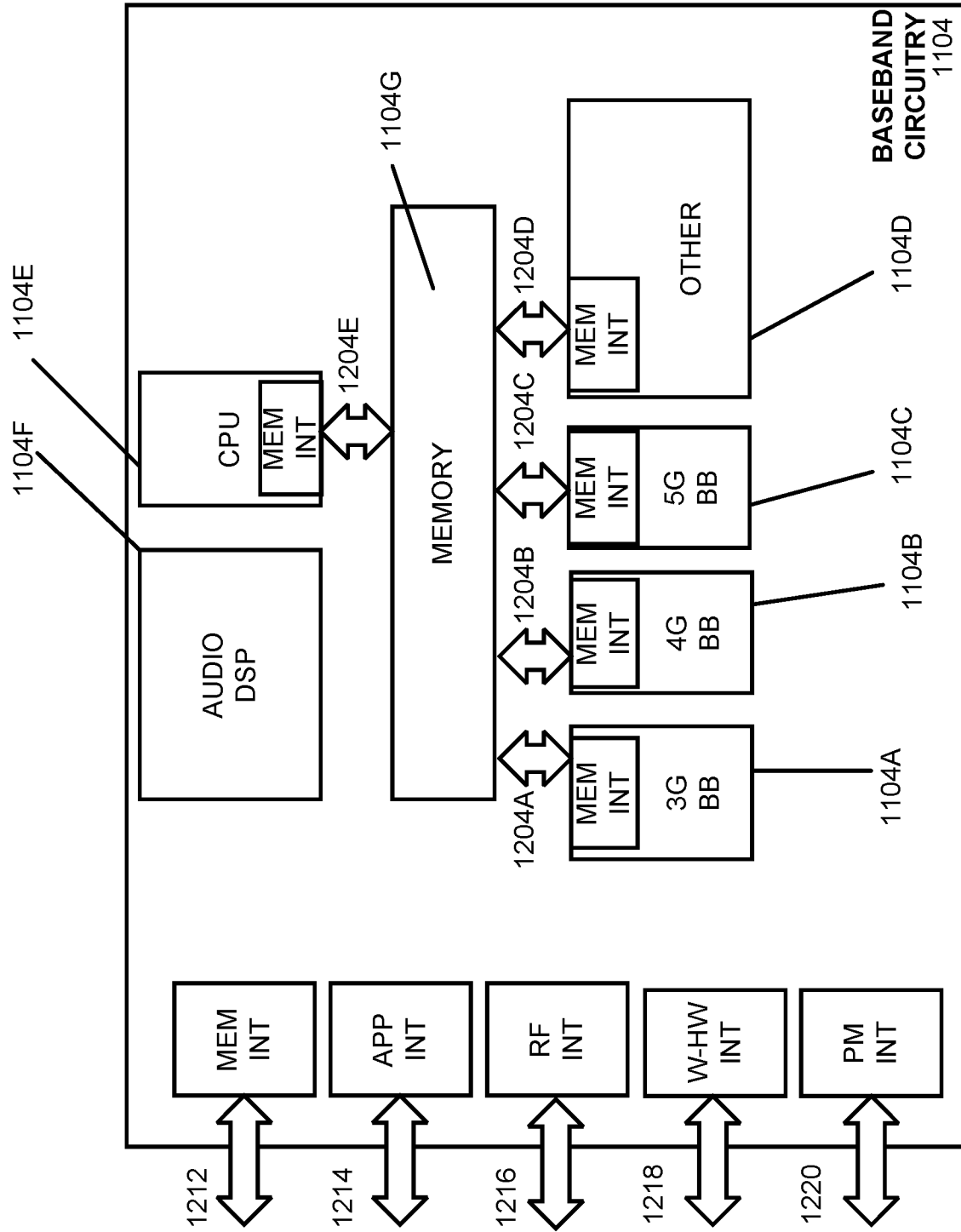


FIG. 12

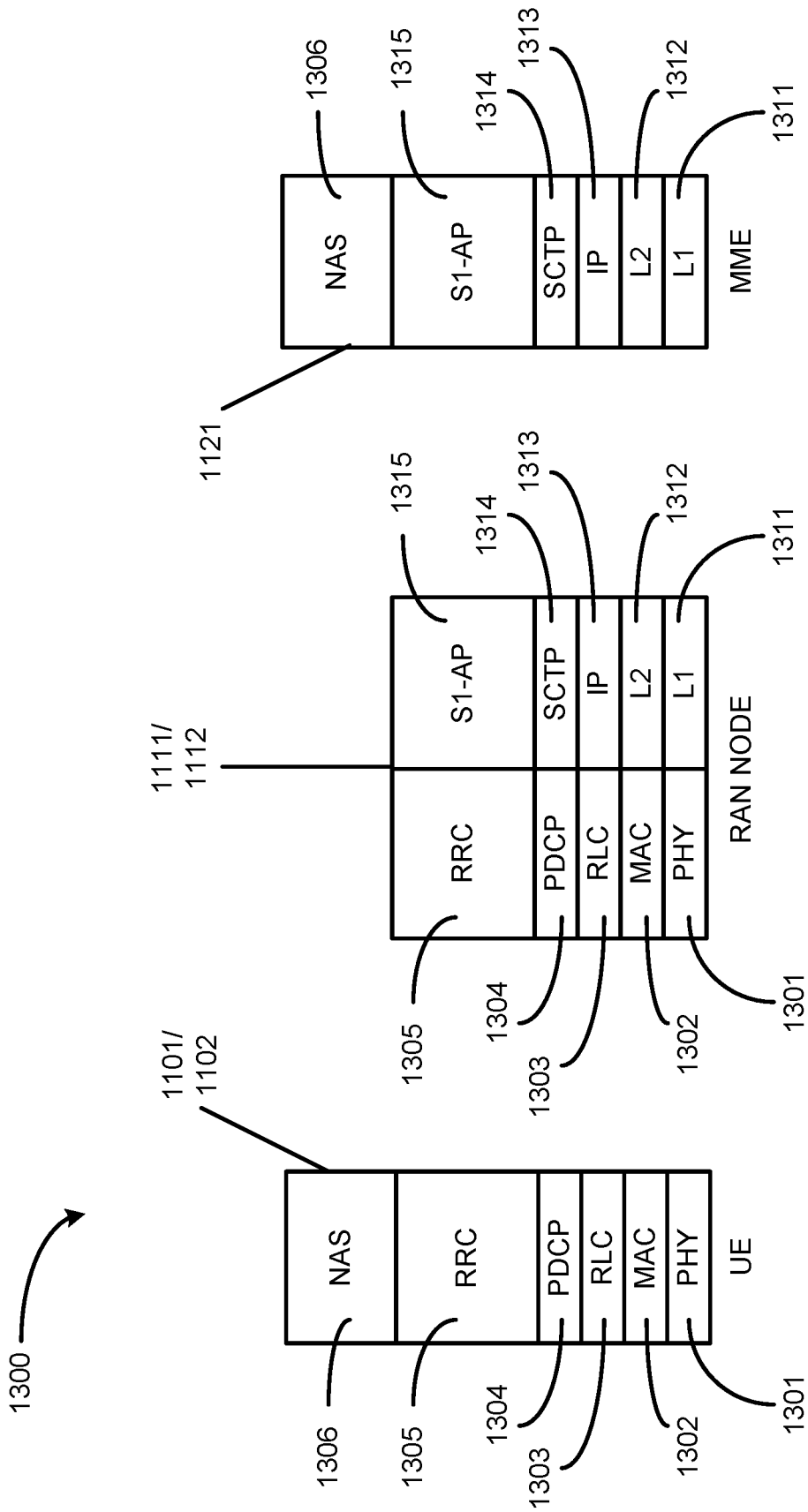


FIG. 13

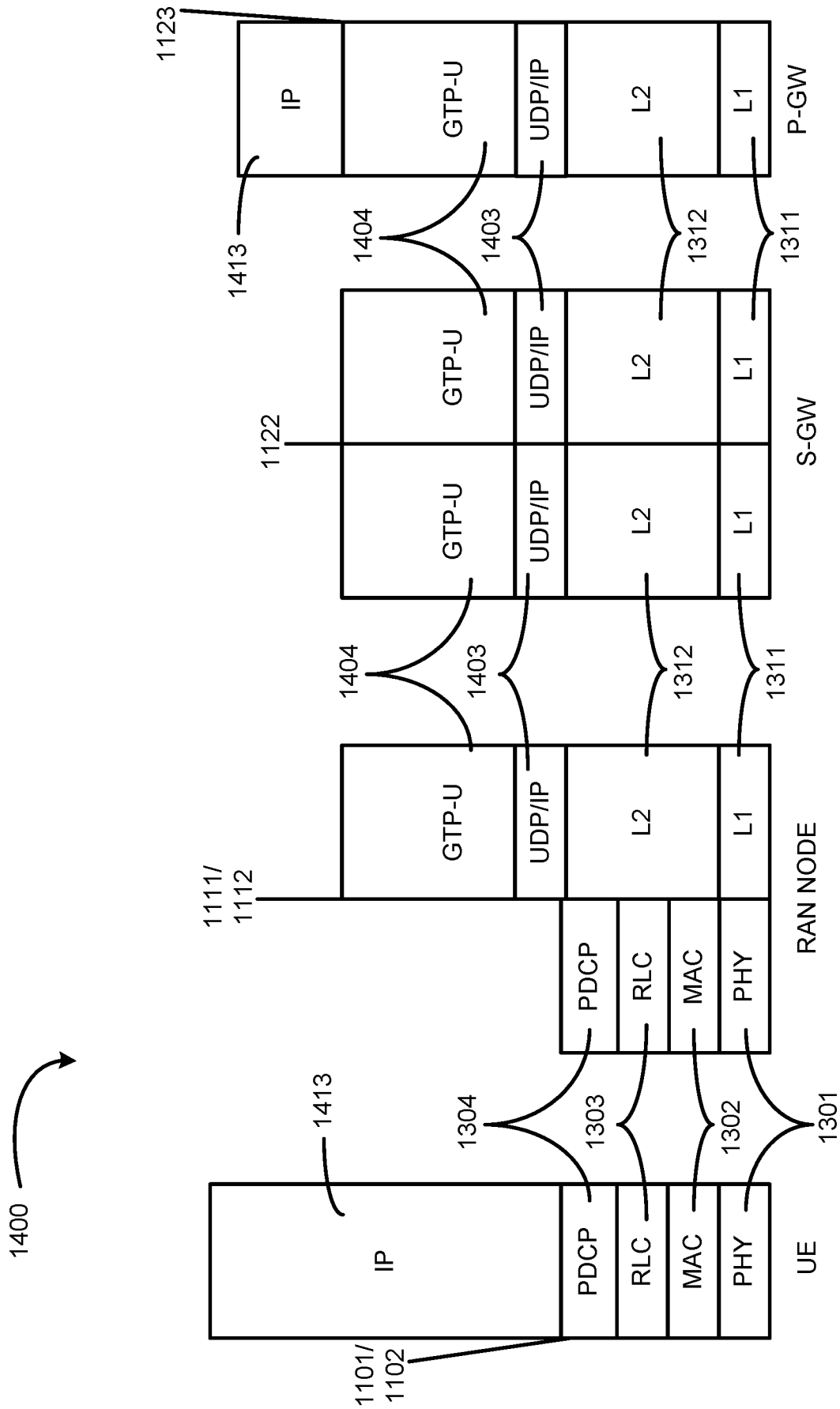


FIG. 14

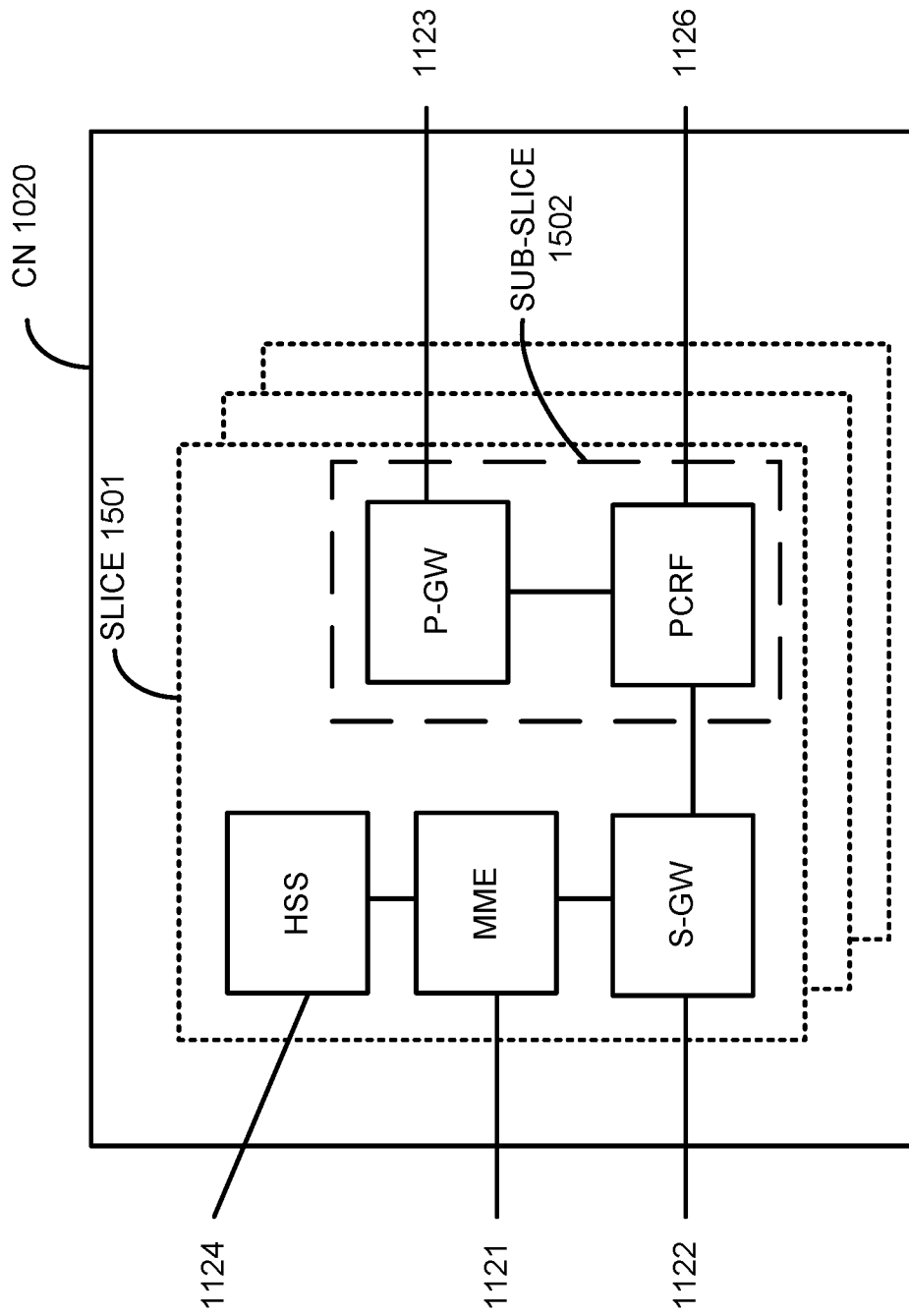


FIG. 15

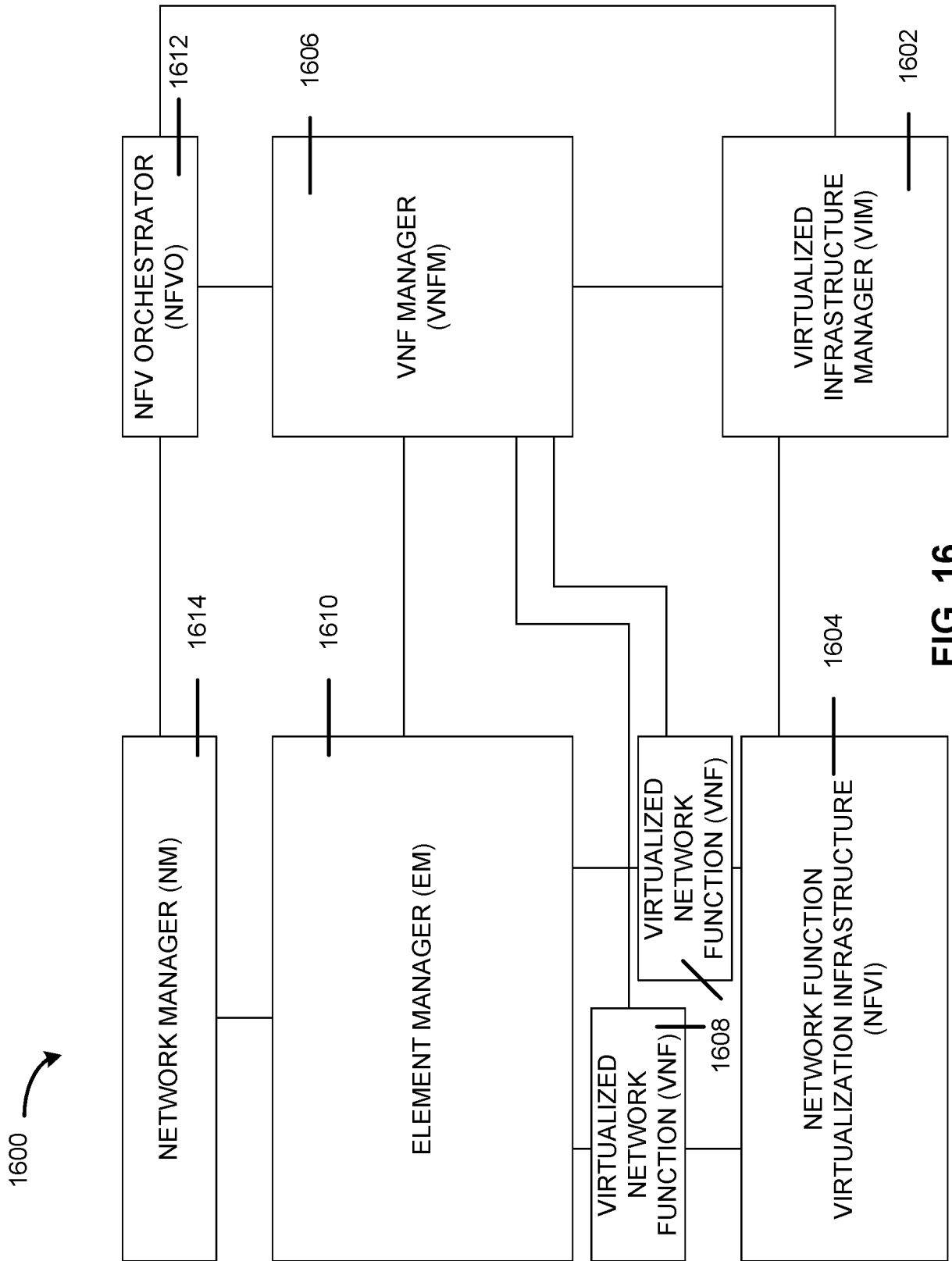


FIG. 16

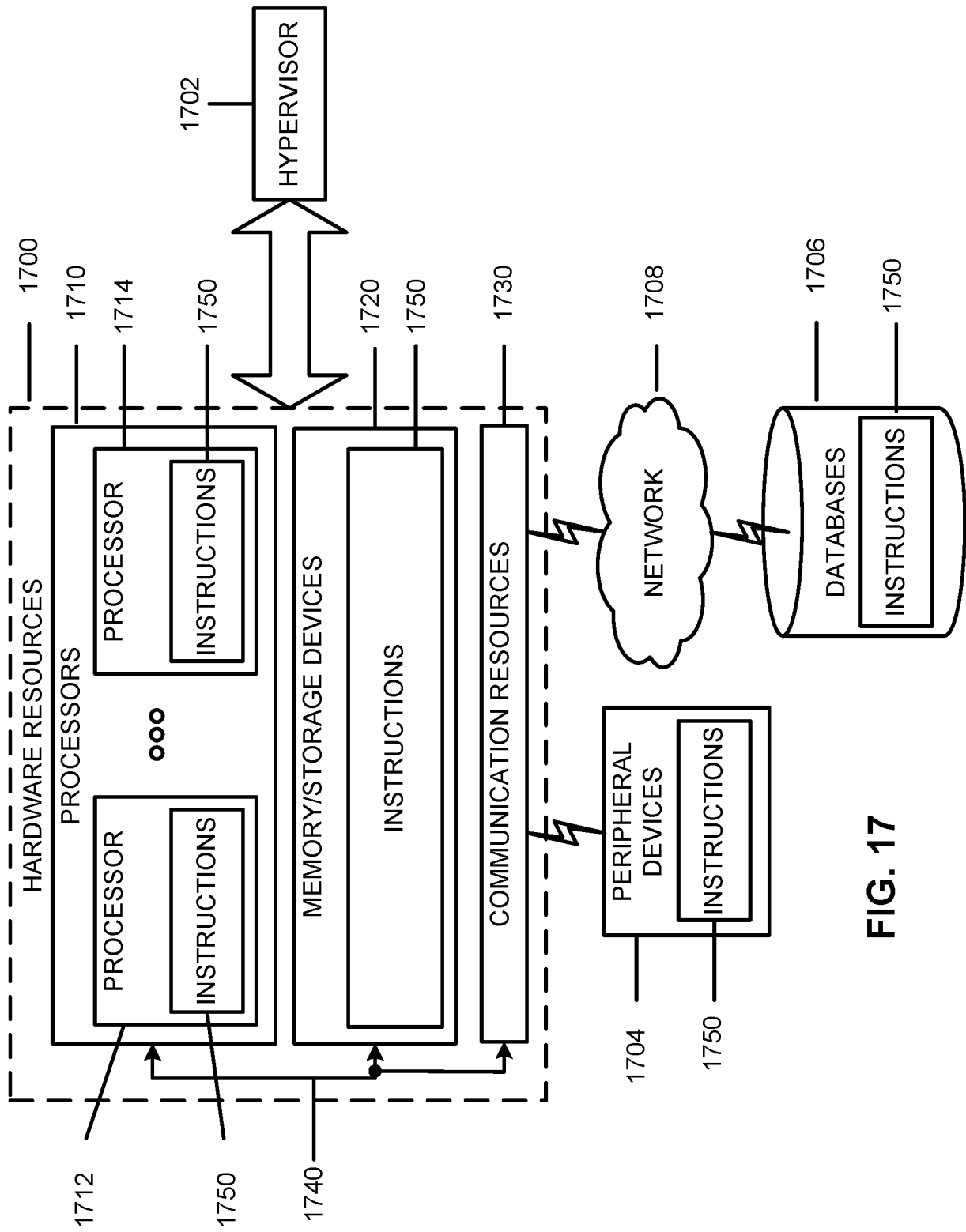


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/032380

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L5/00
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	<p>LG ELECTRONICS: "Study on TTI shortening for downlink transmissions", 3GPP DRAFT; R1-160649, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>, vol. RAN WG1, no. St Julian's, Malta; 20160215 - 20160219 14 February 2016 (2016-02-14), XP051053978, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2016-02-14] figure 1 page 1 - page 3</p> <p style="text-align: center;">----- -/--</p>	1-12,25

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

24 July 2017

Date of mailing of the international search report

22/09/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Hanus, Pavol

INTERNATIONAL SEARCH REPORT

International application No PCT/US2017/032380

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>LG ELECTRONICS: "Physical layer aspect of processing time for shortened TTI", 3GPP DRAFT; R1-162511 PROCESSING TIME REDUCTION VF, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>vol. RAN WG1, no. Busan, Korea; 20160411 - 20160415 2 April 2016 (2016-04-02), XP051080247, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-02] page 1 - page 4</p> <p align="center">-----</p>	1-12,25

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/032380

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-12, 25

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12, 25

Mapping transport blocks to TTIs determined based on communications characteristics

2. claims: 13-17

Mapping transport blocks based on reliability

3. claims: 18-21

Mapping transport blocks to physical channels in TTIs

4. claims: 22-24

Mapping transport blocks based on PHY layer parameters
