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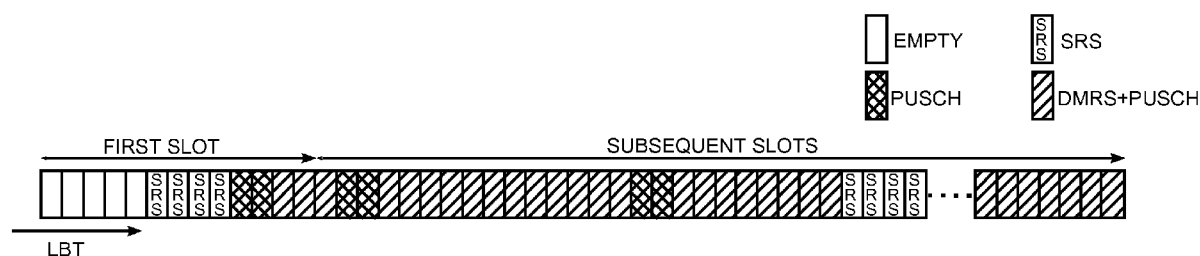


FIG. 5

(57) Abstract: Systems and methods are disclosed herein for SRS transmission in a cellular communications system. Transmission of one or more SRSs at the beginning of a transmission burst shortens the initial transmission delay, which improves resource efficiency. Embodiments of a wireless device and method performed therein include, in a first X slots or mini-slots of a transmission burst from the wireless device, mapping SRSs at a beginning of the transmission from the wireless device. In some embodiments, X is a natural number greater than zero and either the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or minislots for the transmission burst, that occurs immediately after the wireless device gets access to a wireless medium upon completing a Listen-Before-Talk (LBT) procedure, or the transmission burst starts at a predefined starting position of a slot or mini-slot.



SRS TRANSMISSION METHODOLOGIES IN UNLICENSED SPECTRUMTechnical Field

5 This application relates to methods and systems for transmissions in a network operating in the shared or unlicensed spectrum.

Background

10 Allowing unlicensed networks, i.e., networks that operate in shared spectrum (or unlicensed spectrum) to effectively use the available spectrum is an attractive approach to increase system capacity. While unlicensed spectrum can never match the qualities of the licensed regime, solutions that allow an efficient use of unlicensed spectrum as a complement to licensed deployments have the potential to bring great value to the 3GPP operators, and, ultimately, to the 3GPP industry as a whole. These types of solutions would enable operators and vendors to leverage the existing or planned investments in, for example, Long Term Evolution/New Radio (LTE/NR) hardware in the
15 radio and core network.

For a node to be allowed to transmit in unlicensed spectrum, it typically needs to perform a clear channel assessment (CCA) or Listen Before Talk (LBT) procedure. These channel sensing procedures typically includes sensing the unlicensed medium to be idle for a number of time intervals. After sensing the medium idle, a node is typically allowed to transmit for a certain
20 amount of time, sometimes referred to as the MCOT (Maximum Channel Occupancy Time). Another name for this concept is TXOP (transmission opportunity). The length of the MCOT depends on regulation and type of CCA that has been performed, but typically ranges from 1ms to 10ms.

25 In the MCOT concept, a 5G base station (gNB) is allowed to share its channel occupancy, after completing a long LBT, with uplink transmissions from UEs. One main goal with the introduction of the shared MCOT concept is to minimize the need of UEs to perform a long LBT prior to transmissions in the uplink. The scheduled UEs may perform a short LBT (e.g., one shot CCA) immediately following the downlink transmission.

30 An NR slot consists of several Orthogonal Frequency Division Multiplexing (OFDM) symbols, according to current agreements. Figure 1 shows a subframe with 14 OFDM symbols. In Figure 1, T_s and T_{symb} denote the slot and OFDM symbol durations, respectively. In addition, a slot may also be shortened to accommodate DL/UL transient period or both DL and UL transmissions. Some examples of potential slot variations are shown in Figure 2.

In a first example in Figure 2, a DL-only transmission with a late start is shown. In one example, the LBT process is completed after the slot starts, and the node begins DL transmissions late. In a second example, a DL-heavy transmission with an UL part is shown. In such example, the node completes DL and schedules time for UL to begin within the same slot. In a third example in Figure 2, a UL-heavy transmission with a DL control is shown. In this example, after a DL control symbol is transmitted, the remainder of the slot is UL transmission beginning after a DL-UL transition time T_{DL-UL} . In a fourth example, UL-only transmission is performed.

NR also defines mini-slots. Mini-slots are shorter than slots (according to current agreements) and range from 1 or 2 symbols up to N number of symbols in a slot minus one, wherein N is a natural number greater than 2. Mini-slots can start at any symbol. Mini-slots are used if the transmission duration of a slot is too long or the occurrence of the next slot start (slot alignment) is too late. Applications of mini-slots include, among others, latency critical transmissions (in this case both mini-slot length and frequent opportunity of mini-slot are important) and unlicensed spectrum where a transmission should start immediately after listen-before-talk succeeded instead of waiting for the beginning of the next slot (here the frequent opportunity of mini-slot is especially important). An example of mini-slots is shown in Figure 3. As indicated, both a start time of a mini-slot within a slot interval, and a length (e.g., in time and/or OFDM symbols) of a mini-slot are variable.

There currently exist certain challenge(s) in unlicensed operations. The time from when the channel sensing is done to when the transmitter needs to start its transmission is in general very short. According to the regulations in ETSI, the transmitter needs to start its transmission at latest 16 microseconds (μs) after the channel sensing. Otherwise, the node has to perform channel sensing again. Thus, between completion of channel sensing and the beginning of transmission there is sparse time for encoding and conducting remaining data processing for the transport block(s) that the transmitter needs to transmit over available channels.

Summary

Systems and methods are disclosed herein for Sounding Reference Signals (SRS) transmission in a cellular communications system. Embodiments of a method performed in a User Equipment (UE) for SRS transmission in a cellular communications system are disclosed. The method includes, in a first X slots or mini-slots of a transmission burst from the UE, mapping SRSs at a beginning of the transmission burst from the UE. In some embodiments, X is a natural number greater than zero and either the transmission burst starts at any symbol of a slot or mini-slot, from

among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to a corresponding wireless medium upon completing a Listen-Before-Talk (LBT) procedure, or the transmission burst starts at a predefined starting position of a slot or mini-slot. The method further includes transmitting the mapped SRSs in the first X slots or mini-slots of the transmission burst.

In some embodiments, the transmission burst starts at the predefined starting position. In some embodiments, in subsequent slots in which SRSs are to be transmitted, the SRSs are transmitted at the end of the slots. In some embodiments, the predefined starting position is either Radio Resource Control (RRC) configured or indicated via Layer 1 signaling. In such embodiments, in the first X slots or mini-slots of the transmission burst from the UE, mapping the SRSs at the beginning of the transmission burst from the UE comprises mapping the SRSs to a first Y consecutive Orthogonal Frequency Division Multiplexing (OFDM) symbols at the beginning of the transmission burst from the UE. In some of the disclosed embodiments, Y is in a range of and including 1 to L where L is a natural number that represents a maximum allowed number of SRS symbols. In some embodiments Y is a function of a length of the slot or mini-slot. In some embodiments, if the length of the slot or mini-slot is greater than L, remaining symbols in the slot or mini-slot are used to transmit any one or any combination of: Physical Uplink Control Channel (PUCCH), Demodulation Reference Signal (DMRS), and Physical Uplink Shared Channel (PUSCH). In some embodiments, if the length of the mini-slot is less than L, remaining SRSs are mapped to the beginning of a next slot. In any of the disclosed embodiments, $X=1$ or $X>1$. In some of the disclosed embodiments, one or more uplink channels follow a different mapping in the first X slots or mini-slots of the transmission burst than in remaining slots or mini-slots of the transmission burst. Some embodiments further include receiving, from the base station via RRC signaling, different patterns of the first min-slot(s) of the transmission burst corresponding to different starting points of the SRS.

In some embodiments, the disclosed method includes receiving, from a base station, an indication that that UE is allowed to transmit a SRS at the beginning of the transmission burst. In some embodiments, the transmission burst starts at any symbol of a slot or mini-slot, from among the plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to the corresponding wireless medium upon completing the LBT procedure. In such embodiments, the LBT procedure may include a one shot clear channel assessment (CCA). In some embodiments, the transmission starts at a symbol of a slot or mini-slot no later than 16 microseconds (μ s) later than completing the LBT procedure.

Embodiments disclosed herein include a UE for a cellular communications system. In some embodiments, the UE is adapted to, in a first X slots or mini-slots of a transmission burst from the UE, map SRSs at a beginning of the transmission burst from the UE. In some embodiments, X is a natural number greater than zero and either the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to a corresponding wireless medium upon completing a LBT procedure, or the transmission burst starts at a predefined starting position. The UE may be further adapted to transmit the mapped SRSs in the first X slots or mini-slots of the transmission burst. In some embodiments, the UE is further adapted to start the transmission burst at the predefined starting position. In some embodiments, the UE is further adapted to start the transmission burst at any symbol of a slot or mini-slot, from among the plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to the corresponding wireless medium upon completing the LBT procedure.

Embodiments disclosed herein include a wireless device (WD) for a cellular communications system. In some embodiments, the WD disclosed herein includes processing circuitry and a memory. In some embodiments, the processing circuitry may execute instructions stored in the memory within the processing circuitry to control the WD to, in a first X slots or mini-slots of a transmission burst from the WD, map SRS, at a beginning of the transmission burst from the WD. In some embodiments, X is a natural number greater than zero and either the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the WD gets access to a corresponding wireless medium upon completing a LBT, procedure, or the transmission burst starts at a predefined starting position. In some embodiments the processing circuitry may execute instructions to transmit the mapped SRSs in the first X slots or mini-slots of the transmission burst.

Embodiments disclosed herein also include a method performed in a network node for SRS reception in a cellular communications system. In some embodiments, the disclosed method includes receiving a transmission burst from a UE in which, in a first X slots or mini-slots of the transmission burst, SRSs are mapped at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero. Some embodiments further include indicating, to a UE, that the UE is allowed to start a transmission burst with a SRS. In some embodiments, the receiving a transmission burst from a UE further includes receiving, in a subsequent slot, SRSs placed at the end of the slot. Some embodiments further include pre-configuring the UE with different patterns of the first X slots or mini-slots with SRS. In some embodiments, receiving a transmission burst from the

UE further includes monitoring for a first SRS and, based on a position of the SRS in a slot or mini-slot, recognizing one of the patterns.

Embodiments disclosed herein also include a network node implementing a method for SRS reception in a cellular communications system, including receiving a transmission burst from a UE in which, in a first X slots or mini-slots of the transmission burst, SRSs are mapped at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

Embodiments disclosed herein also includes a network node in a cellular communications system, the network node adapted to receive a transmission burst from a UE in which in a first X slots or mini-slots of the transmission burst, SRSs are mapped at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

Brief Description of the Drawings

The accompanying drawing figures incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

Figure 1 is an illustration of a slot of time T_s including 14 symbols of time T_{symb} according to Third Generation Partnership Project (3GPP) New Radio (NR);

Figure 2 is an illustration of variations of uplink (UL)/downlink (DL) transmissions within a slot;

Figure 3 is an illustration of a mini-slot with two Orthogonal Frequency Division Multiplexing (OFDM) symbols starting at the second slot symbol in a slot;

Figure 4 is an illustration of an example of a UL slot including Demodulation Reference Signal (DMRS), Physical Uplink Shared Channel (PUSCH), and Sounding Reference Signal (SRS) according to 3GPP NR;

Figure 5 is an illustration of consecutive slots in an example according to the present disclosure in which SRS symbols are transmitted at the beginning of a transmission after a node gets access to a channel, and subsequently transmitted in the end symbols of a slot;

Figure 6 illustrates one example of a wireless network in which embodiments of the present disclosure may be implemented;

Figure 7 illustrates one embodiment of a User Equipment (UE) in accordance with various aspects of the present disclosure;

Figure 8 illustrates a method of a next generation Node B (gNB) performing a Listen Before Talk (LBT) procedure and indicating that a UE is allowed to start transmission with SRSs, and a UE starting transmission with SRSs at flexible positions within a slot;

Figure 9 is a flowchart of a method of performed in a UE for SRS transmission in a cellular communications system; and;

Figure 10 is a flowchart of a method performed in a network node for SRS reception in a cellular communications system.

Detailed Description

The embodiments set forth below represent information to enable those skilled in the art to practice the embodiments and illustrate the best mode of practicing the embodiments. Upon reading the following description in light of the accompanying drawing figures, those skilled in the art will understand the concepts of the disclosure and will recognize applications of these concepts not particularly addressed herein. It should be understood that these concepts and applications fall within the scope of the disclosure.

A typical structure of the UL slot with SRS according to New Radio (NR) is illustrated in Figure 4. Here, the demodulation reference signal (DMRS) is allocated in the beginning of the slot, following by a shared uplink (UL) data channel (Physical Uplink Shared Channel (PUSCH)). Sounding reference signals (SRSs) are allocated in the end of slot. After a User Equipment (UE) is assigned the parameters for SRS transmission by the next generation Node B (gNB), the generation of the SRS signal is straightforward and requires no data processing such as channel encoding for Physical Uplink Control Channel (PUCCH) and PUSCH.

There are, proposed herein, various embodiments which address one or more issues of the typical structure disclosed above. This disclosure proposes a method to flexibly transmit SRSs in unlicensed operation within a UL transmission burst. Here, the SRSs are allocated depending on where the transmission starts in the slot. In at least some embodiments, the SRSs are allocated at the beginning of the first (mini-)slot(s) right after a node gets access to the medium after completing the Listen Before Talk (LBT) procedure. In the subsequent slots, the SRSs are placed at the end of the slot as in regular NR.

Certain embodiments may provide one or more of the following technical advantage(s). The transmission of one (or more) SRS(s) at the beginning of a transmission burst provides the transmitting node more time to prepare the signals to be sent in the UL PHY channels (such as DMRS, PUCCH, and PUSCH). The transmission of one (or more) SRS(s) at the beginning of a

transmission burst also shortens the initial transmission delay, which improves the resource efficiency. Re-allocating this already standardized signal still allows for a possibility of using all procedures related to SRS such as link configuration and beam management procedures.

Figure 5 is a diagram of a transmission that is in accordance with a first embodiment in accordance with the present disclosure. The first embodiment provides a method to allocate the position of SRSs in slots of one transmission burst, in which the SRSs are allocated to an X number of the first (mini) slot(s) at the beginning of the transmission, wherein X is a natural number greater than zero. The transmission may start at any symbol of the scheduled slot or mini-slot right after a UE gets access to the medium after completing the LBT procedure.

As illustrated in Figure 5, in this example, the transmission starts at the sixth symbol in the first scheduled slot right after the UE gets access to the medium after completing the LBT procedure. In the illustrated example, SRSs are allocated in the first slot at the beginning of the transmission in the sixth, seventh, eighth, and ninth symbols of the first slot (i.e., in the first four symbols of the transmission). That is, in this example, SRSs are allocated (by the network) to the first four symbols of the transmission, and the UE maps SRSs to those symbols accordingly.

Disclosed methods performed by a wireless device for transmitting in unlicensed spectrum include transmitting a transmission burst such that SRSs are flexibly allocated depending on where the transmission starts in a slot. In some embodiments, the methods further include determining if a channel of the unlicensed spectrum is clear for transmission before transmitting the transmission burst.

Alternatively, transmission may start at a predefined transmission starting position. The starting position is Radio Resource Control (RRC) configured or indicated via L1 signaling. In the subsequent slots (where the SRS is configured to be transmitted) the SRS is placed at the end of the slot.

When a UE successfully completes the LBT procedure, the UE needs to occupy the medium right away. However, since the UE does not know, in advance, when the unlicensed medium will be accessible, the UE may not have concluded all the processing required to transmit in channels such as DMRS, PUSCH, and PUCCH. Therefore, since the SRS structure is predefined, the UE can start the transmission by sending one of few SRSs so that, in the meanwhile, it has more time to prepare the control/information signals for transmission. In the case of an Orthogonal Frequency Division Multiplexing (OFDM) transmission with subcarrier spacing of 15 kilohertz (KHz), sending N number of SRSs at the beginning of the burst provides the UE with more than $20N/3$ microseconds (μ s) to prepare other data, wherein N is a natural number. In the subsequent slots, the SRS can

switch back to the end of the slot, as in regular NR, to preserve the places in the beginning of the slots for other UL channel such as DMRS or PUCCH.

In a second embodiment, the number of consecutive SRS symbols in the first (mini) slot can also be flexible, and varies from 1 to L depending on the length of the first (mini) slot, wherein L is a natural number representing the maximum allowed number of SRSs. The setting of L should consider, for example, 1) how fast the UE can prepare the information to send in the DMRS, PUSCH, and PUCCH, and 2) the sub-carrier spacing used, etc. The parameter L should be decided, for example, either autonomously by the transmitting UE, or signaled by a node (e.g., the gNB in the DCI).

Another aspect of this second embodiment provides that if the length of the first (mini) slot is larger than L, the remaining symbols in the slot(s) could be used to transmit PUCCH and/or DMRS and/or PUSCH. Yet, another aspect of this second embodiment provides for cases in which the remaining symbols in the first (mini) slot are only enough for either PUCCH/DMRS or PUSCH. In a first case, in which the PUCCH/DMRS is transmitted in the first (mini) slot without PUSCH, this PUCCH/DMRS can be used for a subsequent slot, if applicable. In a second case, in which the PUSCH is transmitted in the first (mini) slot without PUCCH/DMRS, the PUCCH/DMRS in a subsequent slot can be used for this PUSCH, if applicable. In some embodiments disclosed herein, the flexibly allocated SRSs take up L number of consecutive symbol positions of the slot, wherein L is a natural number greater than zero and less than or equal to a maximum number of symbol positions available for the SRSs. In other disclosed embodiments, remaining symbol positions of the slot are free to transmit PUCCH and/or DMRS and/or PUSCH.

In a third embodiment, directed to a case in which the UE accesses the channel in one of the last OFDM symbols of the slot, some of the SRS(s) sent at the beginning of the transmission burst may occupy the first OFDM symbols of the next slot. In this case, the front-loaded SRS transmission spans two (consecutive) slots. In some embodiments, symbol positions of the SRSs overlap beginning symbol positions of a consecutive slot.

In a fourth embodiment, directed to a case in which, in the transmission slots having front-loaded SRSs inserted (which can be either in the first or the first and the second slots after initiating the transmission burst), the UL channels such as PUSCH and PUCCH may follow a different allocation than in the subsequent consecutive slots. Figure 5 is a diagram of an example of an allocation of PUSCH and DMRS in the first slot. In particular, Figure 5 provides an example in which the UE gains access to the channel in some OFDM symbol of the slot. In this case, the UE starts by transmitting four SRS symbols, and other UL channels are allocated in a certain manner

until the end of the slot. In the third slot, an NR allocation convention is used in which the first symbols belong to the DMRS/PUSCH, the intermediate symbols belong to the PUSCH, and the last symbols are SRSs.

5 In a fifth embodiment, the front-loaded SRS transmission is optional and can be activated by the gNB. The gNB sends an indication to the UE indicating the UE is allowed to start the transmission with a SRS. In order to help the gNB to detect and decode the front-load SRS UL burst, different patterns of the first mini-slot(s) with front-load SRS (corresponding to different starting points of SRS in the first slot) of the UL burst are pre-configured via RRC signaling. When front-load SRS is activated, gNB will monitor for the first SRS symbol, based on the position of the first SRS symbol, it can recognize the pattern(s) of the first mini-slot(s) and decodes them.

10 Other embodiments include a method performed by a base station for transmitting in unlicensed spectrum are disclosed. Some embodiments include the base station transmitting, to a wireless device, an indication that transmission may begin with SRSs. In some embodiments, the SRSs are flexibly allocated depending on where the transmission starts in a slot. In some
15 embodiments, the method further include determining if a channel of the unlicensed spectrum is clear for transmission before transmitting the indication that transmission may begin with SRSs. In some of the above embodiments, the method includes obtaining user data, and forwarding the user data to a host computer or a wireless device.

20 Although the subject matter described herein may be implemented in any appropriate type of system using any suitable components, the embodiments disclosed herein are described in relation to a wireless network, such as the example wireless network illustrated in Figure 6. For simplicity, the wireless network of Figure 6 only depicts a network 606, network nodes 660 and 660B, and Wireless Devices (WDs) 610, 610B, and 610C. In practice, a wireless network may further include any additional elements suitable to support communication between wireless devices or between a
25 wireless device and another communication device, such as a landline telephone, a service provider, or any other network node or end device. Of the illustrated components, the network node 660 and the WD 610 are depicted with additional detail. The wireless network may provide communication and other types of services to one or more wireless devices to facilitate the wireless devices' access to and/or use of the services provided by, or via, the wireless network.

30 The wireless network may comprise and/or interface with any type of communication, telecommunication, data, cellular, and/or radio network or other similar type of system. In some embodiments, the wireless network may be configured to operate according to specific standards or other types of predefined rules or procedures. Thus, particular embodiments of the wireless network

may implement communication standards, such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), and/or other suitable Second, Third, Fourth, or Fifth Generation (2G, 3G, 4G, or 5G) standards; Wireless Local Area Network (WLAN) standards, such as the IEEE 802.11 standards; and/or any
5 other appropriate wireless communication standard, such as the Worldwide Interoperability for Microwave Access (WiMax), Bluetooth, Z-Wave, and/or ZigBee standards.

The network 606 may comprise one or more backhaul networks, core networks, Internet Protocol (IP) networks, Public Switched Telephone Networks (PSTNs), packet data networks, optical networks, Wide Area Networks (WANs), Local Area Networks (LANs), WLANs, wired
10 networks, wireless networks, metropolitan area networks, and other networks to enable communication between devices.

The network node 660 and the WD 610 comprise various components described in more detail below. These components work together in order to provide network node and/or wireless device functionality, such as providing wireless connections in a wireless network. In different
15 embodiments, the wireless network may comprise any number of wired or wireless networks, network nodes, base stations, controllers, wireless devices, relay stations, and/or any other components or systems that may facilitate or participate in the communication of data and/or signals whether via wired or wireless connections.

As used herein, network node refers to equipment capable, configured, arranged, and/or
20 operable to communicate directly or indirectly with a wireless device and/or with other network nodes or equipment in the wireless network to enable and/or provide wireless access to the wireless device and/or to perform other functions (e.g., administration) in the wireless network. Examples of network nodes include, but are not limited to, Access Points (APs) (e.g., radio APs), Base Stations (BSs) (e.g., radio base stations, Node Bs, evolved Node Bs (eNBs), and New Radio (NR) Node Bs
25 (gNBs)). Base stations may be categorized based on the amount of coverage they provide (or, stated differently, their transmit power level) and may then also be referred to as femto base stations, pico base stations, micro base stations, or macro base stations. A base station may be a relay node or a relay donor node controlling a relay. A network node may also include one or more (or all) parts of a distributed radio base station such as centralized digital units and/or Remote Radio Units (RRUs),
30 sometimes referred to as Remote Radio Heads (RRHs). Such RRUs may or may not be integrated with an antenna as an antenna integrated radio. Parts of a distributed radio base station may also be referred to as nodes in a Distributed Antenna System (DAS). Yet further examples of network nodes include Multi-Standard Radio (MSR) equipment such as MSR BSs, network controllers such

as Radio Network Controllers (RNCs) or BS Controllers (BSCs), Base Transceiver Stations (BTSs), transmission points, transmission nodes, Multi-Cell/Multicast Coordination Entities (MCEs), core network nodes (e.g., Mobile Switching Centers (MSCs), Mobility Management Entities (MMEs)), Operation and Maintenance (O&M) nodes, Operations Support System (OSS) nodes, Self-
5 Organizing Network (SON) nodes, positioning nodes (e.g., Evolved Serving Mobile Location Center (E-SMLCs)), and/or Minimization of Drive Tests (MDTs). As another example, a network node may be a virtual network node as described in more detail below. More generally, however, network nodes may represent any suitable device (or group of devices) capable, configured,
10 arranged, and/or operable to enable and/or provide a wireless device with access to the wireless network or to provide some service to a wireless device that has accessed the wireless network.

In Figure 6, the network node 660 includes processing circuitry 670, a device readable medium 680, an interface 690, auxiliary equipment 684, a power source 686, power circuitry 687, and an antenna 662. Although the network node 660 illustrated in the example wireless network of Figure 6 may represent a device that includes the illustrated combination of hardware components,
15 other embodiments may comprise network nodes with different combinations of components. It is to be understood that a network node comprises any suitable combination of hardware and/or software needed to perform the tasks, features, functions, and methods disclosed herein. Moreover, while the components of the network node 660 are depicted as single boxes located within a larger box, or nested within multiple boxes, in practice, a network node may comprise multiple different
20 physical components that make up a single illustrated component (e.g., the device readable medium 680 may comprise multiple separate hard drives as well as multiple Random Access Memory (RAM) modules).

Similarly, the network node 660 may be composed of multiple physically separate components (e.g., a Node B component and a RNC component, or a BTS component and a BSC
25 component, etc.), which may each have their own respective components. In certain scenarios in which the network node 660 comprises multiple separate components (e.g., BTS and BSC components), one or more of the separate components may be shared among several network nodes. For example, a single RNC may control multiple Node Bs. In such a scenario, each unique Node B and RNC pair may in some instances be considered a single separate network node. In some
30 embodiments, the network node 660 may be configured to support multiple Radio Access Technologies (RATs). In such embodiments, some components may be duplicated (e.g., a separate device readable medium 680 for the different RATs) and some components may be reused (e.g., the same antenna 662 may be shared by the RATs). The network node 660 may also include multiple

sets of the various illustrated components for different wireless technologies integrated into the network node 660, such as, for example, GSM, Wideband Code Division Multiple Access (WCDMA), LTE, NR, WiFi, or Bluetooth wireless technologies. These wireless technologies may be integrated into the same or a different chip or set of chips and other components within the network node 660.

The processing circuitry 670 is configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being provided by a network node. These operations performed by the processing circuitry 670 may include processing information obtained by the processing circuitry 670 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored in the network node, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

The processing circuitry 670 may comprise a combination of one or more of a microprocessor, a controller, a microcontroller, a Central Processing Unit (CPU), a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or any other suitable computing device, resource, or combination of hardware, software, and/or encoded logic operable to provide, either alone or in conjunction with other network node 660 components, such as the device readable medium 680, network node 660 functionality. For example, the processing circuitry 670 may execute instructions stored in the device readable medium 680 or in memory within the processing circuitry 670. Such functionality may include providing any of the various wireless features, functions, or benefits discussed herein. In some embodiments, the processing circuitry 670 may include a System on a Chip (SOC).

In some embodiments, the processing circuitry 670 may include one or more of Radio Frequency (RF) transceiver circuitry 672 and baseband processing circuitry 674. In some embodiments, the RF transceiver circuitry 672 and the baseband processing circuitry 674 may be on separate chips (or sets of chips), boards, or units, such as radio units and digital units. In alternative embodiments, part or all of the RF transceiver circuitry 672 and the baseband processing circuitry 674 may be on the same chip or set of chips, boards, or units.

In certain embodiments, some or all of the functionality described herein as being provided by a network node, base station, eNB, or other such network device may be performed by the processing circuitry 670 executing instructions stored on the device readable medium 680 or memory within the processing circuitry 670. In alternative embodiments, some or all of the

functionality may be provided by the processing circuitry 670 without executing instructions stored on a separate or discrete device readable medium, such as in a hard-wired manner. In any of those embodiments, whether executing instructions stored on a device readable storage medium or not, the processing circuitry 670 can be configured to perform the described functionality. The benefits
5 provided by such functionality are not limited to the processing circuitry 670 alone or to other components of the network node 660, but are enjoyed by the network node 660 as a whole, and/or by end users and the wireless network generally.

The device readable medium 680 may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid state memory,
10 remotely mounted memory, magnetic media, optical media, RAM, Read Only Memory (ROM), mass storage media (for example, a hard disk), removable storage media (for example, a flash drive, a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer-executable memory devices that store information, data, and/or instructions that may be used by the processing circuitry 670. The device readable
15 medium 680 may store any suitable instructions; data or information, including a computer program; software; an application including one or more of logic, rules, code, tables, etc.; and/or other instructions capable of being executed by the processing circuitry 670 and utilized by the network node 660. The device readable medium 680 may be used to store any calculations made by the processing circuitry 670 and/or any data received via the interface 690. In some embodiments, the
20 processing circuitry 670 and the device readable medium 680 may be considered to be integrated.

The interface 690 is used in the wired or wireless communication of signaling and/or data between the network node 660, a network 606, and/or WDs 610. As illustrated, the interface 690 comprises port(s)/terminal(s) 694 to send and receive data, for example to and from the network 606 over a wired connection. The interface 690 also includes radio front end circuitry 692 that may be
25 coupled to, or in certain embodiments a part of, the antenna 662. The radio front end circuitry 692 comprises filters 698 and amplifiers 696. The radio front end circuitry 692 may be connected to the antenna 662 and the processing circuitry 670. The radio front end circuitry 692 may be configured to condition signals communicated between the antenna 662 and the processing circuitry 670. The radio front end circuitry 692 may receive digital data that is to be sent out to other network nodes or
30 WDs via a wireless connection. The radio front end circuitry 692 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of the filters 698 and/or the amplifiers 696. The radio signal may then be transmitted via the antenna 662. Similarly, when receiving data, the antenna 662 may collect radio signals which are then converted

into digital data by the radio front end circuitry 692. The digital data may be passed to the processing circuitry 670. In other embodiments, the interface 690 may comprise different components and/or different combinations of components.

5 In certain alternative embodiments, the network node 660 may not include separate radio front end circuitry 692; instead, the processing circuitry 670 may comprise radio front end circuitry and may be connected to the antenna 662 without separate radio front end circuitry 692. Similarly, in some embodiments, all or some of the RF transceiver circuitry 672 may be considered a part of the interface 690. In still other embodiments, the interface 690 may include the one or more ports or terminals 694, the radio front end circuitry 692, and the RF transceiver circuitry 672 as part of a
10 radio unit (not shown), and the interface 690 may communicate with the baseband processing circuitry 674, which is part of a digital unit (not shown).

The antenna 662 may include one or more antennas, or antenna arrays, configured to send and/or receive wireless signals. The antenna 662 may be coupled to the radio front end circuitry 692 and may be any type of antenna capable of transmitting and receiving data and/or signals wirelessly.
15 In some embodiments, the antenna 662 may comprise one or more omni-directional, sector, or panel antennas operable to transmit/receive radio signals between, for example, 2 gigahertz (GHz) and 66 GHz. An omni-directional antenna may be used to transmit/receive radio signals in any direction, a sector antenna may be used to transmit/receive radio signals from devices within a particular area, and a panel antenna may be a line of sight antenna used to transmit/receive radio signals in a
20 relatively straight line. In some instances, the use of more than one antenna may be referred to as Multiple Input Multiple Output (MIMO). In certain embodiments, the antenna 662 may be separate from the network node 660 and may be connectable to the network node 660 through an interface or port.

The antenna 662, the interface 690, and/or the processing circuitry 670 may be configured to
25 perform any receiving operations and/or certain obtaining operations described herein as being performed by a network node. Any information, data, and/or signals may be received from a WD, another network node, and/or any other network equipment. Similarly, the antenna 662, the interface 690, and/or the processing circuitry 670 may be configured to perform any transmitting operations described herein as being performed by a network node. Any information, data, and/or
30 signals may be transmitted to a WD, another network node, and/or any other network equipment.

The power circuitry 687 may comprise, or be coupled to, power management circuitry and is configured to supply the components of the network node 660 with power for performing the functionality described herein. The power circuitry 687 may receive power from the power source

686. The power source 686 and/or the power circuitry 687 may be configured to provide power to the various components of the network node 660 in a form suitable for the respective components (e.g., at a voltage and current level needed for each respective component). The power source 686 may either be included in, or be external to, the power circuitry 687 and/or the network node 660.

- 5 For example, the network node 660 may be connectable to an external power source (e.g., an electricity outlet) via an input circuitry or interface such as an electrical cable, whereby the external power source supplies power to the power circuitry 687. As a further example, the power source 686 may comprise a source of power in the form of a battery or battery pack which is connected to, or integrated in, the power circuitry 687. The battery may provide backup power should the external
10 power source fail. Other types of power sources, such as photovoltaic devices, may also be used.

- Alternative embodiments of the network node 660 may include additional components beyond those shown in Figure 6 that may be responsible for providing certain aspects of the network node's functionality, including any of the functionality described herein and/or any functionality necessary to support the subject matter described herein. For example, the network node 660 may
15 include user interface equipment to allow input of information into the network node 660 and to allow output of information from the network node 660. This may allow a user to perform diagnostic, maintenance, repair, and other administrative functions for the network node 660.

- As used herein, WD refers to a device capable, configured, arranged, and/or operable to communicate wirelessly with network nodes and/or other WDs. Unless otherwise noted, the term
20 WD may be used interchangeably herein with User Equipment (UE). Communicating wirelessly may involve transmitting and/or receiving wireless signals using electromagnetic waves, radio waves, infrared waves, and/or other types of signals suitable for conveying information through air. In some embodiments, a WD may be configured to transmit and/or receive information without direct human interaction. For instance, a WD may be designed to transmit information to a network
25 on a predetermined schedule, when triggered by an internal or external event, or in response to requests from the network. Examples of a WD include, but are not limited to, a smart phone, a mobile phone, a cell phone, a Voice over IP (VoIP) phone, a wireless local loop phone, a desktop computer, a Personal Digital Assistant (PDA), a wireless camera, a gaming console or device, a music storage device, a playback appliance, a wearable terminal device, a wireless endpoint, a
30 mobile station, a tablet, a laptop, Laptop Embedded Equipment (LEE), Laptop Mounted Equipment (LME), a smart device, a wireless Customer Premise Equipment (CPE), a vehicle mounted wireless terminal device, etc.. A WD may support Device-to-Device (D2D) communication, for example by implementing a 3G Partnership Project (3GPP) standard for sidelink communication, Vehicle-to-

Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Everything (V2X), and may in this case be referred to as a D2D communication device. As yet another specific example, in an Internet of Things (IoT) scenario, a WD may represent a machine or other device that performs monitoring and/or measurements, and transmits the results of such monitoring and/or measurements to another WD and/or a network node. The WD may in this case be a Machine-to-Machine (M2M) device, which may in a 3GPP context be referred to as a Machine-Type Communication (MTC) device. As one particular example, the WD may be a UE implementing the 3GPP Narrowband IoT (NB-IoT) standard. Particular examples of such machines or devices are sensors, metering devices such as power meters, industrial machinery, home or personal appliances (e.g., refrigerators, televisions, etc.), or personal wearables (e.g., watches, fitness trackers, etc.). In other scenarios, a WD may represent a vehicle or other equipment that is capable of monitoring and/or reporting on its operational status or other functions associated with its operation. A WD as described above may represent the endpoint of a wireless connection, in which case the device may be referred to as a wireless terminal. Furthermore, a WD as described above may be mobile, in which case it may also be referred to as a mobile device or a mobile terminal.

As illustrated in Figure 6, a WD 610 includes an antenna 611, an interface 614, processing circuitry 620, a device readable medium 630, user interface equipment 632, auxiliary equipment 634, a power source 636, and power circuitry 637. The WD 610 may include multiple sets of one or more of the illustrated components for different wireless technologies supported by the WD 610, such as, for example, GSM, WCDMA, LTE, NR, WiFi, WiMAX, or Bluetooth wireless technologies, just to mention a few. These wireless technologies may be integrated into the same or different chips or set of chips as other components within the WD 610.

The antenna 611 may include one or more antennas or antenna arrays configured to send and/or receive wireless signals, and is connected to the interface 614. In certain alternative embodiments, the antenna 611 may be separate from the WD 610 and be connectable to the WD 610 through an interface or port. The antenna 611, the interface 614, and/or the processing circuitry 620 may be configured to perform any receiving or transmitting operations described herein as being performed by a WD. Any information, data, and/or signals may be received from a network node and/or another WD. In some embodiments, radio front end circuitry and/or the antenna 611 may be considered an interface.

As illustrated, the interface 614 comprises radio front end circuitry 612 and the antenna 611. The radio front end circuitry 612 comprises one or more filters 618 and amplifiers 616. The radio front end circuitry 612 is connected to the antenna 611 and the processing circuitry 620 and is

configured to condition signals communicated between the antenna 611 and the processing circuitry 620. The radio front end circuitry 612 may be coupled to or be a part of the antenna 611. In some embodiments, the WD 610 may not include separate radio front end circuitry 612; rather, the processing circuitry 620 may comprise radio front end circuitry and may be connected to the antenna 611. Similarly, in some embodiments, some or all of RF transceiver circuitry 622 may be considered a part of the interface 614. The radio front end circuitry 612 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. The radio front end circuitry 612 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of the filters 618 and/or the amplifiers 616. The radio signal may then be transmitted via the antenna 611. Similarly, when receiving data, the antenna 611 may collect radio signals which are then converted into digital data by the radio front end circuitry 612. The digital data may be passed to the processing circuitry 620. In other embodiments, the interface 614 may comprise different components and/or different combinations of components.

The processing circuitry 620 may comprise a combination of one or more of a microprocessor, a controller, a microcontroller, a CPU, a DSP, an ASIC, a FPGA, or any other suitable computing device, resource, or combination of hardware, software, and/or encoded logic operable to provide, either alone or in conjunction with other WD 610 components, such as the device readable medium 630, WD 610 functionality. Such functionality may include providing any of the various wireless features or benefits discussed herein. For example, the processing circuitry 620 may execute instructions stored in the device readable medium 630 or in memory within the processing circuitry 620 to provide the functionality disclosed herein.

As illustrated, the processing circuitry 620 includes one or more of the RF transceiver circuitry 622, baseband processing circuitry 624, and application processing circuitry 626. In other embodiments, the processing circuitry 620 may comprise different components and/or different combinations of components. In certain embodiments, the processing circuitry 620 of the WD 610 may comprise a SOC. In some embodiments, the RF transceiver circuitry 622, the baseband processing circuitry 624, and the application processing circuitry 626 may be on separate chips or sets of chips. In alternative embodiments, part or all of the baseband processing circuitry 624 and the application processing circuitry 626 may be combined into one chip or set of chips, and the RF transceiver circuitry 622 may be on a separate chip or set of chips. In still alternative embodiments, part or all of the RF transceiver circuitry 622 and the baseband processing circuitry 624 may be on the same chip or set of chips, and the application processing circuitry 626 may be on a separate chip or set of chips. In yet other alternative embodiments, part or all of the RF transceiver circuitry 622,

the baseband processing circuitry 624, and the application processing circuitry 626 may be combined in the same chip or set of chips. In some embodiments, the RF transceiver circuitry 622 may be a part of the interface 614. The RF transceiver circuitry 622 may condition RF signals for the processing circuitry 620.

5 In certain embodiments, some or all of the functionality described herein as being performed by a WD may be provided by the processing circuitry 620 executing instructions stored on the device readable medium 630, which in certain embodiments may be a computer-readable storage medium. In alternative embodiments, some or all of the functionality may be provided by the processing circuitry 620 without executing instructions stored on a separate or discrete device
10 readable storage medium, such as in a hard-wired manner. In any of those particular embodiments, whether executing instructions stored on a device readable storage medium or not, the processing circuitry 620 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to the processing circuitry 620 alone or to other components of the WD 610, but are enjoyed by the WD 610 as a whole, and/or by end users and the wireless network
15 generally.

 The processing circuitry 620 may be configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being performed by a WD. These operations, as performed by the processing circuitry 620, may include processing information obtained by the processing circuitry 620 by, for example, converting the obtained information into
20 other information, comparing the obtained information or converted information to information stored by the WD 610, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

 The device readable medium 630 may be operable to store a computer program; software; an application including one or more of logic, rules, code, tables, etc.; and/or other instructions capable
25 of being executed by the processing circuitry 620. The device readable medium 630 may include computer memory (e.g., RAM or ROM), mass storage media (e.g., a hard disk), removable storage media (e.g., a CD or a DVD), and/or any other volatile or non-volatile, non-transitory device readable and/or computer executable memory devices that store information, data, and/or instructions that may be used by the processing circuitry 620. In some embodiments, the processing
30 circuitry 620 and the device readable medium 630 may be considered to be integrated.

 The user interface equipment 632 may provide components that allow for a human user to interact with the WD 610. Such interaction may be of many forms, such as visual, audial, tactile, etc. The user interface equipment 632 may be operable to produce output to the user and to allow

the user to provide input to the WD 610. The type of interaction may vary depending on the type of user interface equipment 632 installed in the WD 610. For example, if the WD 610 is a smart phone, the interaction may be via a touch screen; if the WD 610 is a smart meter, the interaction may be through a screen that provides usage (e.g., the number of gallons used) or a speaker that provides an audible alert (e.g., if smoke is detected). The user interface equipment 632 may include input interfaces, devices and circuits, and output interfaces, devices and circuits. The user interface equipment 632 is configured to allow input of information into the WD 610, and is connected to the processing circuitry 620 to allow the processing circuitry 620 to process the input information. The user interface equipment 632 may include, for example, a microphone, a proximity or other sensor, keys/buttons, a touch display, one or more cameras, a Universal Serial Bus (USB) port, or other input circuitry. The user interface equipment 632 is also configured to allow output of information from the WD 610 and to allow the processing circuitry 620 to output information from the WD 610. The user interface equipment 632 may include, for example, a speaker, a display, vibrating circuitry, a USB port, a headphone interface, or other output circuitry. Using one or more input and output interfaces, devices, and circuits of the user interface equipment 632, the WD 610 may communicate with end users and/or the wireless network, and allow them to benefit from the functionality described herein.

The auxiliary equipment 634 is operable to provide more specific functionality which may not be generally performed by WDs. This may comprise specialized sensors for doing measurements for various purposes, interfaces for additional types of communication such as wired communications, etc. The inclusion and type of components of the auxiliary equipment 634 may vary depending on the embodiment and/or scenario.

The power source 636 may, in some embodiments, be in the form of a battery or battery pack. Other types of power sources, such as an external power source (e.g., an electricity outlet), photovoltaic devices, or power cells may also be used. The WD 610 may further comprise the power circuitry 637 for delivering power from the power source 636 to the various parts of the WD 610 which need power from the power source 636 to carry out any functionality described or indicated herein. The power circuitry 637 may in certain embodiments comprise power management circuitry. The power circuitry 637 may additionally or alternatively be operable to receive power from an external power source, in which case the WD 610 may be connectable to the external power source (such as an electricity outlet) via input circuitry or an interface such as an electrical power cable. The power circuitry 637 may also in certain embodiments be operable to deliver power from an external power source to the power source 636. This may be, for example,

for the charging of the power source 636. The power circuitry 637 may perform any formatting, converting, or other modification to the power from the power source 636 to make the power suitable for the respective components of the WD 610 to which power is supplied.

Figure 7 illustrates one embodiment of a UE in accordance with various aspects described herein. As used herein, a user equipment or UE may not necessarily have a user in the sense of a human user who owns and/or operates the relevant device. Instead, a UE may represent a device that is intended for sale to, or operation by, a human user but which may not, or which may not initially, be associated with a specific human user (e.g., a smart sprinkler controller). Alternatively, a UE may represent a device that is not intended for sale to, or operation by, an end user but which may be associated with or operated for the benefit of a user (e.g., a smart power meter). A UE 700 may be any UE identified by 3GPP, including a NB-IoT UE, a MTC UE, and/or an enhanced MTC (eMTC) UE. The UE 700, as illustrated in Figure 7, is one example of a WD configured for communication in accordance with one or more communication standards promulgated by 3GPP, such as 3GPP's GSM, UMTS, LTE, and/or 5G standards. As mentioned previously, the term WD and UE may be used interchangeably. Accordingly, although Figure 7 is a UE, the components discussed herein are equally applicable to a WD, and vice-versa.

In Figure 7, the UE 700 includes processing circuitry 701 that is operatively coupled to an input/output interface 705, an RF interface 709, a network connection interface 711, memory 715 including RAM 717, ROM 719, and a storage medium 721 or the like, a communication subsystem 731, a power source 713, and/or any other component, or any combination thereof. The storage medium 721 includes an operating system 723, an application program 725, and data 727. In other embodiments, the storage medium 721 may include other similar types of information. Certain UEs may utilize all of the components shown in Figure 7, or only a subset of the components. The level of integration between the components may vary from one UE to another UE. Further, certain UEs may contain multiple instances of a component, such as multiple processors, memories, transceivers, transmitters, receivers, etc.

In Figure 7, the processing circuitry 701 may be configured to process computer instructions and data. The processing circuitry 701 may be configured to implement any sequential state machine operative to execute machine instructions stored as machine-readable computer programs in the memory, such as one or more hardware-implemented state machines (e.g., in discrete logic, FPGA, ASIC, etc.); programmable logic together with appropriate firmware; one or more stored programs, general purpose processors, such as a microprocessor or DSP, together with appropriate

software; or any combination of the above. For example, the processing circuitry 701 may include two CPUs. Data may be information in a form suitable for use by a computer.

In the depicted embodiment, the input/output interface 705 may be configured to provide a communication interface to an input device, output device, or input and output device. The UE 700
5 may be configured to use an output device via the input/output interface 705. An output device may use the same type of interface port as an input device. For example, a USB port may be used to provide input to and output from the UE 700. The output device may be a speaker, a sound card, a video card, a display, a monitor, a printer, an actuator, an emitter, a smartcard, another output device, or any combination thereof. The UE 700 may be configured to use an input device via the
10 input/output interface 705 to allow a user to capture information into the UE 700. The input device may include a touch-sensitive or presence-sensitive display, a camera (e.g., a digital camera, a digital video camera, a web camera, etc.), a microphone, a sensor, a mouse, a trackball, a directional pad, a trackpad, a scroll wheel, a smartcard, and the like. The presence-sensitive display may include a capacitive or resistive touch sensor to sense input from a user. A sensor may be, for
15 instance, an accelerometer, a gyroscope, a tilt sensor, a force sensor, a magnetometer, an optical sensor, a proximity sensor, another like sensor, or any combination thereof. For example, the input device may be an accelerometer, a magnetometer, a digital camera, a microphone, and an optical sensor.

In Figure 7, the RF interface 709 may be configured to provide a communication interface to
20 RF components such as a transmitter, a receiver, and an antenna. The network connection interface 711 may be configured to provide a communication interface to a network 743A. The network 743A may encompass wired and/or wireless networks such as a LAN, a WAN, a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, the network 743A may comprise a WiFi network. The network connection
25 interface 711 may be configured to include a receiver and a transmitter interface used to communicate with one or more other devices over a communication network according to one or more communication protocols, such as Ethernet, Transmission Control Protocol (TCP) / IP, Synchronous Optical Networking (SONET), Asynchronous Transfer Mode (ATM), or the like. The network connection interface 711 may implement receiver and transmitter functionality appropriate
30 to the communication network links (e.g., optical, electrical, and the like). The transmitter and receiver functions may share circuit components, software, or firmware, or alternatively may be implemented separately.

The RAM 717 may be configured to interface via a bus 702 to the processing circuitry 701 to provide storage or caching of data or computer instructions during the execution of software programs such as the operating system, application programs, and device drivers. The ROM 719 may be configured to provide computer instructions or data to the processing circuitry 701. For example, the ROM 719 may be configured to store invariant low-level system code or data for basic system functions such as basic Input and Output (I/O), startup, or reception of keystrokes from a keyboard that are stored in a non-volatile memory. The Storage medium 721 may be configured to include memory such as RAM, ROM, Programmable ROM (PROM), Erasable PROM (EPROM), Electrically EPROM (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, or flash drives. In one example, the storage medium 721 may be configured to include the operating system 723, the application program 725 such as a web browser application, a widget or gadget engine, or another application, and the data 727. The storage medium 721 may store, for use by the UE 700, any of a variety of various operating systems or combinations of operating systems.

The storage medium 721 may be configured to include a number of physical drive units, such as a Redundant Array of Independent Disks (RAID), a floppy disk drive, flash memory, a USB flash drive, an external hard disk drive, a thumb drive, a pen drive, a key drive, a High-Density Digital Versatile Disc (HD-DVD) optical disc drive, an internal hard disk drive, a Blu-Ray optical disc drive, a Holographic Digital Data Storage (HDDS) optical disc drive, an external mini-Dual In-Line Memory Module (DIMM), Synchronous Dynamic RAM (SDRAM), external micro-DIMM SDRAM, smartcard memory such as a Subscriber Identity Module (SIM) or a Removable User Identity (RUIM) module, other memory, or any combination thereof. The storage medium 721 may allow the UE 700 to access computer-executable instructions, application programs, or the like, stored on transitory or non-transitory memory media, to off-load data or to upload data. An article of manufacture, such as one utilizing a communication system, may be tangibly embodied in the storage medium 721, which may comprise a device readable medium.

In Figure 7, the processing circuitry 701 may be configured to communicate with a network 743B using the communication subsystem 731. The network 743A and the network 743B may be the same network or networks or different network or networks. The communication subsystem 731 may be configured to include one or more transceivers used to communicate with the network 743B. For example, the communication subsystem 731 may be configured to include one or more transceivers used to communicate with one or more remote transceivers of another device capable of wireless communication such as another WD, UE, or base station of a Radio Access Network

(RAN) according to one or more communication protocols, such as IEEE 802.7, Code Division Multiple Access (CDMA), WCDMA, GSM, LTE, Universal Terrestrial RAN (UTRAN), WiMax, or the like. Each transceiver may include a transmitter 733 and/or a receiver 735 to implement transmitter or receiver functionality, respectively, appropriate to the RAN links (e.g., frequency allocations and the like). Further, the transmitter 733 and the receiver 735 of each transceiver may share circuit components, software, or firmware, or alternatively may be implemented separately.

In the illustrated embodiment, the communication functions of the communication subsystem 731 may include data communication, voice communication, multimedia communication, short-range communications such as Bluetooth, near-field communication, location-based communication such as the use of the Global Positioning System (GPS) to determine a location, another like communication function, or any combination thereof. For example, the communication subsystem 731 may include cellular communication, WiFi communication, Bluetooth communication, and GPS communication. The network 743B may encompass wired and/or wireless networks such as a LAN, a WAN, a computer network, a wireless network, a telecommunications network, another like network, or any combination thereof. For example, the network 743B may be a cellular network, a WiFi network, and/or a near-field network. A power source 713 may be configured to provide Alternating Current (AC) or Direct Current (DC) power to components of the UE 700.

The features, benefits, and/or functions described herein may be implemented in one of the components of the UE 700 or partitioned across multiple components of the UE 700. Further, the features, benefits, and/or functions described herein may be implemented in any combination of hardware, software, or firmware. In one example, the communication subsystem 731 may be configured to include any of the components described herein. Further, the processing circuitry 701 may be configured to communicate with any of such components over the bus 702. In another example, any of such components may be represented by program instructions stored in memory that, when executed by the processing circuitry 701, perform the corresponding functions described herein. In another example, the functionality of any of such components may be partitioned between the processing circuitry 701 and the communication subsystem 731. In another example, the non-computationally intensive functions of any of such components may be implemented in software or firmware and the computationally intensive functions may be implemented in hardware.

Figure 8 depicts a method in accordance with particular embodiments. The method may begin at an optional step 802 of ensuring an unlicensed spectrum channel is clear with a LBT procedure before the gNB transmits. Once the gNB determines the unlicensed spectrum channel is

clear, the method may continue with an optional step 804 of transmitting to a UE (i.e., a wireless device) an indication that the UE is allowed to start transmission with SRSs. Another optional step 806 is a LBT procedure (e.g., a short LBT procedure) to determine that the unlicensed spectrum channel is clear. In a next step 808, the UE starts transmitting a transmission burst such that SRSs are flexibly allocated depending on where the transmission starts in a slot, in accordance with any of the embodiments described herein. Optional steps are shown in dashed line.

Figure 9 is a flowchart of a method performed in a UE for SRS transmission in a cellular communications system. The method in Figure 9 includes (block 902), in a first X slots or mini-slots of a transmission burst from the UE, mapping SRSs at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero. In the method of Figure 9, either the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to a corresponding wireless medium upon completing a LBT procedure; or the transmission burst starts at a predefined starting position within a slot or mini-slot. The method of Figure 9 further includes (block 904) transmitting the mapped SRSs in the first X slots or mini-slots of the transmission burst.

Figure 10 is a flowchart of a method performed in a network node for SRS reception in a cellular communications system. Optionally, the method may include sending (block 1002), to the UE, an indication that the UE is allowed to start a transmission burst with a SRS. The method in Figure 10 includes receiving (block 1004) a transmission burst from a UE in which, in a first X slots or mini-slots of the transmission burst, SRSs are located at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

Any appropriate steps, methods, features, functions, or benefits disclosed herein may be performed through one or more functional units or modules of one or more virtual apparatuses. Each virtual apparatus may comprise a number of these functional units. These functional units may be implemented via processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include DSPs, special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as ROM, RAM, cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein. In some implementations, the processing circuitry may be used to cause the respective functional unit to perform corresponding functions according one or more embodiments of the present disclosure.

Some example embodiments of the present disclosure are as follows:

Group A Embodiments

Embodiment 1: A method performed by a wireless device for transmitting in unlicensed
5 spectrum, the method comprising transmitting the transmission burst such that sounding reference
signals (SRSs) are flexibly allocated depending on where the transmission starts in a slot.

Embodiment 2: The method of embodiment 1 further comprising the step of determining if a
channel of the unlicensed spectrum is clear for transmission before transmitting the transmission
burst.

10 Embodiment 3: The method of embodiment 2 wherein the flexibly allocated SRSs take up L
number of consecutive symbol positions of the slot, wherein L is a natural number greater than zero
and less than or equal to a maximum number of symbol positions available for the SRSs.

Embodiment 4: The method of embodiment 3 wherein remaining symbol positions of the
slot are free to transmit PUCCH and/or DMRS and/or PUSCH.

15 Embodiment 5: The method of any of the previous embodiments wherein symbol positions
of the SRSs may overlap beginning symbol positions of a consecutive slot.

Embodiment 6: The method of any of the previous embodiments wherein the slot is a mini-
slot.

Embodiment 7: The method of any of the previous embodiments, further comprising:

- 20
- providing user data; and
 - forwarding the user data to a host computer via the transmission to the base station.

Group B Embodiments

Embodiment 8: A method performed by a base station for transmitting in unlicensed
25 spectrum, the method comprising transmitting to a UE (i.e., a wireless device) an indication that the
UE is allowed to start transmission with SRSs.

Embodiment 9: The method of embodiment 8 wherein SRSs are flexibly allocated
depending on where the transmission starts in a slot.

Embodiment 10: The method of embodiment 8 or 9, further comprising the step of
30 determining if a channel of the unlicensed spectrum is clear for transmission before transmitting the
indication that transmissions may begin with SRSs.

Embodiment 11: The method of any of the previous embodiments, further comprising:

- obtaining user data; and

- forwarding the user data to a host computer or a wireless device.

Group C Embodiments

5 Embodiment 12: A wireless device for transmitting in unlicensed spectrum, the wireless device comprising processing circuitry configured to perform any of the steps of any of the Group A embodiments; and power supply circuitry configured to supply power to the wireless device.

Embodiment 13: A base station for transmitting in unlicensed spectrum, the base station comprising processing circuitry configured to perform any of the steps of any of the Group B embodiments; and power supply circuitry configured to supply power to the base station.

10 Embodiment 14: A User Equipment, UE, for transmitting in unlicensed spectrum, the UE comprising an antenna configured to send and receive wireless signals; radio front-end circuitry connected to the antenna and to processing circuitry, and configured to condition signals communicated between the antenna and the processing circuitry; the processing circuitry being configured to perform any of the steps of any of the Group A embodiments; an input interface
15 connected to the processing circuitry and configured to allow input of information into the UE to be processed by the processing circuitry; an output interface connected to the processing circuitry and configured to output information from the UE that has been processed by the processing circuitry; and a battery connected to the processing circuitry and configured to supply power to the UE.

20 Those skilled in the art will recognize improvements and modifications to the embodiments of the present disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein.

Claims

What is claimed is:

1. A method performed in a User Equipment, UE, for Sounding Reference Signal, SRS,
5 transmission in a cellular communications system, comprising:
 - in a first X slots or mini-slots of a transmission burst from the UE, mapping (808, 902) SRSs at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero and either:
 - 10 ○ the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to a corresponding wireless medium upon completing a Listen-Before-Talk, LBT, procedure; or
 - the transmission burst starts at a predefined starting position within a slot or mini-slot; and
 - 15 • transmitting (808, 904) the mapped SRSs in the first X slots or mini-slots of the transmission burst.
2. The method of claim 1, wherein the transmission burst starts at the predefined starting position.
- 20 3. The method of claim 1 or 2, further comprising, in subsequent slots in which SRSs are to be transmitted, transmitting the SRSs at the end of the slots.
4. The method of claim 2 or 3, wherein the predefined starting position is either Radio Resource Control, RRC, configured or indicated via Layer 1 signaling.
- 25 5. The method of claim 2, 3 or 4, wherein, in the first X slots or mini-slots of the transmission burst from the UE, mapping the SRSs at the beginning of the transmission burst from the UE comprises mapping the SRSs to a first Y consecutive Orthogonal Frequency Division Multiplexing, OFDM, symbols at the beginning of the transmission burst from the UE.
- 30 6. The method of claim 5, wherein Y is in a range of and including 1 to L, where L is a natural number that represents a maximum allowed number of SRS symbols.

7. The method of claim 5 or 6, wherein Y is a function of a length of the slot or mini-slot.
8. The method of claim 7, wherein, if the length of the slot or mini-slot is greater than L, remaining symbols in the slot or mini-slot are used to transmit any one or any combination of: Physical Uplink Control Channel, PUCCH, Demodulation Reference Signal, DMRS, and Physical Uplink Shared Channel, PUSCH.
9. The method of claim 8, wherein, if the length of the slot or mini-slot is less than L, remaining SRSs are mapped to the beginning of a next slot.
10. The method of any one of claims 1 to 9, wherein $X=1$.
11. The method of any one of claims 1 to 9, wherein $X>1$.
12. The method of any one of claims 1 to 11, wherein one or more uplink channels follow a different mapping in the first X slots or mini-slots of the transmission burst than in remaining slots or mini-slots of the transmission burst.
13. The method of any one of claims 1 to 12, further comprising receiving (804), from a base station, an indication that the UE is allowed to transmit a SRS at the beginning of the transmission burst.
14. The method of claim 13, further comprising receiving, from the base station via RRC signaling, different patterns of the first X slots or mini-slots of the transmission burst corresponding to different starting points of the SRS.
15. The method of claim 1, wherein the transmission burst starts at any symbol of a slot or mini-slot, from among the plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to the corresponding wireless medium upon completing the LBT procedure.
16. The method of claim 15, wherein the LBT procedure comprises a one shot clear channel assessment, CCA.

17. A User Equipment, UE, for a cellular communications system, the UE adapted to:

- in a first X slots or mini-slots of a transmission burst from the UE, map (808) Sounding Reference Signals, SRSs, at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero and either:
 - the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to a corresponding wireless medium upon completing a Listen-Before-Talk, LBT, procedure; or
 - the transmission burst starts at a predefined starting position; and
- transmit (808) the mapped SRSs in the first X slots or mini-slots of the transmission burst.

18. The UE of claim 17, further adapted to start the transmission burst at the predefined starting position.

19. The UE of claim 17, further adapted to start the transmission burst at any symbol of a slot or mini-slot, from among the plurality of slots or mini-slots for the transmission burst, that occurs immediately after the UE gets access to the corresponding wireless medium upon completing the LBT procedure.

20. A wireless device (610, 700), WD, for a cellular communications system, the WD comprising:
processing circuitry (620, 701); and

a memory (630, 715);

wherein the processing circuitry may execute instructions stored in the memory within the processing circuitry to control the WD to:

- in a first X slots or mini-slots of a transmission burst from the WD, map (808) Sounding Reference Signals, SRSs, at a beginning of the transmission burst from the WD, wherein X is a natural number greater than zero and either:
 - the transmission burst starts at any symbol of a slot or mini-slot, from among a plurality of slots or mini-slots for the transmission burst, that occurs immediately

after the WD gets access to a corresponding wireless medium upon completing a Listen-Before-Talk, LBT, procedure; or

- the transmission burst starts at a predefined starting position; and
- transmit (808) the mapped SRSs in the first X slots or mini-slots of the transmission burst.

21. A method performed in a network node for Sounding Reference Signal, SRS, reception in a cellular communications system, comprising:

- receiving (808, 1004) a transmission burst from a User Equipment, UE, in which, in a first X slots or mini-slots of the transmission burst, SRSs are located at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

22. The method of claim 21, further comprising:

sending (802, 1002), to the UE, an indication that the UE is allowed to start a transmission burst with an SRS.

23. The method of claim 21 or 22, wherein:

receiving (808) the transmission burst from the UE further comprises receiving, in a subsequent slot, SRSs positioned at the end of the slot.

24. The method of claims 21 to 23, further comprising:

pre-configuring the UE with different patterns of the first X slots or mini-slots corresponding to different starting points of an SRS in a first slot.

25. The method of claims 21 to 24, wherein receiving (808) the transmission burst from the UE further comprises monitoring for a first SRS and, based on a position of the SRS in a slot or mini-slot, recognizing one of the patterns.

26. The method of claim 21, further comprising:

sending, to the UE, an allocation for the transmission burst.

27. A network node implementing a method for Sounding Reference Signal, SRS, reception in a cellular communications system to the network node comprising:

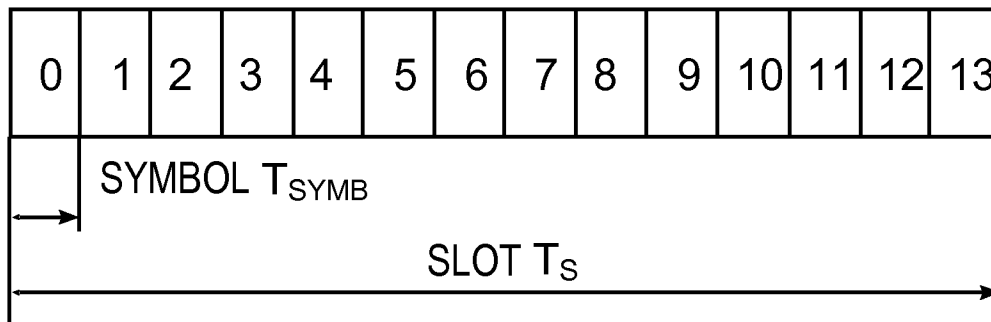
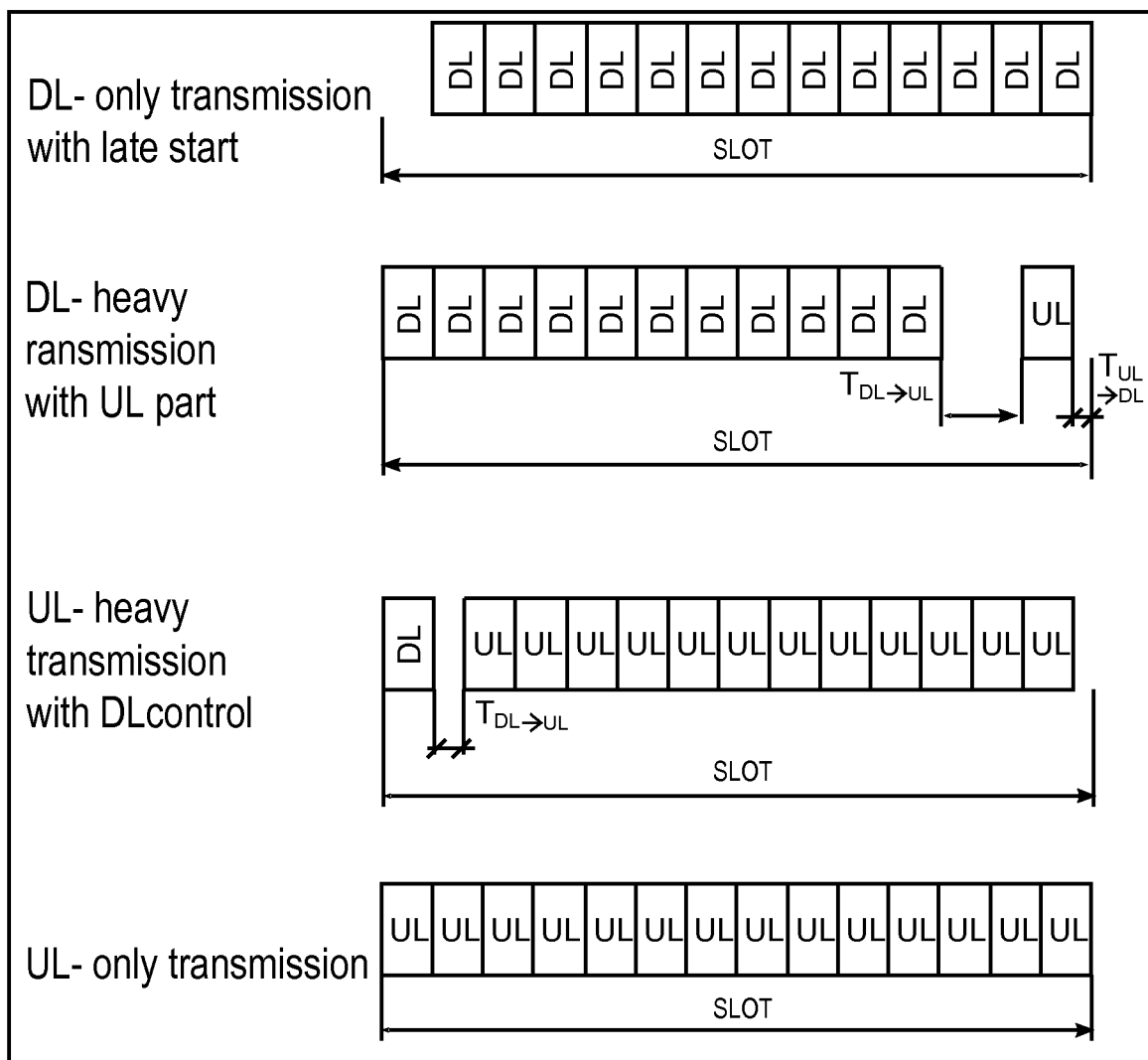
- processing circuitry configured to cause the network node to receive (808) a transmission burst from a User Equipment, UE, in which, in a first X slots or mini-slots of the transmission burst, SRSs are positioned at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

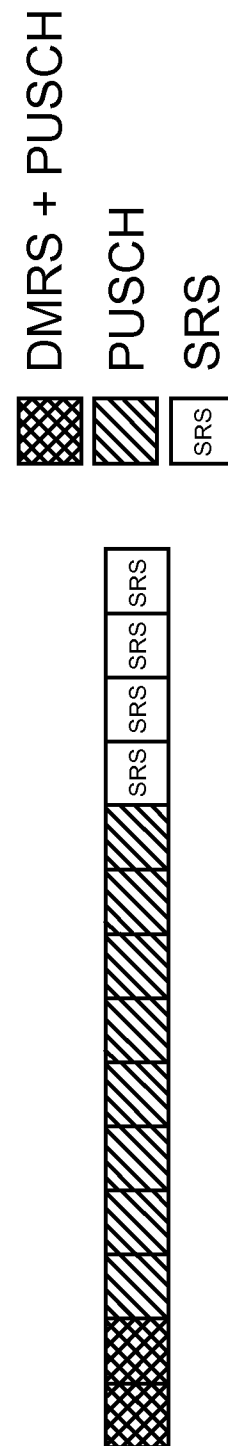
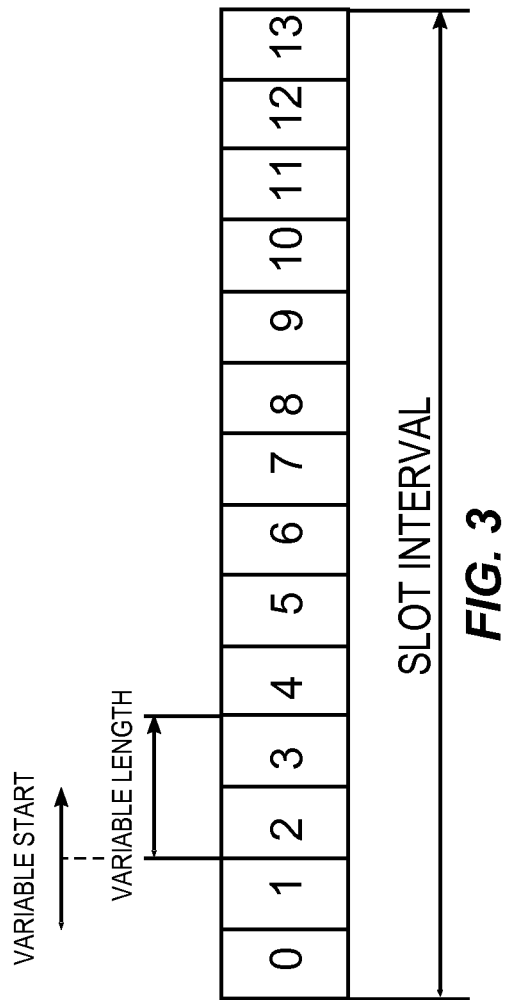
5

28. A network node in a cellular communications system, the network node adapted to:

- receive (808) a transmission burst from a User Equipment, UE, in which, in a first X slots or mini-slots of the transmission burst, Sounding Reference Signals, SRSs, are positioned at a beginning of the transmission burst from the UE, wherein X is a natural number greater than zero.

10

**FIG. 1****FIG. 2**



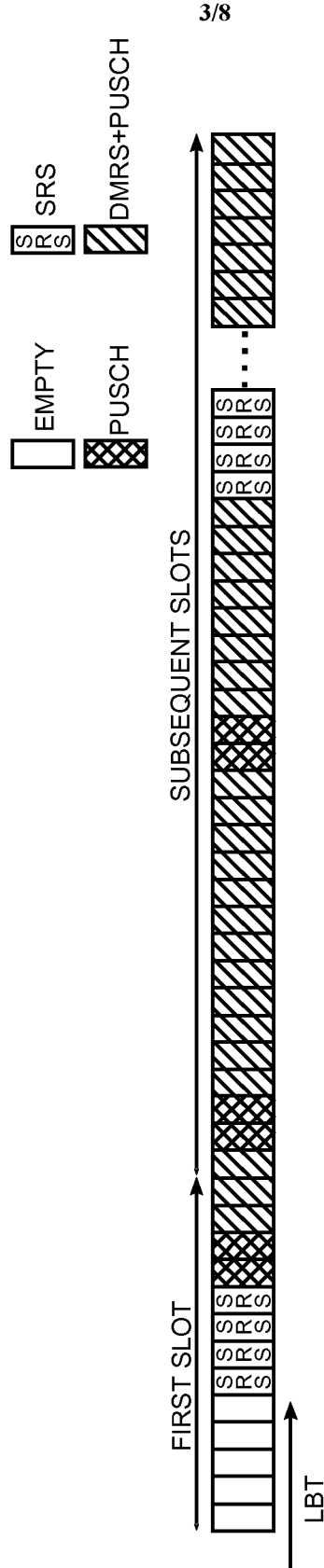


FIG. 5

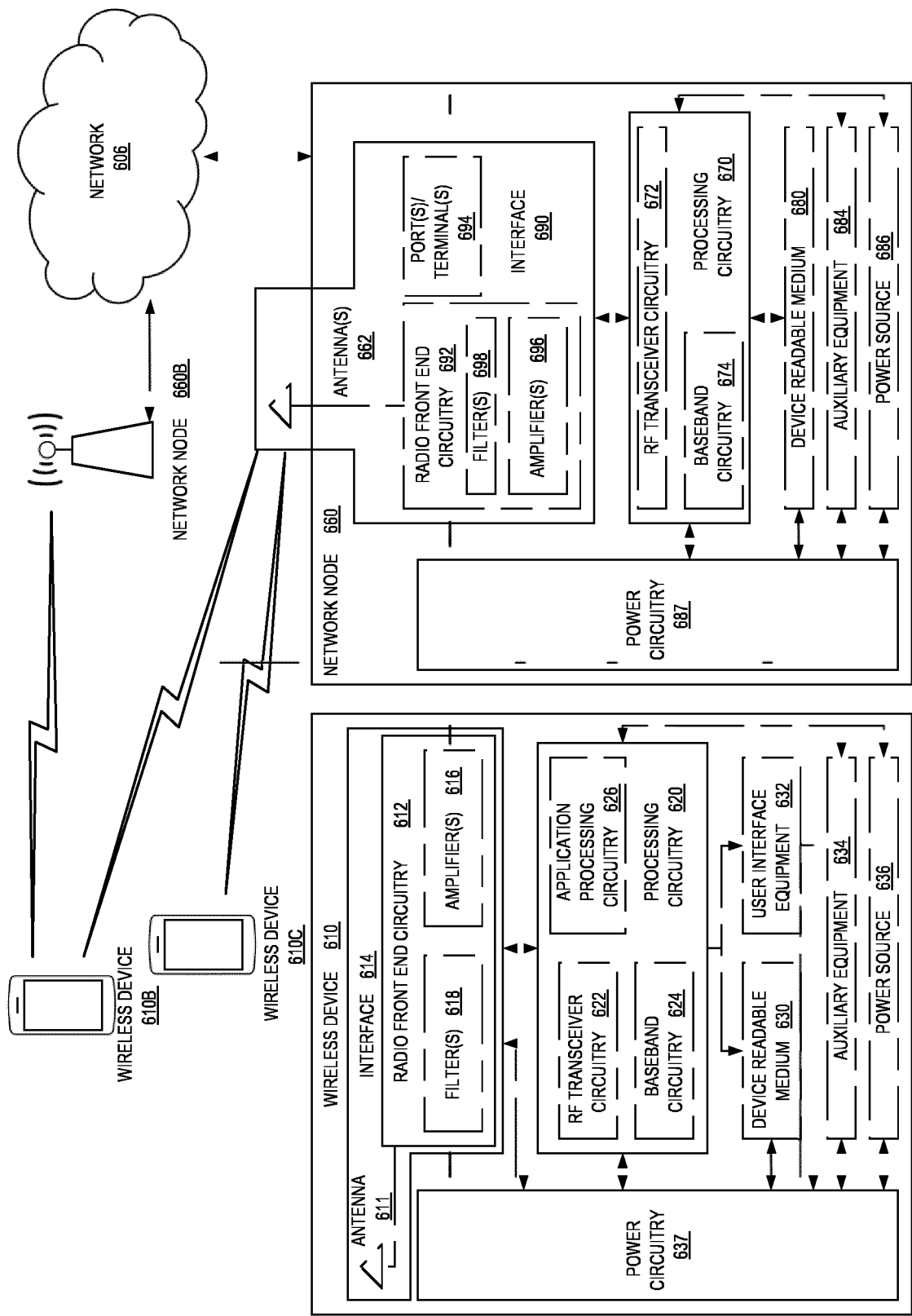


FIG. 6

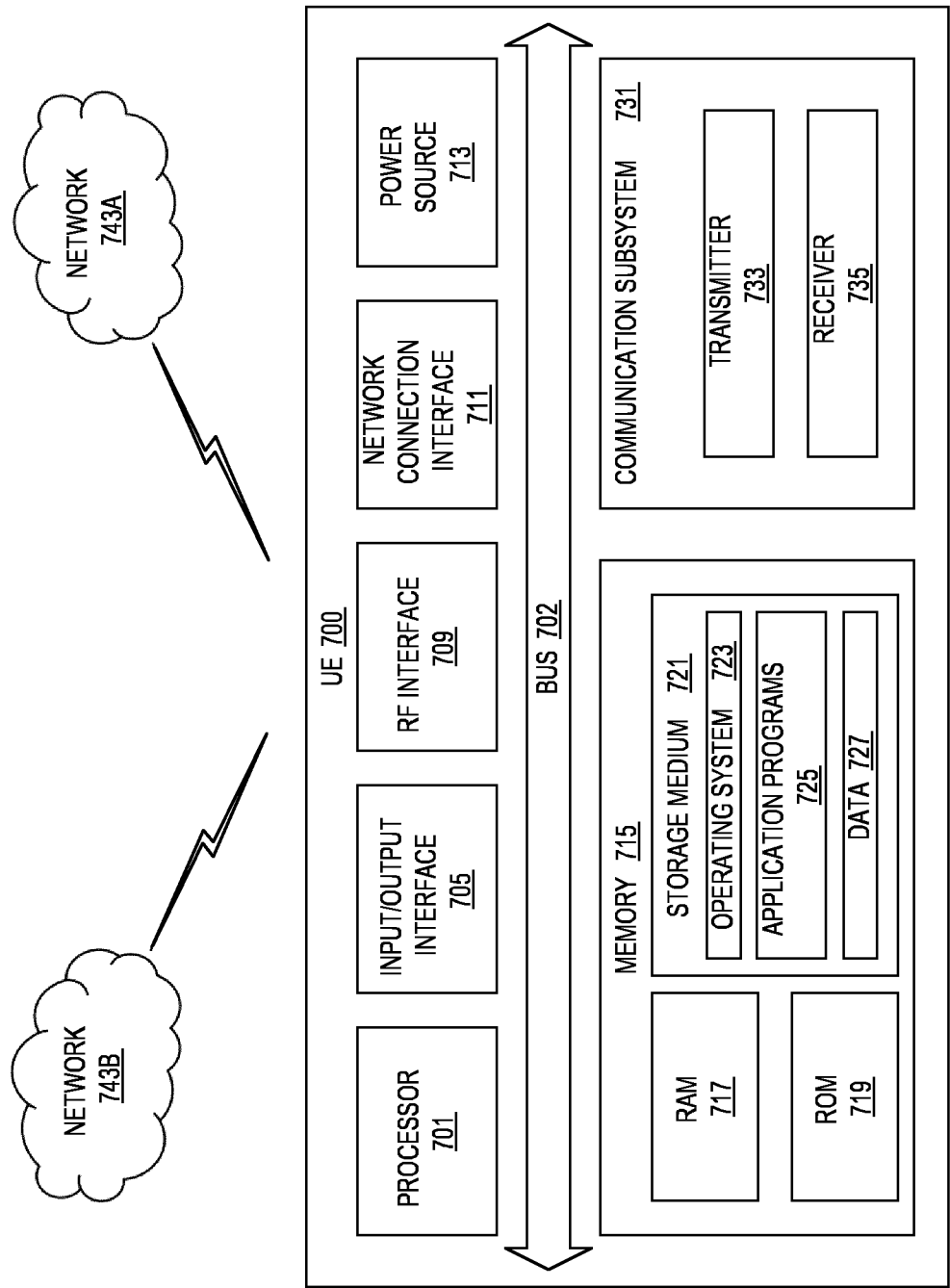


FIG. 7

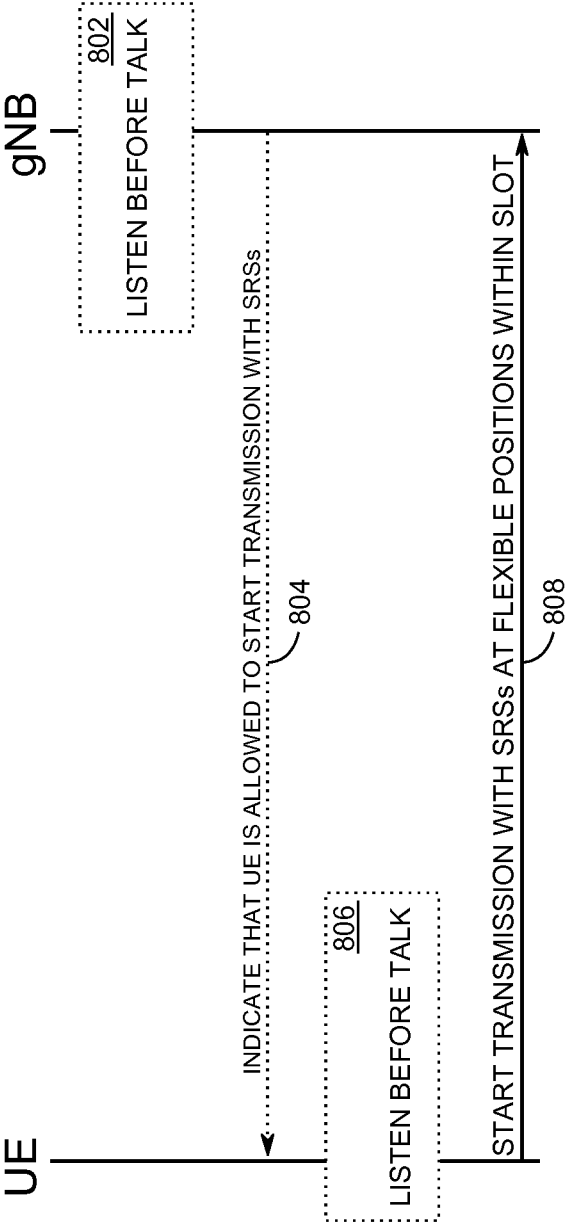
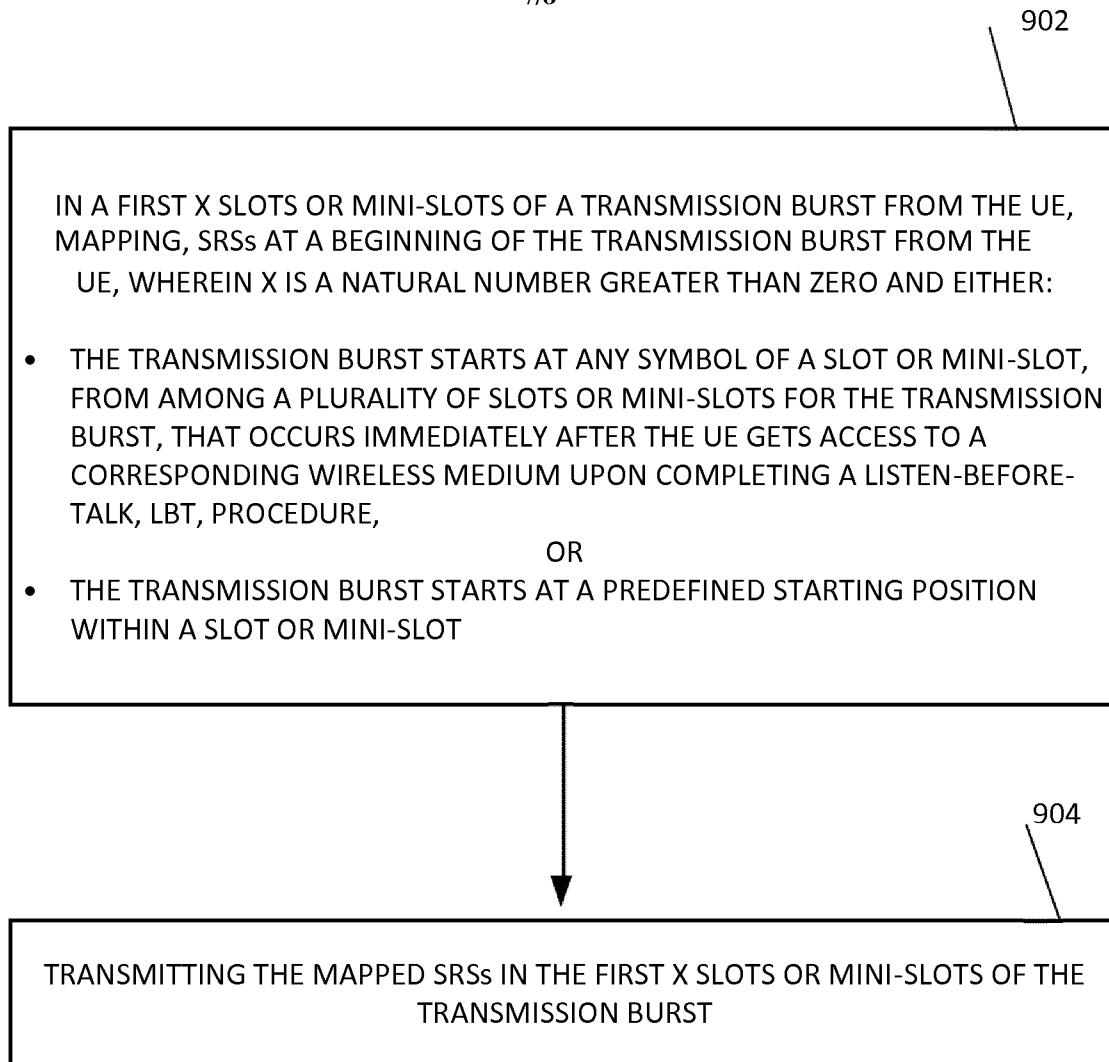
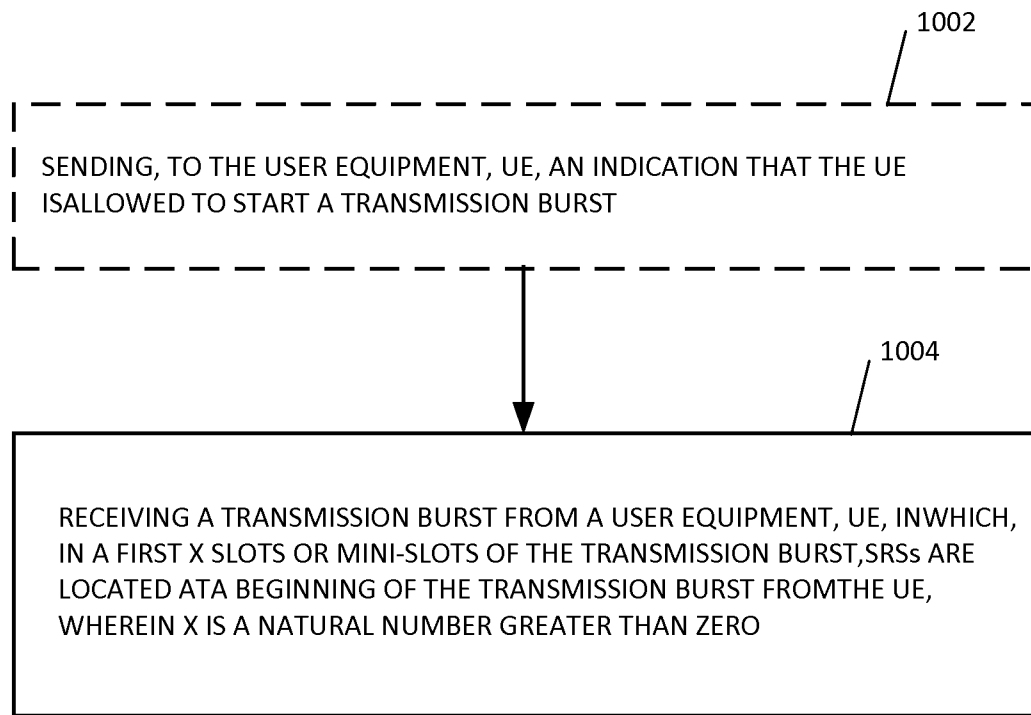


FIG. 8

**FIG. 9**

**FIG. 10**

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/076252

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W74/08

ADD. H04L25/02 H04W72/04

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	the whole document ----- -/--	2-14,18, 22-26



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

3 December 2019

Date of mailing of the international search report

11/12/2019

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/076252

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Y	paragraph [0005]	8,9,26
A	paragraphs [0021] - [0058] paragraphs [0091] - [0220]	15,16,19
X	ERICSSON: "Feature lead summary 2 for UL Signals and Channels", 3GPP DRAFT; R1-1809819 FEATURE LEAD SUMMARY 2 FOR 7.2.2.3.2 UL SIGNALS AND CHANNELS, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTI , vol. RAN WG1, no. Gothenburg, Sweden; 20180820 - 20180824 23 August 2018 (2018-08-23), XP051517176, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg%5Fran/WG1% 5FRL1/TSGR1%5F94/Docs/R1%2D1809819%2Ezip [retrieved on 2018-08-23]	1,17,20, 21,27,28
A	page 10, Section 5 SRS design Aspects	2-16,18, 19,22-26
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Information on patent family members

International application No

PCT/EP2019/076252

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			US 2018242372 A1	23-08-2018
			WO 2017024988 A1	16-02-2017
