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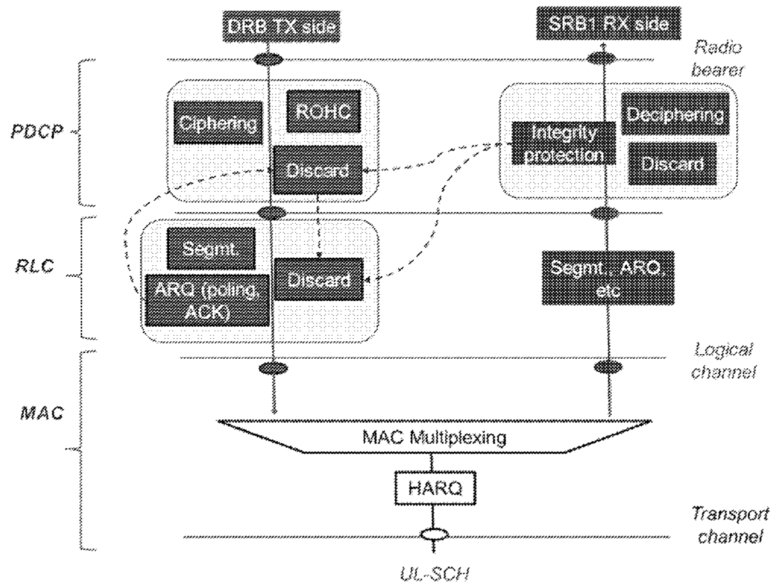

Fig. 2

(57) Abstract: According to some embodiments, a method for early data transmission (EDT) performed by a wireless device comprises: assembling a random access message 3 that includes uplink data for random access EDT; transmitting the random access message 3 to a network node; receiving a random access message 4 from the network node; determining whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3; and upon determining the random access message 4 includes a successful integrity check, discarding transmission protocol information corresponding to the uplink data in random access message 3.

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EARLY DATA DELIVERY FOR RANDOM ACCESS PROCEDURE

TECHNICAL FIELD

Embodiments of the present disclosure are directed to wireless communications and, more particularly, to reliable delivery of early data during a random access procedure.

BACKGROUND

Generally, all terms used herein are to be interpreted according to their ordinary meaning in the relevant technical field, unless a different meaning is clearly given and/or is implied from the context in which it is used. All references to a/an/the element, apparatus, component, means, step, etc. are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any methods disclosed herein do not have to be performed in the exact order disclosed, unless a step is explicitly described as following or preceding another step and/or where it is implicit that a step must follow or precede another step. Any feature of any of the embodiments disclosed herein may be applied to any other embodiment, wherever appropriate. Likewise, any advantage of any of the embodiments may apply to any other embodiments, and vice versa. Other objectives, features, and advantages of the enclosed embodiments will be apparent from the following description.

Third Generation Partnership Project (3GPP) specifications include technologies such as Machine-to-Machine (M2M) communication and Internet of Things (IoT). Recent work for 3GPP Release 13 and 14 includes enhancements to support Machine-Type Communications (MTC) with new user equipment (UE) categories (e.g., Cat-M1, Cat-M2), supporting reduced bandwidth of up to 6 and 24 physical resource blocks (PRBs), and Narrowband IoT (NB-IoT) UEs providing a new radio interface (and UE categories Cat-NB1 and Cat-NB2).

Herein, the LTE enhancements introduced in 3GPP Release 13, 14, and 15 for MTC are referred to as “eMTC,” including (but not limited to) support for bandwidth limited UEs, Cat-M1, and support for coverage enhancements. This is to distinguish from NB-IoT, although the supported features are similar on a general level.

3GPP Release 13 includes cellular IoT (CIoT) Evolved Packet System (EPS) User Plane (UP) optimization and CIoT EPS Control Plane (CP) optimization signaling reductions for both eMTC and NB-IoT. The former, referred to herein as the UP-solution, enables the UE to resume a previously stored radio resource control (RRC) connection (also referred to as RRC Suspend/Resume). The latter, referred to herein as the CP-solution, enables the transmission of user-plane data over non-access stratum (NAS) (also referred to as data over NAS (DoNAS)).

3GPP Release 15 includes further enhanced MTC for LTE (LTE_eMTC4) and further NB-IoT enhancements (NB_IOTenh2). A common objective is to reduce UE power consumption and latency through the possibility of sending data as early as possible during the random access (RA) procedure, or commonly referred to as early data transmission (EDT).

3GPP Release 15 also includes transmission of user data in random access Msg3 and Msg4 for mobile-originated (MO) calls for both UP- and CP CIoT EPS optimizations (MO UP-EDT and MO CP-EDT, respectively). In MO EDT solutions, the UE with a small amount of uplink data can indicate its intention of using EDT by selecting an EDT preamble in random access Msg1. The eNB provides the UE with an EDT uplink grant that allows the UE to transmit uplink data together with signaling in Msg3. Depending on uplink conditions, the UE selects a suitable value of transport block size (TBS) among the possible values specified based on the maximum TBS value as well as the permitted number of blind decodes (i.e., number of TBS values smaller than the maximum value) broadcast in the system information. Downlink data, if any, can be included in Msg4 together with signaling that instructs the UE to remain in RRC_IDLE mode for power saving. If more user data is available, Msg4 can instruct the UE to move to RRC_CONNECTED mode for further data transmissions.

FIGURE 1 is a flow diagram illustrating an example random access message exchange. To facilitate the description of particular embodiments, the messages in the random access procedure are commonly referred to as message 1 (Msg1) through message 4 (Msg4). FIGURE 1 illustrates the contention-based RA procedure as described in 3GPP TS 36.200: At step 1, the UE sends a random access preamble (Msg1) to the eNB. The eNB responds at step 2 with a random access response (Msg2). At step 3, the UE sends a scheduled transmission (Msg3) to the eNB. The eNB responds at step 4 with a contention resolution message (msg4).

There currently exist certain challenges with EDT. For example, in UP-EDT or data transmission during random access procedure in general, the UE and network do not conventionally authenticate each other using three signaling messages (Msg3, 4, 5) before transmitting uplink data. Instead, uplink data is transmitted in Msg3 by multiplexing with RRC signaling. The authenticity is based only on the 16-bit authentication code included in the RRC signaling in Msg3, which is considered weaker than the legacy integrity protection of 32-bit packet data convergence protocol (PDCP) MAC-I. Thus, the UE cannot validate that it is sending data to the correct eNB before the actual data transmission.

The PDCP sub-layer discards user data on the dedicated traffic channel (DTCH) if it receives an indication from the radio link control (RLC) sub-layer that the corresponding PDCP service data unit (SDU) was successfully delivered (e.g., based on the reception of a corresponding RLC status report) or if the PDCP *discardTimer* expires. In cases where the UE does not poll for RLC status report, the PDCP will discard uplink data based only on the *discardTimer* timer. The existing operation causes the UE to discard the PDCP/RLC SDU corresponding to uplink data sent in Msg3 (either user data on a data radio bearer (DRB) or signaling radio bearer 1 or 2 (SRB1/SRB2) data) before or even without knowing whether the data has been successfully delivered to the right eNB.

<u>SUMMARY</u>

Based on the description above, certain challenges currently exist with early data transmission (EDT). Certain aspects of the present disclosure and their embodiments may provide solutions to these or other challenges. For example, particular embodiments facilitate a user equipment (UE) processing user data transmitted in Msg3 in a reliable manner by avoiding the discarding of unsuccessfully delivered data. Particular embodiments may be described with respect to long term evolution (LTE) and narrowband Internet of things (NB-IoT), but the embodiments also apply to fifth generation (5G) new radio (NR), and any other suitable radio technology.

Particular embodiments enable a UE to validate the authenticity of the eNB to which the UE sends Msg3 with uplink data, and thus the UE is able to determine whether its uplink data has been successfully delivered to the correct eNB. In addition, particular embodiments further enhance the discard operation at the UE by timely starting (enabling) the *discardTimer* timer associated with the DRB/SRB1/SRB2 data sent in Msg3 to avoid possible data loss because of early timer activation.

Particular embodiments enable a UE to validate the authenticity of the eNB and in accordance process layer 2 (L2) data corresponding to uplink data sent in Msg3 in a reliable manner. The UE determines that it sent Msg3 to the correct eNB if the UE receives a Msg4 with a radio resource control (RRC) message indicating the integrity check passed. The uplink data sent in Msg3 is considered successfully delivered only if the integrity check of the RRC message in Msg4 (i.e., the *RRCConnectionRelease* or *RRCConnectionResume*) is successful. Packet data convergence protocol (PDCP) and/or radio link control (RLC) data corresponding to the uplink data sent in Msg3 is not discarded/removed (it is kept for possible retransmission) until the integrity check is successful. For early data/signaling transmission in Msg3 (e.g., UP-EDT), packet data convergence protocol (PDCP) entities for downlink SRB1/SRB2 and uplink DRB/SRB1/SRB2 interact to facilitate the handling of L2 data corresponding to DRB/SRB1/SRB2 data sent in Msg3.

Particular embodiments enhance the PDCP service data unit (SDU) discard timer operation to enable timely (re)activation of SDU discard (timer) functionality and/or to enable avoiding loss of initial data because of early (re)activation of SDU discard (timer) functionality. In general, particular embodiments avoid the issue of preamble partitioning and extension and provide unused uplink grant in control plane (CP) and user plane (UP) early data transmissions for LTE, NB-IoT, and 5G/NR.

According to some embodiments, a method for EDT performed by a wireless device comprises: assembling a random access message 3 that includes uplink data for random access EDT; transmitting the random access message 3 to a network node; receiving a random access message 4 from the network node; determining whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3; and upon determining the random access message 4 includes a successful integrity check, discarding transmission protocol information corresponding to the uplink data in random access message 3.

In particular embodiments, the method further comprises, upon determining the random access message 4 does not indicate a successful integrity check, preserving transmission protocol information corresponding to the uplink data in random access message 3 for use in a future transmission.

In particular embodiments, the transmission protocol information comprises PDCP information. The transmission protocol information may comprise layer 2 (L2) data corresponding to the uplink data in random access message 3. The uplink data in random access message 3 may comprise a DRB SDU and the method may further comprise disabling polling for a radio link control (RLC) status report associated with the DRB SDU. The random access message 4 may include a RRC message.

In particular embodiments, determining whether the random access message 4 includes a successful integrity check comprises a PDCP entity receiving an integrity check indication on a signaling radio bearer, and the method further comprises communicating the integrity check indication to a PDCP entity associated with a radio bearer associated with the uplink data in the random access message 3.

In particular embodiments, the PDCP entity associated with the radio bearer associated with the uplink data in the random access message 3 starts a PDCP service data unit (SDU) discard timer after determining whether the random access message 4 includes a successful integrity check.

In particular embodiments, determining whether the random access message 4 includes a successful integrity check comprises a PDCP entity receiving an integrity check indication on a signaling radio bearer, and the method further comprises communicating the integrity check indication to a RLC entity associated with the uplink data transmitted in the random access message 3.

In particular embodiments, the uplink data comprises one of user data and signaling data.

According to some embodiments, a wireless device is capable of EDT. The wireless device comprises processing circuitry operable to perform any of the wireless device methods described above.

According to some embodiments, a wireless device is capable of EDT. The wireless device comprises a transmitting module, a receiving module, and a determining module. The transmitting module is operable to assemble a random access message 3 that includes uplink data for random access EDT and transmit the random access message 3 to a network node. The receiving module is operable to receive a random access message 4 from the network node. The determining module is operable to determine whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3 and upon determining the random access message 4 includes a successful integrity check, discard transmission protocol information corresponding to the uplink data in random access message 3.

Also disclosed is a computer program product comprising a non-transitory computer readable medium storing computer readable program code, the computer readable program code operable, when executed by processing circuitry to perform any of the methods performed by the wireless device described above.

Certain embodiments may provide one or more of the following technical advantages. For example, particular embodiments enable a UE to determine whether early data in Msg3 has been successfully delivered. This also helps the UE to avoid discarding data improperly, which improves operational efficiency. Furthermore, particular embodiments facilitate backward compatibility.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the disclosed embodiments and their features and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a flow diagram illustrating an example random access message exchange;

FIGURE 2 s a block diagram illustrating an example layer 2 (L2) structure for reliable delivery of data in early data transmission (EDT) Msg3;

FIGURE 3 is a block diagram illustrating an example wireless network;

FIGURE 4 illustrates an example user equipment, according to certain embodiments;

FIGURE 5 is flowchart illustrating an example method in a wireless device, according to certain embodiments;

FIGURE 6 illustrates a schematic block diagram of a wireless device and network node in a wireless network, according to certain embodiments;

FIGURE 7 illustrates an example virtualization environment, according to certain embodiments;

FIGURE 8 illustrates an example telecommunication network connected via an intermediate network to a host computer, according to certain embodiments;

FIGURE 9 illustrates an example host computer communicating via a base station with a user equipment over a partially wireless connection, according to certain embodiments;

FIGURE 10 is a flowchart illustrating a method implemented, according to certain embodiments;

FIGURE 11 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments;

FIGURE 12 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments; and

FIGURE 13 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments.

DETAILED DESCRIPTION

As described above, certain challenges currently exist with early data transmission (EDT). For example, for data transmission during a random access procedure, the user equipment (UE) and network do not conventionally authenticate each other before transmitting uplink data. Instead, uplink data is transmitted in Msg3 by multiplexing with radio resource control (RRC) signaling. Thus, the UE cannot validate that it is sending data to the correct eNB before the actual data transmission.

Also, the packet data convergence protocol (PDCP) sub-layer discards user data on the dedicated traffic channel (DTCH) if it receives an indication from the radio link control (RLC) sub-layer that the corresponding PDCP service data unit (SDU) was successfully delivered or if the PDCP *discardTimer* expires. The existing operation causes the UE to discard the PDCP/RLC SDU corresponding to uplink data sent in Msg3 before or even without knowing whether the data has been successfully delivered to the correct eNB.

Certain aspects of the present disclosure and their embodiments may provide solutions to these or other challenges. For example, particular embodiments facilitate a UE processing user data transmitted in Msg3 in a reliable manner and avoiding the discarding of unsuccessfully delivered data.

Particular embodiments are described more fully with reference to the accompanying drawings. Other embodiments, however, are contained within the scope of the subject matter disclosed herein, the disclosed subject matter should not be construed as limited to only the embodiments set forth herein; rather, these embodiments are provided by way of example to convey the scope of the subject matter to those skilled in the art.

Relying on the radio link control (RLC) acknowledgement (ACK) for the data part in random access Msg3 is not sufficient to determine whether data in Msg3 has been successfully delivered to the correct eNB because it can easily be produced by an attacker (instead of from the correct eNB). In addition, it is optional for the UE to poll for RLC status reports. A UE that does not poll for an RLC status report may consider a downlink random access Msg4 as a confirmation that the transport block with Msg3 (including uplink data) was successfully received by the correct eNB. For the same reason as for the RLC ACK case above, however, this is not reliable/robust.

In particular embodiments, the UE only considers the uplink data sent in Msg3 as successfully delivered if it receives Msg4 with a RRC message (e.g., the *RRCConnectionRelease* or *RRCConnectionResume*) that includes a successful integrity check. The UE keeps uplink data until the integrity check is successful. The uplink data sent in Msg3 can be user data, such as in user plane early data transmission (UP-EDT), or signaling/configuration information, such as early measurement reporting in Msg3.

In some embodiments, discarding/removing of layer 2 (L2) data or signaling radio bearer (DRB/SRB1/SRB2) data corresponding to uplink data sent in Msg3 at packet data convergence protocol (PDCP) and RLC sub-layers at the UE is based on the integrity check of the received SRB1/SRB2 service data unit (SDU) in Msg4, i.e., containing RRC message (e.g., RRCConnectionRelease or RRCConnectionResume in case of UP-EDT). The discarding/removing of successfully transmitted data takes input from the PDCP entity for SRB1/SRB2 regarding the integrity protection verification for determining whether to discard a PDCP SDU along with corresponding PDCP protocol data unit (PDU) mapped on DRB/SRB1/SRB2 data sent in Msg3. The successful verification and/or successful transmission of data and/or discard/remove may be indicated to lower layers (RLC) for discarding/removing corresponding SDU/PDU.

In some embodiments, the UE does not poll for RLC status reports for the DRB SDU in Msg3 in EDT. A benefit is that the UE can skip an unnecessary RLC ACK in downlink and further improve the performance of the EDT procedure and improve UE battery life.

In some embodiments, the PDCP entities associated with early data transmission during random access procedure interact to determine whether L2 data corresponding to the uplink data sent in Msg3 were successfully delivered. An example of such interaction at L2 is illustrated in FIGURE 2.

FIGURE 2 is a block diagram illustrating an example of L2 structure for reliable delivery of data in EDT Msg3. The receiving side of the SRB1 PDCP entity indicates to the transmitting side of the DRB PDCP entity the outcome of integrity check of received SRB1 PDU from lower layers. In the illustrated example, SRB1 PDU includes either the *RRCConnectionRelease* or *RRCConnectionResume* message. The DRB PDCP entity at the transmitting side can determine to discard or keep L2 data according to the integrity check outcome.

In some embodiments, if the UE receives Msg4 with a RRC message over SRB0, e.g., the *RRCConnectionSetup* in UP-EDT in response to a Msg3 with uplink data, the uplink data is considered unsuccessfully delivered and kept for possible (re)transmissions.

In some embodiments, PDCP SDU discard timers are enabled/activated before integrity protection verification for the RRC message in Msg4, e.g., *RRCConnectionResume* or *RRCConnectionRelease*; for example, upon re-establishment of respective PDCP entities or upon resume of respective DRB. In another embodiment, PDCP SDU discard timers are enabled/activated upon/after successful integrity protection verification for the RRC message in Msg4, e.g., *RRCConnectionResume* or *RRCConnectionRelease*.

FIGURE 3 illustrates an example wireless network, according to certain embodiments. 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 2G, 3G, 4G, or 5G standards; wireless local area network (WLAN) standards, such as the IEEE 802.11 standards; and/or any other appropriate wireless communication standard, such as the Worldwide Interoperability for Microwave Access (WiMax), Bluetooth, Z-Wave and/or ZigBee standards.

Network 106 may comprise one or more backhaul networks, core networks, IP networks, public switched telephone networks (PSTNs), packet data networks, optical networks, wide-area networks (WANs), local area networks (LANs), wireless local area networks (WLANs), wired networks, wireless networks, metropolitan area networks, and other networks to enable communication between devices.

Network node 160 and WD 110 comprise various components described in more detail below. These components work together to provide network node and/or wireless device functionality, such as providing wireless connections in a wireless network. In different 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 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 access points), base stations (BSs) (e.g., radio base stations, Node Bs, evolved Node Bs (eNBs) and NR NodeBs (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), sometimes referred to as Remote Radio Heads (RRHs). Such remote radio units 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 base station controllers (BSCs), base transceiver stations (BTSs), transmission points, transmission nodes, multi-cell/multicast coordination entities (MCEs), core network nodes (e.g., MSCs, MMEs), O&M nodes, OSS nodes, SON nodes, positioning nodes (e.g., E-SMLCs), and/or 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, 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 3, network node 160 includes processing circuitry 170, device readable medium 180, interface 190, auxiliary equipment 184, power source 186, power circuitry 187, and antenna 162. Although network node 160 illustrated in the example wireless network of FIGURE 3 may represent a device that includes the illustrated combination of hardware components, 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 network node 160 are depicted as single boxes located within a larger box, or nested within multiple boxes, in practice, a network node may comprise multiple different physical components that make up a single illustrated component (e.g., device readable medium 180 may comprise multiple separate hard drives as well as multiple RAM modules).

Similarly, network node 160 may be composed of multiple physically separate components (e.g., a NodeB component and a RNC component, or a BTS component and a BSC component, etc.), which may each have their own respective components. In certain scenarios in which network node 160 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 NodeB's. In such a scenario, each unique NodeB and RNC pair, may in some instances be considered a single separate network node.

In some embodiments, network node 160 may be configured to support multiple radio access technologies (RATs). In such embodiments, some components may be duplicated (e.g., separate device readable medium 180 for the different RATs) and some components may be reused (e.g., the same antenna 162 may be shared by the RATs). Network node 160 may also include multiple sets of the various illustrated components for different wireless technologies integrated into network node 160, such as, for example, GSM, WCDMA, LTE, NR, WiFi, or Bluetooth wireless technologies. These wireless technologies may be integrated into the same or different chip or set of chips and other components within network node 160.

Processing circuitry 170 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 processing circuitry 170 may include processing information obtained by processing circuitry 170 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.

Processing circuitry 170 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, 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 160 components, such as device readable medium 180, network node 160 functionality.

For example, processing circuitry 170 may execute instructions stored in device readable medium 180 or in memory within processing circuitry 170. Such functionality may include providing any of the various wireless features, functions, or benefits discussed herein. In some embodiments, processing circuitry 170 may include a system on a chip (SOC).

In some embodiments, processing circuitry 170 may include one or more of radio frequency (RF) transceiver circuitry 172 and baseband processing circuitry 174. In some embodiments, radio frequency (RF) transceiver circuitry 172 and baseband processing circuitry 174 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 RF transceiver circuitry 172 and baseband processing circuitry 174 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 processing circuitry 170 executing instructions stored on device readable medium 180 or memory within processing circuitry 170. In alternative embodiments, some or all of the functionality may be provided by processing circuitry 170 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, processing circuitry 170 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 170 alone or to other components of network node 160 but are enjoyed by network node 160 as a whole, and/or by end users and the wireless network generally.

Device readable medium 180 may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid-state memory, remotely mounted memory, magnetic media, optical media, random access memory (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 processing circuitry 170. Device readable medium 180 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 processing circuitry 170 and, utilized by network node 160. Device readable medium 180 may be used to store any calculations made by processing circuitry 170 and/or any data received via interface 190. In some embodiments, processing circuitry 170 and device readable medium 180 may be considered to be integrated.

Interface 190 is used in the wired or wireless communication of signaling and/or data between network node 160, network 106, and/or WDs 110. As illustrated, interface 190 comprises port(s)/terminal(s) 194 to send and receive data, for example to and from network 106 over a wired connection. Interface 190 also includes radio front end circuitry 192 that may be coupled to, or in certain embodiments a part of, antenna 162.

Radio front end circuitry 192 comprises filters 198 and amplifiers 196. Radio front end circuitry 192 may be connected to antenna 162 and processing circuitry 170. Radio front end circuitry may be configured to condition signals communicated between antenna 162 and processing circuitry 170. Radio front end circuitry 192 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 192 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 198 and/or amplifiers 196. The radio signal may then be transmitted via antenna 162. Similarly, when receiving data, antenna 162 may collect radio signals which are then converted into digital data by radio front end circuitry 192. The digital data may be passed to processing circuitry 170. In other embodiments, the interface may comprise different components and/or different combinations of components.

In certain alternative embodiments, network node 160 may not include separate radio front end circuitry 192, instead, processing circuitry 170 may comprise radio front end circuitry and may be connected to antenna 162 without separate radio front end circuitry 192. Similarly, in some embodiments, all or some of RF transceiver circuitry 172 may be considered a part of interface 190. In still other embodiments, interface 190 may include one or more ports or terminals 194, radio front end circuitry 192, and RF transceiver circuitry 172, as part of a radio unit (not shown), and interface 190 may communicate with baseband processing circuitry 174, which is part of a digital unit (not shown).

Antenna 162 may include one or more antennas, or antenna arrays, configured to send and/or receive wireless signals. Antenna 162 may be coupled to radio front end circuitry 190 and may be any type of antenna capable of transmitting and receiving data and/or signals wirelessly. In some embodiments, antenna 162 may comprise one or more omni-directional, sector or panel antennas operable to transmit/receive radio signals between, for example, 2 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 relatively straight line. In some instances, the use of more than one antenna may be referred to as MIMO. In certain embodiments, antenna 162 may be separate from network node 160 and may be connectable to network node 160 through an interface or port.

Antenna 162, interface 190, and/or processing circuitry 170 may be configured to 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 wireless device, another network node and/or any other network equipment. Similarly, antenna 162, interface 190, and/or processing circuitry 170 may be configured to perform any transmitting operations described herein as being performed by a network node.

Any information, data and/or signals may be transmitted to a wireless device, another network node and/or any other network equipment.

Power circuitry 187 may comprise, or be coupled to, power management circuitry and is configured to supply the components of network node 160 with power for performing the functionality described herein. Power circuitry 187 may receive power from power source 186. Power source 186 and/or power circuitry 187 may be configured to provide power to the various components of network node 160 in a form suitable for the respective components (e.g., at a voltage and current level needed for each respective component). Power source 186 may either be included in, or external to, power circuitry 187 and/or network node 160. For example, network node 160 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 power circuitry 187. As a further example, power source 186 may comprise a source of power in the form of a battery or battery pack which is connected to, or integrated in, power circuitry 187. The battery may provide backup power should the external power source fail. Other types of power sources, such as photovoltaic devices, may also be used.

Alternative embodiments of network node 160 may include additional components beyond those shown in FIGURE 3 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, network node 160 may include user interface equipment to allow input of information into network node 160 and to allow output of information from network node 160. This may allow a user to perform diagnostic, maintenance, repair, and other administrative functions for network node 160.

As used herein, wireless device (WD) refers to a device capable, configured, arranged and/or operable to communicate wirelessly with network nodes and/or other wireless devices. Unless otherwise noted, the term 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 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 cameras, a gaming console or device, a music storage device, a playback appliance, a wearable terminal device, a wireless endpoint, a mobile station, a tablet, a laptop, a laptop-embedded equipment (LEE), a 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 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 an MTC device. As one example, the WD may be a UE implementing the 3GPP narrow band internet of things (NB-IoT) standard. Examples of such machines or devices are sensors, metering devices such as power meters, industrial machinery, or home or personal appliances (e.g. refrigerators, televisions, etc.) 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, wireless device 110 includes antenna 111, interface 114, processing circuitry 120, device readable medium 130, user interface equipment 132, auxiliary equipment 134, power source 136 and power circuitry 137. WD 110 may include multiple sets of one or more of the illustrated components for different wireless technologies supported by WD 110, 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 WD 110.

Antenna 111 may include one or more antennas or antenna arrays, configured to send and/or receive wireless signals, and is connected to interface 114. In certain alternative embodiments, antenna 111 may be separate from WD 110 and be connectable to WD 110 through an interface or port. Antenna 111, interface 114, and/or processing circuitry 120 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 antenna 111 may be considered an interface.

As illustrated, interface 114 comprises radio front end circuitry 112 and antenna 111. Radio front end circuitry 112 comprise one or more filters 118 and amplifiers 116. Radio front end circuitry 114 is connected to antenna 111 and processing circuitry 120 and is configured to condition signals communicated between antenna 111 and processing circuitry 120. Radio front end circuitry 112 may be coupled to or a part of antenna 111. In some embodiments, WD 110 may not include separate radio front end circuitry 112; rather, processing circuitry 120 may comprise radio front end circuitry and may be connected to antenna 111. Similarly, in some embodiments, some or all of RF transceiver circuitry 122 may be considered a part of interface 114.

Radio front end circuitry 112 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 112 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 118 and/or amplifiers 116. The radio signal may then be transmitted via antenna 111. Similarly, when receiving data, antenna 111 may collect radio signals which are then converted into digital data by radio front end circuitry 112. The digital data may be passed to processing circuitry 120. In other embodiments, the interface may comprise different components and/or different combinations of components.

Processing circuitry 120 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, 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 110 components, such as device readable medium 130, WD 110 functionality. Such functionality may include providing any of the various wireless features or benefits discussed herein. For example, processing circuitry 120 may execute instructions stored in device readable medium 130 or in memory within processing circuitry 120 to provide the functionality disclosed herein.

As illustrated, processing circuitry 120 includes one or more of RF transceiver circuitry 122, baseband processing circuitry 124, and application processing circuitry 126. In other embodiments, the processing circuitry may comprise different components and/or different combinations of components. In certain embodiments processing circuitry 120 of WD 110 may comprise a SOC. In some embodiments, RF transceiver circuitry 122, baseband processing circuitry 124, and application processing circuitry 126 may be on separate chips or sets of chips.

In alternative embodiments, part or all of baseband processing circuitry 124 and application processing circuitry 126 may be combined into one chip or set of chips, and RF transceiver circuitry 122 may be on a separate chip or set of chips. In still alternative embodiments, part or all of RF transceiver circuitry 122 and baseband processing circuitry 124 may be on the same chip or set of chips, and application processing circuitry 126 may be on a separate chip or set of chips. In yet other alternative embodiments, part or all of RF transceiver circuitry 122, baseband processing circuitry 124, and application processing circuitry 126 may be combined in the same chip or set of chips. In some embodiments, RF transceiver circuitry 122 may be a part of interface 114. RF transceiver circuitry 122 may condition RF signals for processing circuitry 120.

In certain embodiments, some or all of the functionality described herein as being performed by a WD may be provided by processing circuitry 120 executing instructions stored on device readable medium 130, which in certain embodiments may be a computer-readable storage medium. In alternative embodiments, some or all of the functionality may be provided by processing circuitry 120 without executing instructions stored on a separate or discrete device readable storage 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, processing circuitry 120 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 120 alone or to other components of WD 110, but are enjoyed by WD 110, and/or by end users and the wireless network generally.

Processing circuitry 120 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 processing circuitry 120, may include processing information obtained by processing circuitry 120 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored by WD 110, 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.

Device readable medium 130 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 of being executed by processing circuitry 120. Device readable medium 130 may include computer memory (e.g., Random Access Memory (RAM) or Read Only Memory (ROM)), mass storage media (e.g., a hard disk), removable storage media (e.g., 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 processing circuitry 120. In some embodiments, processing circuitry 120 and device readable medium 130 may be integrated.

User interface equipment 132 may provide components that allow for a human user to interact with WD 110. Such interaction may be of many forms, such as visual, audial, tactile, etc. User interface equipment 132 may be operable to produce output to the user and to allow the user to provide input to WD 110. The type of interaction may vary depending on the type of user interface equipment 132 installed in WD 110. For example, if WD 110 is a smart phone, the interaction may be via a touch screen; if WD 110 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).

User interface equipment 132 may include input interfaces, devices and circuits, and output interfaces, devices and circuits. User interface equipment 132 is configured to allow input of information into WD 110 and is connected to processing circuitry 120 to allow processing circuitry 120 to process the input information. User interface equipment 132 may include, for example, a microphone, a proximity or other sensor, keys/buttons, a touch display, one or more cameras, a USB port, or other input circuitry. User interface equipment 132 is also configured to allow output of information from WD 110, and to allow processing circuitry 120 to output information from WD 110. User interface equipment 132 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 user interface equipment 132, WD 110 may communicate with end users and/or the wireless network and allow them to benefit from the functionality described herein.

Auxiliary equipment 134 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 auxiliary equipment 134 may vary depending on the embodiment and/or scenario.

Power source 136 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. WD 110 may further comprise power circuitry 137 for delivering power from power source 136 to the various parts of WD 110 which need power from power source 136 to carry out any functionality described or indicated herein. Power circuitry 137 may in certain embodiments comprise power management circuitry.

Power circuitry 137 may additionally or alternatively be operable to receive power from an external power source; in which case WD 110 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. Power circuitry 137 may also in certain embodiments be operable to deliver power from an external power source to power source 136. This may be, for example, for the charging of power source 136. Power circuitry 137 may perform any formatting, converting, or other modification to the power from power source 136 to make the power suitable for the respective components of WD 110 to which power is supplied.

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 3. For simplicity, the wireless network of FIGURE 3 only depicts network 106, network nodes 160 and 160b, and WDs 110, 110b, and 110c. In practice, a wireless network may further include any additional elements suitable to support communication between wireless devices or between a 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, network node 160 and wireless device (WD) 110 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.

FIGURE 4 illustrates an example user equipment, according to certain embodiments. 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). UE 200 may be any UE identified by the 3rd Generation Partnership Project (3GPP), including a NB-IoT UE, a machine type communication (MTC) UE, and/or an enhanced MTC (eMTC) UE. UE 200, as illustrated in FIGURE 4, is one example of a WD configured for communication in accordance with one or more communication standards promulgated by the 3rd Generation Partnership Project (3GPP), such as 3GPP's GSM, UMTS, LTE, and/or 5G standards. As mentioned previously, the term WD and UE may be used interchangeable. Accordingly, although FIGURE 4 is a UE, the components discussed herein are equally applicable to a WD, and vice-versa.

In FIGURE 4, UE 200 includes processing circuitry 201 that is operatively coupled to input/output interface 205, radio frequency (RF) interface 209, network connection interface 211, memory 215 including random access memory (RAM) 217, read-only memory (ROM) 219, and storage medium 221 or the like, communication subsystem 231, power source 233, and/or any other component, or any combination thereof. Storage medium 221 includes operating system 223, application program 225, and data 227. In other embodiments, storage medium 221 may include other similar types of information. Certain UEs may use all the components shown in FIGURE 4, 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 4, processing circuitry 201 may be configured to process computer instructions and data. Processing circuitry 201 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 program, general-purpose processors, such as a microprocessor or Digital Signal Processor (DSP), together with appropriate software; or any combination of the above. For example, the processing circuitry 201 may include two central processing units (CPUs). Data may be information in a form suitable for use by a computer.

In the depicted embodiment, input/output interface 205 may be configured to provide a communication interface to an input device, output device, or input and output device. UE 200 may be configured to use an output device via input/output interface 205.

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 UE 200. 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.

UE 200 may be configured to use an input device via input/output interface 205 to allow a user to capture information into UE 200. 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 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 4, RF interface 209 may be configured to provide a communication interface to RF components such as a transmitter, a receiver, and an antenna. Network connection interface 211 may be configured to provide a communication interface to network 243a. Network 243a may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 243a may comprise a Wi-Fi network. Network connection interface 211 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, TCP/IP, SONET, ATM, or the like. Network connection interface 211 may implement receiver and transmitter functionality appropriate 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.

RAM 217 may be configured to interface via bus 202 to processing circuitry 201 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. ROM 219 may be configured to provide computer instructions or data to processing circuitry 201. For example, ROM 219 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.

Storage medium 221 may be configured to include memory such as RAM, ROM, programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, or flash drives. In one example, storage medium 221 may be configured to include operating system 223, application program 225 such as a web browser application, a widget or gadget engine or another application, and data file 227. Storage medium 221 may store, for use by UE 200, any of a variety of various operating systems or combinations of operating systems.

Storage medium 221 may be configured to include a number of physical drive units, such as redundant array of independent disks (RAID), floppy disk drive, flash memory, USB flash drive, external hard disk drive, thumb drive, pen drive, key drive, high-density digital versatile disc (HD-DVD) optical disc drive, internal hard disk drive, Blu-Ray optical disc drive, holographic digital data storage (HDDS) optical disc drive, external mini-dual in-line memory module (DIMM), synchronous dynamic random access memory (SDRAM), external micro-DIMM SDRAM, smartcard memory such as a subscriber identity module or a removable user identity (SIM/RUIM) module, other memory, or any combination thereof. Storage medium 221 may allow UE 200 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 storage medium 221, which may comprise a device readable medium.

In FIGURE 4, processing circuitry 201 may be configured to communicate with network 243b using communication subsystem 231. Network 243a and network 243b may be the same network or networks or different network or networks. Communication subsystem 231 may be configured to include one or more transceivers used to communicate with network 243b. For example, communication subsystem 231 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 802.2, CDMA, WCDMA, GSM, LTE, UTRAN, WiMax, or the like. Each transceiver may include transmitter 233 and/or receiver 235 to implement transmitter or receiver functionality, respectively, appropriate to the RAN links (e.g., frequency allocations and the like). Further, transmitter 233 and receiver 235 of each transceiver may share circuit components, software or firmware, or alternatively may be implemented separately.

In the illustrated embodiment, the communication functions of communication subsystem 231 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, communication subsystem 231 may include cellular communication, Wi-Fi communication, Bluetooth communication, and GPS communication. Network 243b may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 243b may be a cellular network, a Wi-Fi network, and/or a near-field network. Power source 213 may be configured to provide alternating current (AC) or direct current (DC) power to components of UE 200.

The features, benefits and/or functions described herein may be implemented in one of the components of UE 200 or partitioned across multiple components of UE 200. Further, the features, benefits, and/or functions described herein may be implemented in any combination of hardware, software or firmware. In one example, communication subsystem

231 may be configured to include any of the components described herein. Further, processing circuitry 201 may be configured to communicate with any of such components over bus 202. In another example, any of such components may be represented by program instructions stored in memory that when executed by processing circuitry 201 perform the corresponding functions described herein. In another example, the functionality of any of such components may be partitioned between processing circuitry 201 and communication subsystem 231. 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 5 is a flowchart illustrating an example method in a user equipment, according to certain embodiments. In particular embodiments, one or more steps of FIGURE 5 may be performed by wireless device 110 described with respect to FIGURE 3.

The method begins at step 512, where the wireless device (e.g., wireless device 110) assembles a random access message 3 that includes uplink data for random access EDT. For example, wireless device 110 may assemble random access message 3 that includes uplink data, such as signaling data or user data.

In particular embodiments, the uplink data may comprise a DRB SDU. The wireless device may disable polling for a RLC status report associated with the DRB SDU

At step 514, the wireless device transmits the random access message 3 to a network node. For example, wireless device 110 may transmit the Msg3 to network node 160. In some embodiments, a PDCP entity and/or a RLC entity is associated with the uplink data.

At step 516, the wireless device receives a random access message 4 from the network node. For example, wireless device 110 may receive Msg4 from network node 160. The random access message 4 may include a RRC message. In some embodiments, a PDCP entity is associated with the received Msg4.

At step 518, the wireless device determines whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3. Upon determining the random access message 4 includes a successful integrity check, the method continues to step 520, otherwise the method continues to step 522.

In some embodiments, determining whether the random access message 4 includes a successful integrity check comprises a PDCP entity receiving an integrity check indication on a signaling radio bearer, and the method further comprises communicating the integrity check indication to a PDCP entity associated with a radio bearer associated with the uplink data in the random access message 3 or communicating the integrity check indication to a RLC entity associated with the uplink data transmitted in the random access message 3.

At step 520, the wireless device discards transmission protocol information corresponding to the uplink data in random access message 3, and at step 522 the wireless device preserves transmission protocol information corresponding to the uplink data in random access message 3 for use in a future transmission The transmission protocol information may comprise PDCP information and/or L2 data corresponding to the uplink data in random access message 3.

Steps 518-522, for example, enable the wireless device to determine whether early data in Msg3 has been successfully delivered. This also helps the wireless device to avoid discarding data improperly, which improves operational efficiency. The steps also facilitate backward compatibility.

Modifications, additions, or omissions may be made to method 500 of FIGURE 5. Additionally, one or more steps in the method of FIGURE 5 may be performed in parallel or in any suitable order.

FIGURE 6 illustrates a schematic block diagram of an apparatus in a wireless network (for example, the wireless network illustrated in FIGURE 3). The apparatus includes a wireless device (e.g., wireless device 110 illustrated in FIGURE 3). Apparatus 1600 is operable to carry out the example method described with reference to FIGURE 5 and possibly any other processes or methods disclosed herein. It is also to be understood that the method of FIGURE 5 is not necessarily carried out solely by apparatus 1600. At least some operations of the method can be performed by one or more other entities.

Virtual apparatus 1600 may comprise processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (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 read-only memory (ROM), random-access memory, 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 several embodiments.

In some implementations, the processing circuitry may be used to cause transmitting module 1602, receiving module 1604, determining module 1606, and any other suitable units of apparatus 1600 to perform corresponding functions according one or more embodiments of the present disclosure.

As illustrated in FIGURE 6, apparatus 1600 includes transmitting module 1602 configured to transmit and/or retransmit random access messages according to any of the embodiments and examples described herein. Receiving module 1604 is configured to receive random access messages according to any of the embodiments and examples described herein. Apparatus 1600 also includes determining module 1606 configured to determine whether a received random access message includes a successful integrity check according to any of the embodiments and examples described herein.

FIGURE 7 is a schematic block diagram illustrating a virtualization environment 300 in which functions implemented by some embodiments may be virtualized. In the present context, virtualizing means creating virtual versions of apparatuses or devices which may include virtualizing hardware platforms, storage devices and networking resources. As used herein, virtualization can be applied to a node (e.g., a virtualized base station or a virtualized radio access node) or to a device (e.g., a UE, a wireless device or any other type of communication device) or components thereof and relates to an implementation in which at least a portion of the functionality is implemented as one or more virtual components (e.g., via one or more applications, components, functions, virtual machines or containers executing on one or more physical processing nodes in one or more networks).

In some embodiments, some or all of the functions described herein may be implemented as virtual components executed by one or more virtual machines implemented in one or more virtual environments 300 hosted by one or more of hardware nodes 330. Further, in embodiments in which the virtual node is not a radio access node or does not require radio connectivity (e.g., a core network node), then the network node may be entirely virtualized.

The functions may be implemented by one or more applications 320 (which may alternatively be called software instances, virtual appliances, network functions, virtual nodes, virtual network functions, etc.) operative to implement some of the features, functions, and/or benefits of some of the embodiments disclosed herein. Applications 320 are run in virtualization environment 300 which provides hardware 330 comprising processing circuitry 360 and memory 390. Memory 390 contains instructions 395 executable by processing circuitry 360 whereby application 320 is operative to provide one or more of the features, benefits, and/or functions disclosed herein.

Virtualization environment 300, comprises general-purpose or special-purpose network hardware devices 330 comprising a set of one or more processors or processing circuitry 360, which may be commercial off-the-shelf (COTS) processors, dedicated Application Specific Integrated Circuits (ASICs), or any other type of processing circuitry including digital or analog hardware components or special purpose processors. Each hardware device may comprise memory 390-1 which may be non-persistent memory for temporarily storing instructions 395 or software executed by processing circuitry 360. Each hardware device may comprise one or more network interface controllers (NICs) 370, also known as network interface cards, which include physical network interface 380. Each hardware device may also include non-transitory, persistent, machine-readable storage media 390-2 having stored therein software 395 and/or instructions executable by processing circuitry 360. Software 395 may include any type of software including software for instantiating one or more virtualization layers 350 (also referred to as hypervisors), software to execute virtual machines 340 as well as software allowing it to execute functions, features and/or benefits described in relation with some embodiments described herein.

Virtual machines 340, comprise virtual processing, virtual memory, virtual networking or interface and virtual storage, and may be run by a corresponding virtualization layer 350 or hypervisor. Different embodiments of the instance of virtual appliance 320 may be implemented on one or more of virtual machines 340, and the implementations may be made in different ways.

During operation, processing circuitry 360 executes software 395 to instantiate the hypervisor or virtualization layer 350, which may sometimes be referred to as a virtual machine monitor (VMM). Virtualization layer 350 may present a virtual operating platform that appears like networking hardware to virtual machine 340.

As shown in FIGURE 7, hardware 330 may be a standalone network node with generic or specific components. Hardware 330 may comprise antenna 3225 and may implement some functions via virtualization. Alternatively, hardware 330 may be part of a larger cluster of hardware (e.g. such as in a data center or customer premise equipment (CPE)) where many hardware nodes work together and are managed via management and orchestration (MANO) 3100, which, among others, oversees lifecycle management of applications 320.

Virtualization of the hardware is in some contexts referred to as network function virtualization (NFV). NFV may be used to consolidate many network equipment types onto industry standard high-volume server hardware, physical switches, and physical storage, which can be located in data centers, and customer premise equipment.

In the context of NFV, virtual machine 340 may be a software implementation of a physical machine that runs programs as if they were executing on a physical, non-virtualized machine. Each of virtual machines 340, and that part of hardware 330 that executes that virtual machine, be it hardware dedicated to that virtual machine and/or hardware shared by that virtual machine with others of the virtual machines 340, forms a separate virtual network elements (VNE).

Still in the context of NFV, Virtual Network Function (VNF) is responsible for handling specific network functions that run in one or more virtual machines 340 on top of hardware networking infrastructure 330 and corresponds to application 320 in Figure 18.

In some embodiments, one or more radio units 3200 that each include one or more transmitters 3220 and one or more receivers 3210 may be coupled to one or more antennas 3225. Radio units 3200 may communicate directly with hardware nodes 330 via one or more appropriate network interfaces and may be used in combination with the virtual components to provide a virtual node with radio capabilities, such as a radio access node or a base station.

In some embodiments, some signaling can be effected with the use of control system 3230 which may alternatively be used for communication between the hardware nodes 330 and radio units 3200.

With reference to FIGURE 8, in accordance with an embodiment, a communication system includes telecommunication network 410, such as a 3GPP-type cellular network, which comprises access network 411, such as a radio access network, and core network 414. Access network 411 comprises a plurality of base stations 412a, 412b, 412c, such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area 413a, 413b, 413c. Each base station 412a, 412b, 412c is connectable to core network 414 over a wired or wireless connection 415. A first UE 491 located in coverage area 413c is configured to wirelessly connect to, or be paged by, the corresponding base station 412c. A second UE 492 in coverage area 413a is wirelessly connectable to the corresponding base station 412a. While a plurality of UEs 491, 492 are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole UE is in the coverage area or where a sole UE is connecting to the corresponding base station 412.

Telecommunication network 410 is itself connected to host computer 430, which may be embodied in the hardware and/or software of a standalone server, a cloud-implemented server, a distributed server or as processing resources in a server farm. Host computer 430 may be under the ownership or control of a service provider or may be operated by the service provider or on behalf of the service provider. Connections 421 and 422 between telecommunication network 410 and host computer 430 may extend directly from core network 414 to host computer 430 or may go via an optional intermediate network 420. Intermediate network 420 may be one of, or a combination of more than one of, a public, private or hosted network; intermediate network 420, if any, may be a backbone network or the Internet; in particular, intermediate network 420 may comprise two or more sub-networks (not shown).

The communication system of FIGURE 8 as a whole enables connectivity between the connected UEs 491, 492 and host computer 430. The connectivity may be described as an over-the-top (OTT) connection 450. Host computer 430 and the connected UEs 491, 492 are configured to communicate data and/or signaling via OTT connection 450, using access network 411, core network 414, any intermediate network 420 and possible further infrastructure (not shown) as intermediaries. OTT connection 450 may be transparent in the sense that the participating communication devices through which OTT connection 450 passes are unaware of routing of uplink and downlink communications. For example, base station 412 may not or need not be informed about the past routing of an incoming downlink communication with data originating from host computer 430 to be forwarded (e.g., handed over) to a connected UE 491. Similarly, base station 412 need not be aware of the future routing of an outgoing uplink communication originating from the UE 491 towards the host computer 430.

FIGURE 9 illustrates an example host computer communicating via a base station with a user equipment over a partially wireless connection, according to certain embodiments. Example implementations, in accordance with an embodiment of the UE, base station and host computer discussed in the preceding paragraphs will now be described with reference to FIGURE 9. In communication system 500, host computer 510 comprises hardware 515 including communication interface 516 configured to set up and maintain a wired or wireless connection with an interface of a different communication device of communication system 500. Host computer 510 further comprises processing circuitry 518, which may have storage and/or processing capabilities. In particular, processing circuitry 518 may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Host computer 510 further comprises software 511, which is stored in or accessible by host computer 510 and executable by processing circuitry 518. Software 511 includes host application 512. Host application 512 may be operable to provide a service to a remote user, such as UE 530 connecting via OTT connection 550 terminating at UE 530 and host computer 510. In providing the service to the remote user, host application 512 may provide user data which is transmitted using OTT connection 550.

Communication system 500 further includes base station 520 provided in a telecommunication system and comprising hardware 525 enabling it to communicate with host computer 510 and with UE 530. Hardware 525 may include communication interface 526 for setting up and maintaining a wired or wireless connection with an interface of a different communication device of communication system 500, as well as radio interface 527 for setting up and maintaining at least wireless connection 570 with UE 530 located in a coverage area (not shown in FIGURE 9) served by base station 520. Communication interface 526 may be configured to facilitate connection 560 to host computer 510. Connection 560 may be direct, or it may pass through a core network (not shown in FIGURE 9) of the telecommunication system and/or through one or more intermediate networks outside the telecommunication system. In the embodiment shown, hardware 525 of base station 520 further includes processing circuitry 528, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Base station 520 further has software 521 stored internally or accessible via an external connection.

Communication system 500 further includes UE 530 already referred to. Its hardware 535 may include radio interface 537 configured to set up and maintain wireless connection 570 with a base station serving a coverage area in which UE 530 is currently located. Hardware 535 of UE 530 further includes processing circuitry 538, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. UE 530 further comprises software 531, which is stored in or accessible by UE 530 and executable by processing circuitry 538. Software 531 includes client application 532. Client application 532 may be operable to provide a service to a human or non-human user via UE 530, with the support of host computer 510. In host computer 510, an executing host application 512 may communicate with the executing client application 532 via OTT connection 550 terminating at UE 530 and host computer 510. In providing the service to the user, client application 532 may receive request data from host application 512 and provide user data in response to the request data. OTT connection 550 may transfer both the request data and the user data. Client application 532 may interact with the user to generate the user data that it provides.

It is noted that host computer 510, base station 520 and UE 530 illustrated in FIGURE 9 may be similar or identical to host computer 430, one of base stations 412a, 412b, 412c and one of UEs 491, 492 of FIGURE 3, respectively. This is to say, the inner workings of these entities may be as shown in FIGURE 9 and independently, the surrounding network topology may be that of FIGURE 3.

In FIGURE 9, OTT connection 550 has been drawn abstractly to illustrate the communication between host computer 510 and UE 530 via base station 520, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from UE 530 or from the service provider operating host computer 510, or both. While OTT connection 550 is active, the network infrastructure may further take decisions by which it dynamically changes the routing (e.g., based on load balancing consideration or reconfiguration of the network).

Wireless connection 570 between UE 530 and base station 520 is in accordance with the teachings of the embodiments described throughout this disclosure. One or more of the various embodiments improve the performance of OTT services provided to UE 530 using OTT connection 550, in which wireless connection 570 forms the last segment. More precisely, the teachings of these embodiments may improve the signaling overhead and reduce latency, which may provide faster internet access for users.

A measurement procedure may be provided for monitoring data rate, latency and other factors on which the one or more embodiments improve. There may further be an optional network functionality for reconfiguring OTT connection 550 between host computer 510 and UE 530, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring OTT connection 550 may be implemented in software 511 and hardware 515 of host computer 510 or in software 531 and hardware 535 of UE 530, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which OTT connection 550 passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above or supplying values of other physical quantities from which software 511, 531 may compute or estimate the monitored quantities. The reconfiguring of OTT connection 550 may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect base station 520, and it may be unknown or imperceptible to base station 520. Such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary UE signaling facilitating host computer 510's measurements of throughput, propagation times, latency and the like. The measurements may be implemented in that software 511 and 531 causes messages to be transmitted, in particular empty or 'dummy' messages, using OTT connection 550 while it monitors propagation times, errors etc.

FIGURE 10 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 8 and 9. For simplicity of the present disclosure, only drawing references to FIGURE 10 will be included in this section.

In step 610, the host computer provides user data. In substep 611 (which may be optional) of step 610, the host computer provides the user data by executing a host application. In step 620, the host computer initiates a transmission carrying the user data to the UE. In step 630 (which may be optional), the base station transmits to the UE the user data which was carried in the transmission that the host computer initiated, in accordance with the teachings of the embodiments described throughout this disclosure. In step 640 (which may also be optional), the UE executes a client application associated with the host application executed by the host computer.

FIGURE 11 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 8 and 9. For simplicity of the present disclosure, only drawing references to FIGURE 11 will be included in this section.

In step 710 of the method, the host computer provides user data. In an optional substep (not shown) the host computer provides the user data by executing a host application. In step 720, the host computer initiates a transmission carrying the user data to the UE. The transmission may pass via the base station, in accordance with the teachings of the embodiments described throughout this disclosure. In step 730 (which may be optional), the UE receives the user data carried in the transmission.

FIGURE 12 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 8 and 9. For simplicity of the present disclosure, only drawing references to FIGURE 12 will be included in this section.

In step 810 (which may be optional), the UE receives input data provided by the host computer. Additionally, or alternatively, in step 820, the UE provides user data. In substep 821 (which may be optional) of step 820, the UE provides the user data by executing a client application. In substep 811 (which may be optional) of step 810, the UE executes a client application which provides the user data in reaction to the received input data provided by the host computer. In providing the user data, the executed client application may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the UE initiates, in substep 830 (which may be optional), transmission of the user data to the host computer. In step 840 of the method, the host computer receives the user data transmitted from the UE, in accordance with the teachings of the embodiments described throughout this disclosure.

FIGURE 13 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 8 and 9. For simplicity of the present disclosure, only drawing references to FIGURE 13 will be included in this section.

In step 910 (which may be optional), in accordance with the teachings of the embodiments described throughout this disclosure, the base station receives user data from the UE. In step 920 (which may be optional), the base station initiates transmission of the received user data to the host computer. In step 930 (which may be optional), the host computer receives the user data carried in the transmission initiated by the base station.

The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

Modifications, additions, or omissions may be made to the systems and apparatuses disclosed herein without departing from the scope of the invention. The components of the systems and apparatuses may be integrated or separated. Moreover, the operations of the systems and apparatuses may be performed by more, fewer, or other components. Additionally, operations of the systems and apparatuses may be performed using any suitable logic comprising software, hardware, and/or other logic. As used in this document, "each" refers to each member of a set or each member of a subset of a set.

Modifications, additions, or omissions may be made to the methods disclosed herein without departing from the scope of the invention. The methods may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order.

The foregoing description sets forth numerous specific details. It is understood, however, that embodiments may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to obscure the understanding of this description. Those of ordinary skill in the art, with the included descriptions, will be able to implement appropriate functionality without undue experimentation.

References in the specification to "one embodiment," "an embodiment," "an example embodiment," etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to implement such feature, structure, or characteristic in connection with other embodiments, whether or not explicitly described.

Although this disclosure has been described in terms of certain embodiments, alterations and permutations of the embodiments will be apparent to those skilled in the art. Accordingly, the above description of the embodiments does not constrain this disclosure.

Other changes, substitutions, and alterations are possible without departing from the scope of this disclosure, as defined by the claims below.

At least some of the following abbreviations may be used in this disclosure. If there is an inconsistency between abbreviations, preference should be given to how it is used above. If listed multiple times below, the first listing should be preferred over any subsequent listing(s).

1x RTT	CDMA2000 1x Radio Transmission Technology
3GPP	3rd Generation Partnership Project
5G	5th Generation
ABS	Almost Blank Subframe
ARQ	Automatic Repeat Request
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BI	Backoff Indicator
BSR	Buffer Status Report
CA	Carrier Aggregation
Cat-M1	Category M1
Cat M2	Category M2
CC	Carrier Component
CCCH SDU	Common Control Channel SDU
CDMA	Code Division Multiplexing Access
CE	Coverage Enhancement
CGI	Cell Global Identifier
CIR	Channel Impulse Response
CP	Cyclic Prefix
CPICH	Common Pilot Channel
CPICH Ec/No	CPICH Received energy per chip divided by the power density in the band
CQI	Channel Quality information

C-RNTI	Cell RNTI
CSI	Channel State Information
DCCH	Dedicated Control Channel
DL	Downlink
DM	Demodulation
DMRS	Demodulation Reference Signal
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
DTCH	Dedicated Traffic Channel
DUT	Device Under Test
E-CID	Enhanced Cell-ID (positioning method)
E-SMLC	Evolved-Serving Mobile Location Centre
ECGI	Evolved CGI
eMTC	enhanced Machine-Type-Communication
eNB	E-UTRAN NodeB
ePDCCH	enhanced Physical Downlink Control Channel
E-SMLC	evolved Serving Mobile Location Center
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
FDD	Frequency Division Duplex
GERAN	GSM EDGE Radio Access Network
gNB	Base station in NR
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile communication
HARQ	Hybrid Automatic Repeat Request
HO	Handover
HSPA	High Speed Packet Access
HRPD	High Rate Packet Data
IoT	Internet of Things
LOS	Line of Sight
LPP	LTE Positioning Protocol

LTE	Long-Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Services
MBSFN	Multimedia Broadcast multicast service Single Frequency Network
MBSFN ABS	MBSFN Almost Blank Subframe
MDT	Minimization of Drive Tests
MIB	Master Information Block
MME	Mobility Management Entity
MTC	Machine Type Communication
MSC	Mobile Switching Center
NAS	Non-Access Stratum
NB-IoT	Narrowband Internet of Things
NPDCCH	Narrowband Physical Downlink Control Channel
(N)PRACH	(Narrowband) Physical Random Access Channel
NR	New Radio
OCNG	OFDMA Channel Noise Generator
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSS	Operations Support System
OTDOA	Observed Time Difference of Arrival
O&M	Operation and Maintenance
PBCH	Physical Broadcast Channel
P-CCPCH	Primary Common Control Physical Channel
PCell	Primary Cell
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDP	Profile Delay Profile
PDSCH	Physical Downlink Shared Channel

PDU	Protocol Data Unit
PGW	Packet Gateway
PHICH	Physical Hybrid-ARQ Indicator Channel
PLMN	Public Land Mobile Network
PMI	Precoder Matrix Indicator
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PRS	Positioning Reference Signal
PSS	Primary Synchronization Signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RACH	Random Access Channel
QAM	Quadrature Amplitude Modulation
RA	Random Access
RAPID	Random Access Preamble Identifier
RAN	Radio Access Network
RAR	Random Access Response
RAT	Radio Access Technology
RLM	Radio Link Management
RNC	Radio Network Controller
RNTI	Radio Network Temporary Identifier
RRC	Radio Resource Control
RRM	Radio Resource Management
RS	Reference Signal
RSCP	Received Signal Code Power
RSRP	Reference Symbol Received Power OR Reference Signal Received Power
RSRQ	Reference Signal Received Quality OR Reference Symbol Received Quality
RSSI	Received Signal Strength Indicator
RSTD	Reference Signal Time Difference
SCH	Synchronization Channel

SCell	Secondary Cell
SDU	Service Data Unit
SFN	System Frame Number
SGW	Serving Gateway
SI	System Information
SIB	System Information Block
SNR	Signal to Noise Ratio
SON	Self Optimized Network
SS	Synchronization Signal
SSS	Secondary Synchronization Signal
TBS	Transport Block Size
TDD	Time Division Duplex
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunication System
USIM	Universal Subscriber Identity Module
UTDOA	Uplink Time Difference of Arrival
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wide CDMA
WLAN	Wide Local Area Network

CLAIMS:

1. A method for early data transmission (EDT) performed by a wireless device, the method comprising:

assembling (512) a random access message 3 that includes uplink data for random access EDT;

transmitting (514) the random access message 3 to a network node;

receiving (516) a random access message 4 from the network node;

determining (518) whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3; and

upon determining the random access message 4 includes a successful integrity check, discarding (520) transmission protocol information corresponding to the uplink data in random access message 3.

2. The method of claim 1, further comprising, upon determining the random access message 4 does not indicate a successful integrity check, preserving (522) transmission protocol information corresponding to the uplink data in random access message 3 for use in a future transmission.

3. The method of any one of claims 1-2, wherein the transmission protocol information comprises packet data convergence protocol (PDCP) information.

4. The method of any one of claims 1-3, wherein the transmission protocol information comprises layer 2 (L2) data corresponding to the uplink data in random access message 3.

5. The method of any one of claims 1-4, wherein the uplink data in random access message 3 comprises a data radio bearer (DRB) service data unit (SDU) and the

method further comprises disabling polling for a radio link control (RLC) status report associated with the DRB SDU.

6. The method of any one of claims 1-5, wherein the random access message 4 includes a radio resource control (RRC) message.

7. The method of any one of claims 1-6, wherein determining whether the random access message 4 includes a successful integrity check comprises a packet data convergence protocol (PDCP) entity receiving an integrity check indication on a signaling radio bearer, and the method further comprises communicating the integrity check indication to a PDCP entity associated with a radio bearer associated with the uplink data in the random access message 3.

8. The method of claim 7, wherein the PDCP entity associated with the radio bearer associated with the uplink data in the random access message 3 starts a PDCP service data unit (SDU) discard timer after determining whether the random access message 4 includes a successful integrity check.

9. The method of any one of claims 1-8, wherein determining whether the random access message 4 includes a successful integrity check comprises a packet data convergence protocol (PDCP) entity receiving an integrity check indication on a signaling radio bearer, and the method further comprises communicating the integrity check indication to a radio link control (RLC) entity associated with the uplink data transmitted in the random access message 3.

10. The method of any one of claims 1-9, wherein the uplink data comprises one of user data and signaling data.

11. A wireless device (110) capable of early data transmission (EDT), the wireless device comprising processing circuitry (120) operable to:

assemble a random access message 3 that includes uplink data for random access EDT;

transmit the random access message 3 to a network node;

receive a random access message 4 from the network node;

determine whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3; and

upon determining the random access message 4 includes a successful integrity check, discard transmission protocol information corresponding to the uplink data in random access message 3.

12. The wireless device of claim 11, the processing circuitry further operable to, upon determining the random access message 4 does not indicate a successful integrity check, preserve transmission protocol information corresponding to the uplink data in random access message 3 for use in a future transmission.

13. The wireless device of any one of claims 111-2, wherein the transmission protocol information comprises packet data convergence protocol (PDCP) information.

14. The wireless device of any one of claims 11-13, wherein the transmission protocol information comprises layer 2 (L2) data corresponding to the uplink data in random access message 3.

15. The wireless device of any one of claims 11-14, wherein the uplink data in random access message 3 comprises a data radio bearer (DRB) service data unit (SDU) and the processing circuitry is further operable to disable polling for a radio link control (RLC) status report associated with the DRB SDU.

16. The wireless device of any one of claims 11-15, wherein the random access message 4 includes a radio resource control (RRC) message.

17. The wireless device of any one of claims 11-16, wherein the processing circuitry is operable to determine whether the random access message 4 includes a successful integrity check by a packet data convergence protocol (PDCP) entity receiving an integrity check indication on a signaling radio bearer, and the processing circuitry is further operable to communicate the integrity check indication to a PDCP entity associated with a radio bearer associated with the uplink data in the random access message 3.

18. The wireless device of claim 17, wherein the PDCP entity associated with the radio bearer associated with the uplink data in the random access message 3 starts a PDCP service data unit (SDU) discard timer after determining whether the random access message 4 includes a successful integrity check.

19. The wireless device of any one of claims 11-18, wherein the processing circuitry is operable to determine whether the random access message 4 includes a successful integrity check by a packet data convergence protocol (PDCP) entity receiving an integrity check indication on a signaling radio bearer, and the processing circuitry is further operable to communicate the integrity check indication to a radio link control (RLC) entity associated with the uplink data transmitted in the random access message 3.

20. The wireless device of any one of claims 11-19, wherein the uplink data comprises one of user data and signaling data.

21. A wireless device (110) capable of early data transmission (EDT), the wireless device comprising a transmitting module (1602), a receiving module (1604), and a determining module (1606);

the transmitting module operable to:

assemble a random access message 3 that includes uplink data for random access EDT;

transmit the random access message 3 to a network node;

the receiving module operable to receive a random access message 4 from the network node;

the determining module operable to:

determine whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3; and

upon determining the random access message 4 includes a successful integrity check, discard transmission protocol information corresponding to the uplink data in random access message 3.

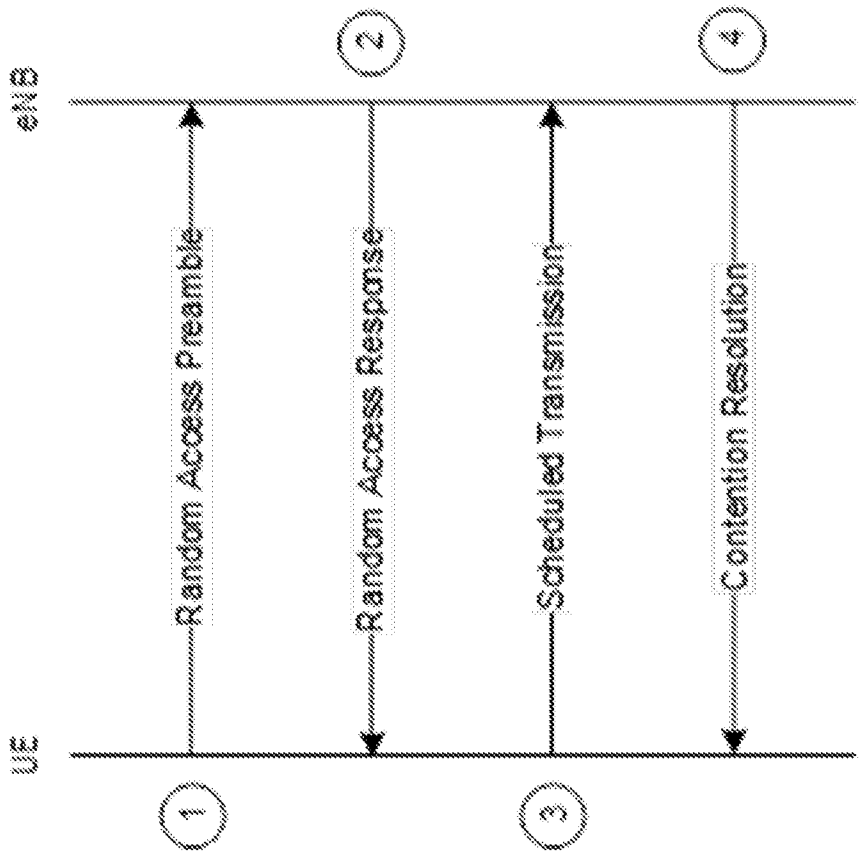

UE
eNB
1
2
3
4
Random Access Preamble
Random Access Response
Scheduled Transmission
Contention Resolution

Fig. 1

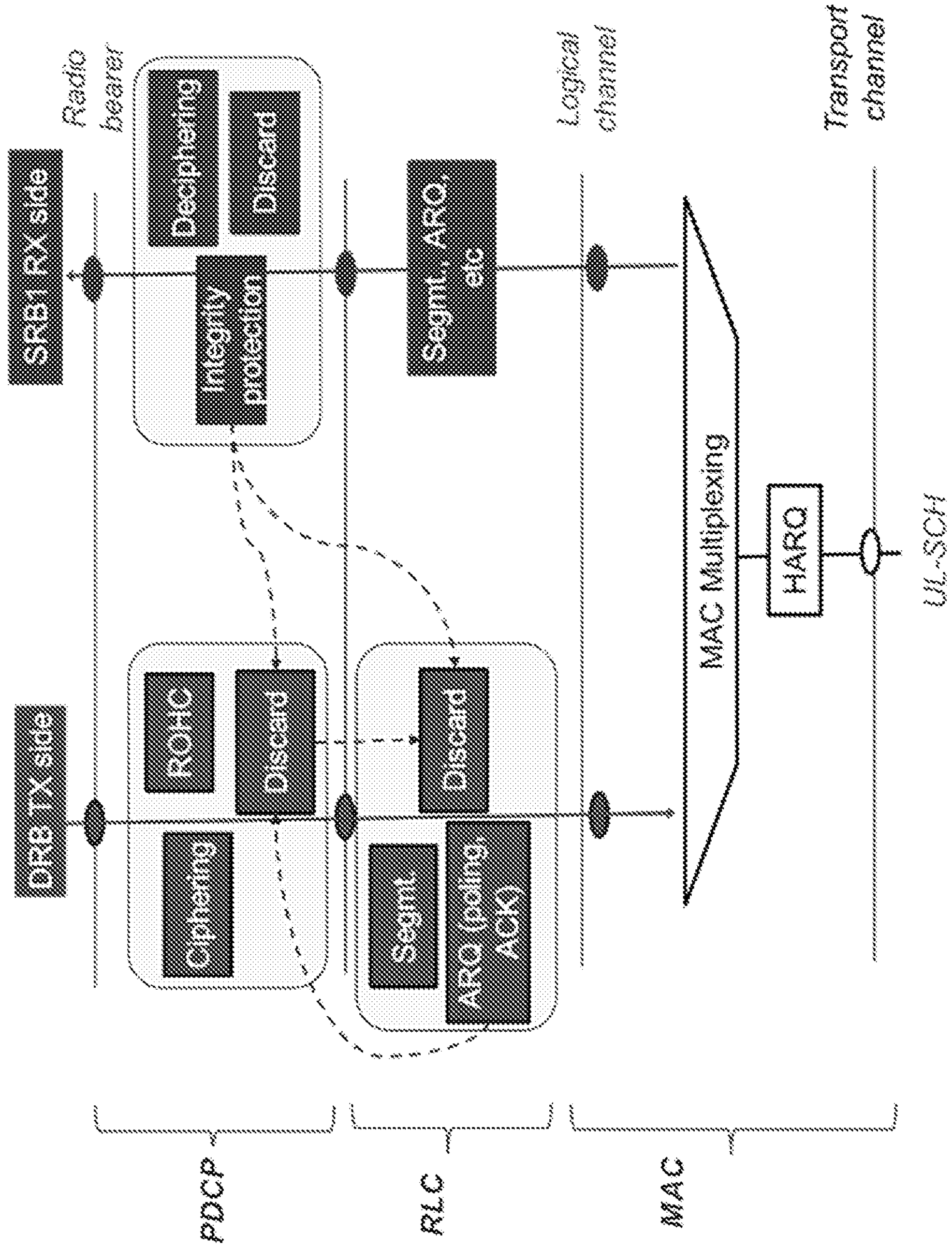
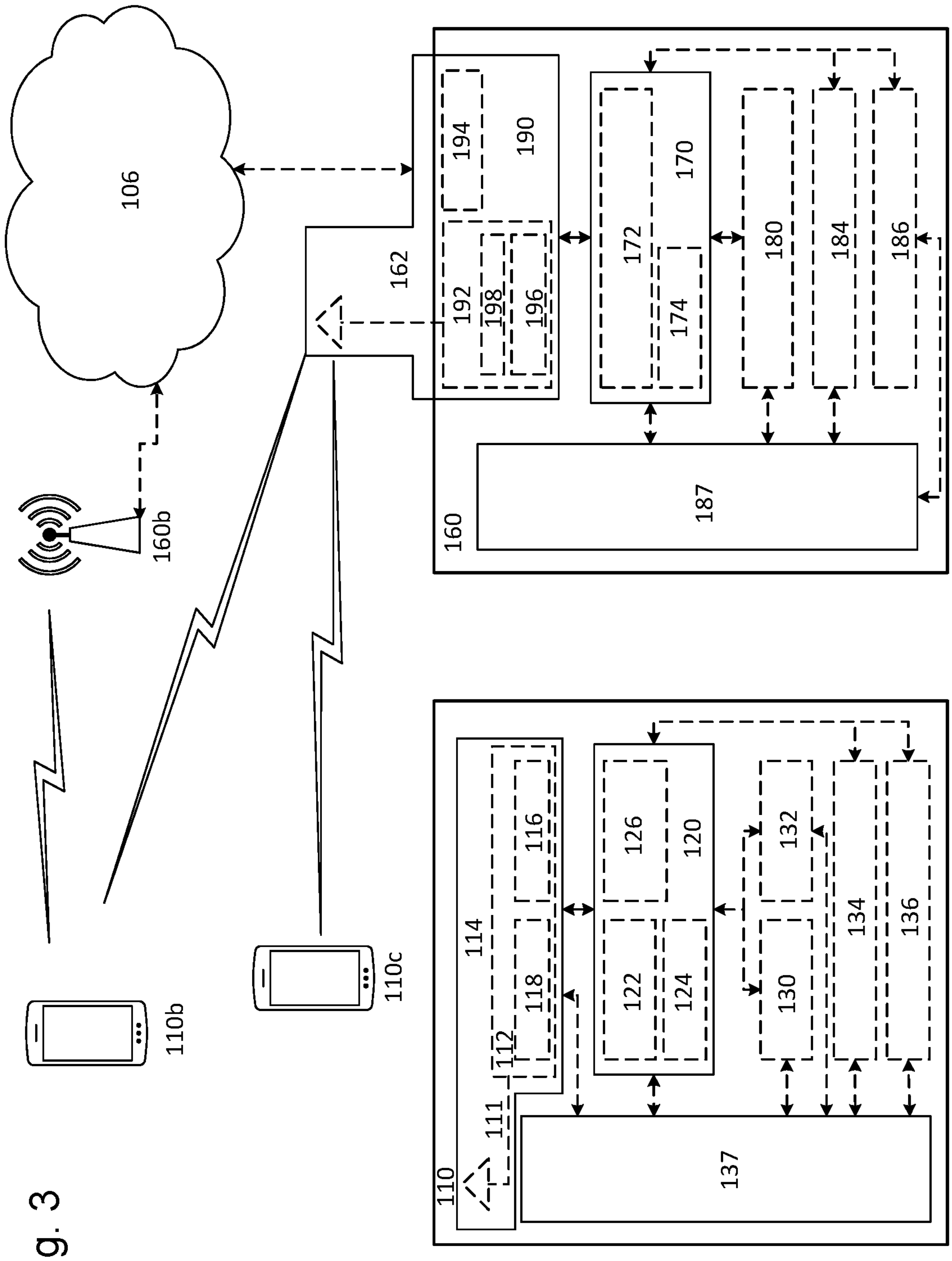

DRB TX side
SRB1 RX side
Radio bearer
Ciphering
ROHC
Discard
Integrity protection
Deciphering
Discard
Segmt
ARQ (poling, ACK)
Discard
Segmt, ARQ, etc
Logical channel
MAC Multiplexing
HARQ
Transport channel
UL-SCH
PDCP
RLC
MAC

Fig. 2


106
160b
110b
110c
162
190
194
192
198
196
170
172
174
180
184
186
187
160
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111
112
114
116
118
120
122
124
126
130
132
134
136
137

Fig. 3

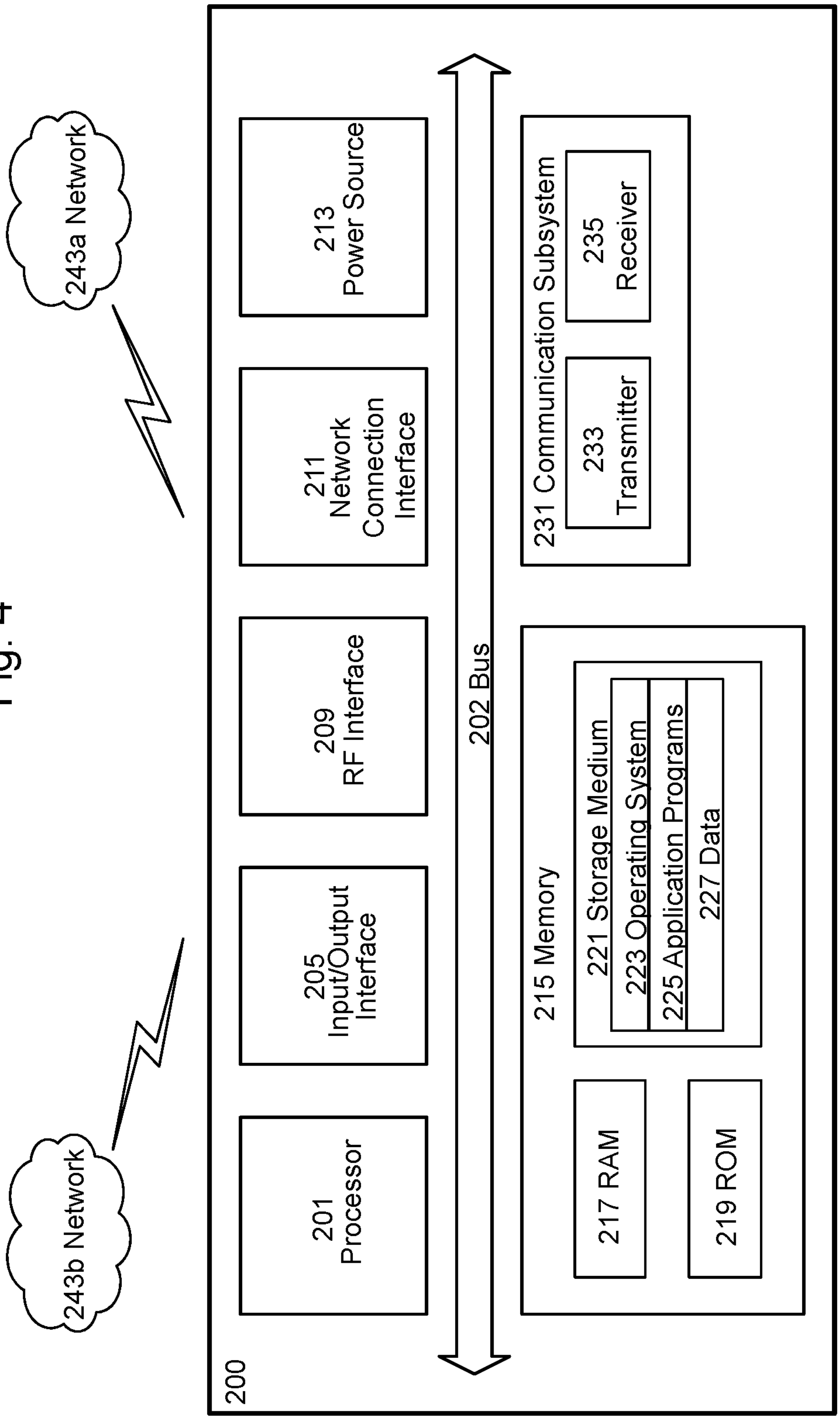
243a Network
243b Network
200
201 Processor
205 Input/Output Interface
209 RF Interface
211 Network Connection Interface
213 Power Source
202 Bus
215 Memory
217 RAM
219 ROM
221 Storage Medium
223 Operating System
225 Application Programs
227 Data
231 Communication Subsystem
233 Transmitter
235 Receiver

Fig. 4

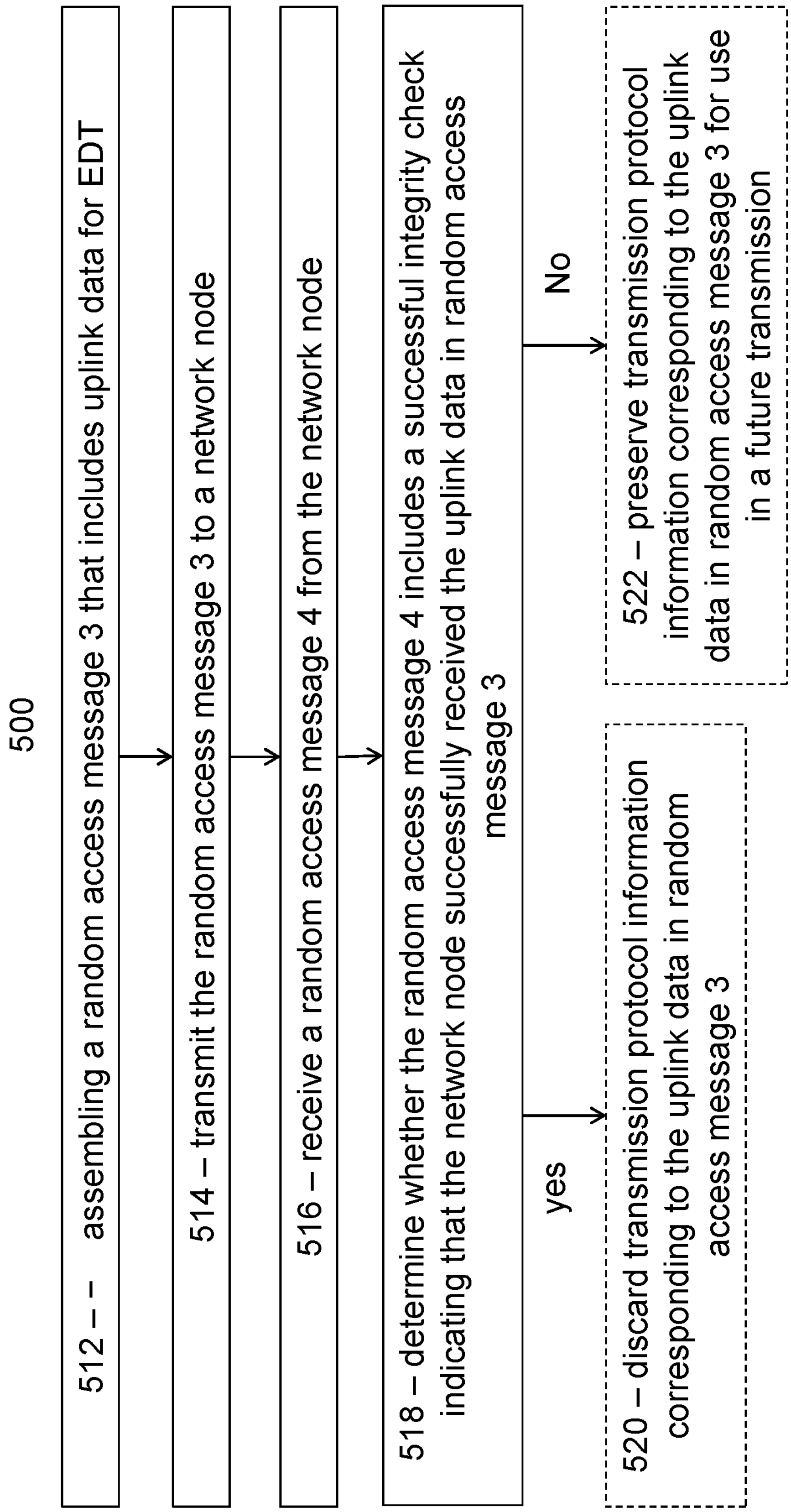
500
512 – – assembling a random access message 3 that includes uplink data for EDT
514 – transmit the random access message 3 to a network node
516 – receive a random access message 4 from the network node
518 – determine whether the random access message 4 includes a successful integrity check indicating that the network node successfully received the uplink data in random access message 3
yes
No
520 – discard transmission protocol information corresponding to the uplink data in random access message 3
522 – preserve transmission protocol information corresponding to the uplink data in random access message 3 for use in a future transmission

Fig. 5

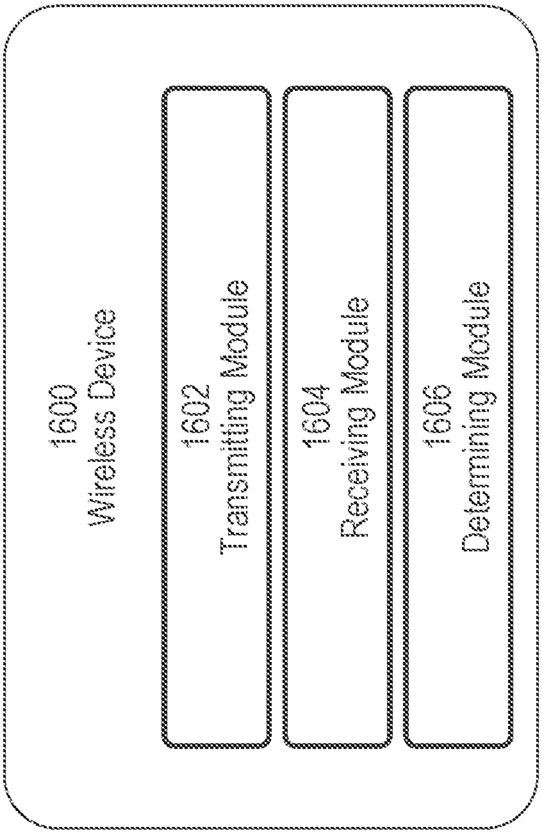
1600
Wireless Device
1602
Transmitting Module
1604
Receiving Module
1606
Determining Module

Fig. 6

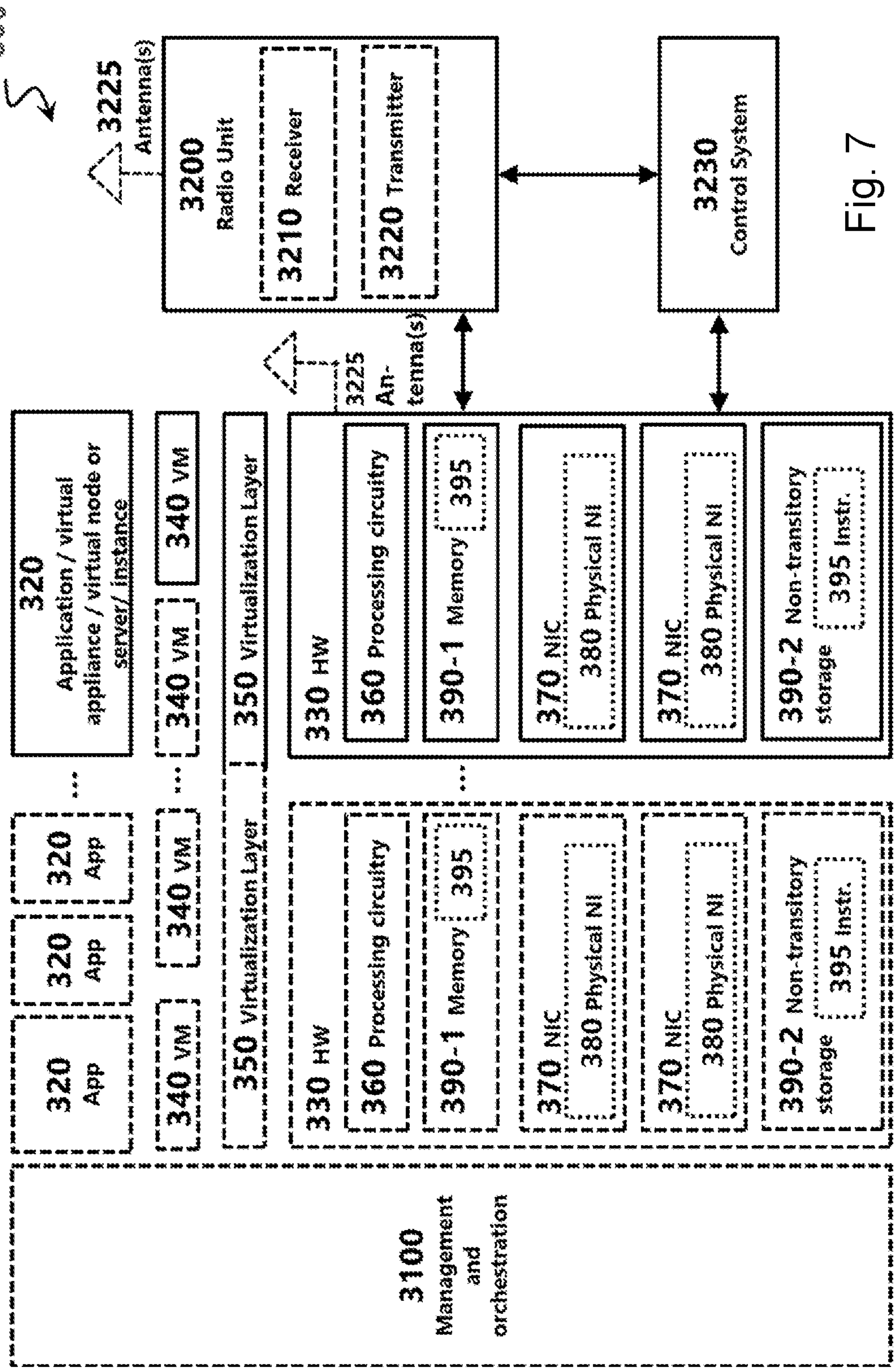
300
3225 Antenna(s)
3200 Radio Unit
3210 Receiver
3220 Transmitter
3230 Control System
3225 Antenna(s)
320 Application / virtual appliance / virtual node or server/ instance
340 VM
340 VM
350 Virtualization Layer
330 HW
360 Processing circuitry
390-1 Memory
395
370 NIC
380 Physical NI
370 NIC
380 Physical NI
390-2 Non-transitory storage
395 Instr.
320 App
320 App
320 App
340 VM
340 VM
350 Virtualization Layer
330 HW
360 Processing circuitry
390-1 Memory
395
370 NIC
380 Physical NI
370 NIC
380 Physical NI
390-2 Non-transitory storage
395 Instr.
3100 Management and orchestration

Fig. 7

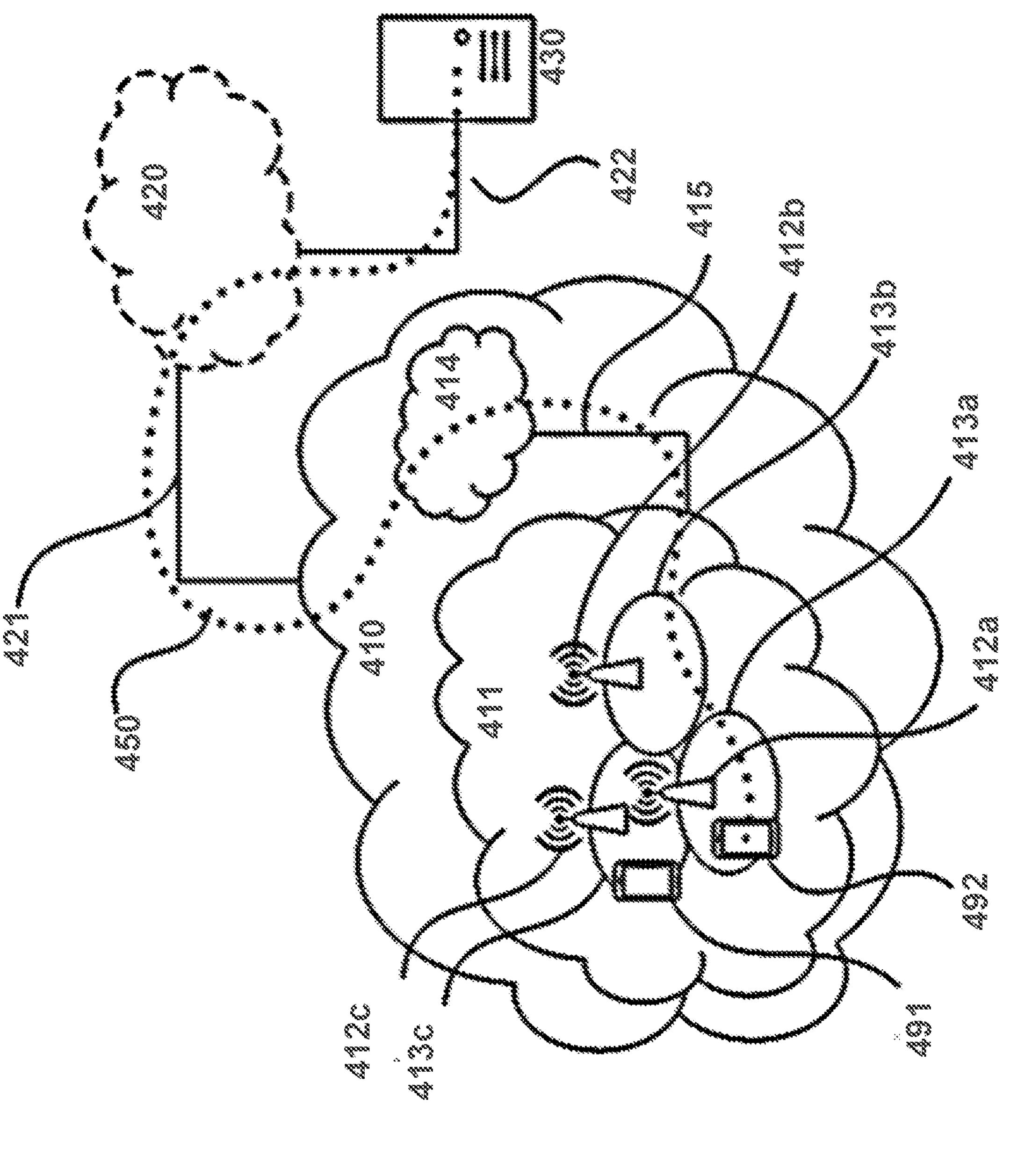
420
430
422
415
412b
413b
413a
412a
492
491
413c
412c
450
421
410
411
414

Fig. 8

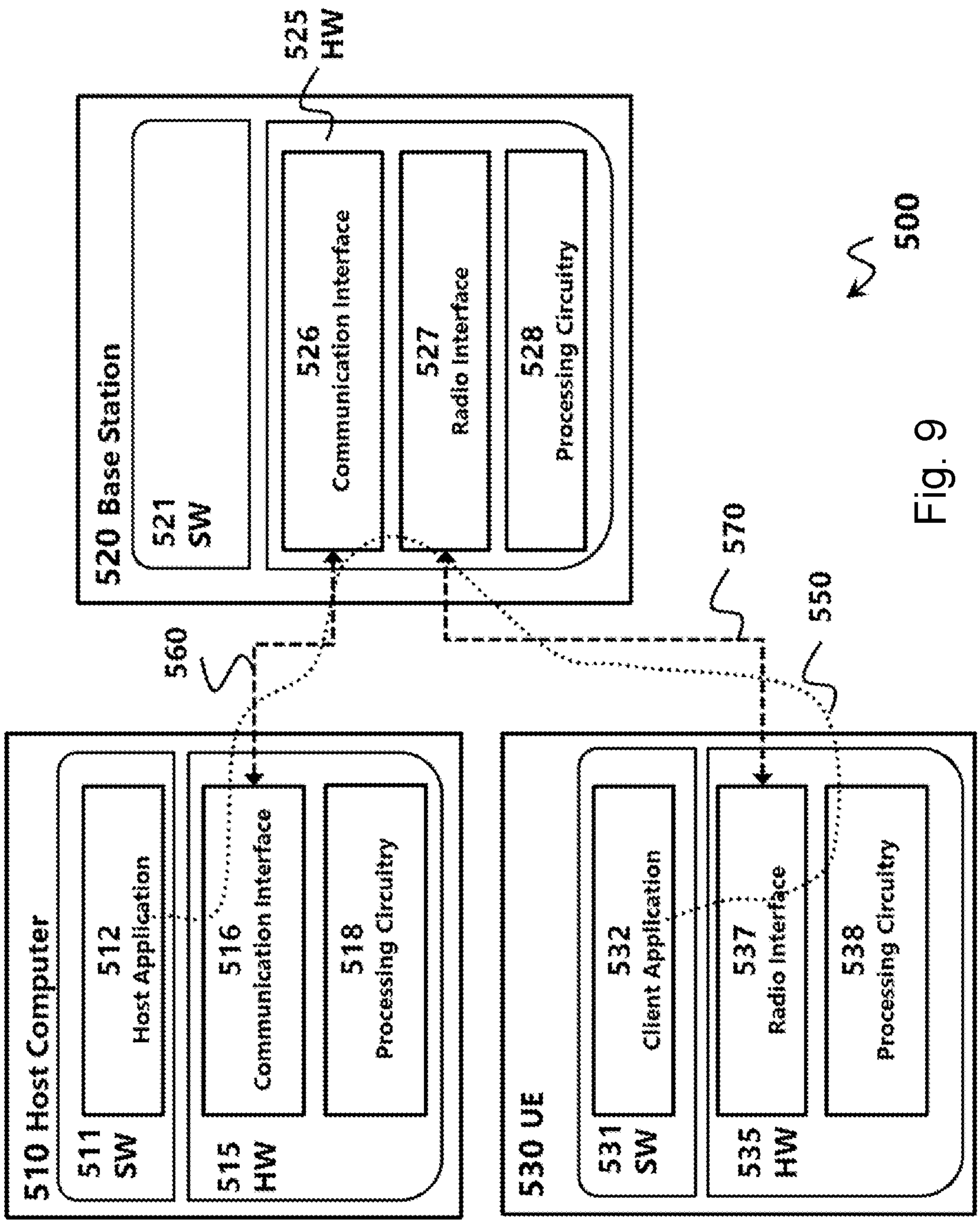
510 Host Computer
511 SW
512 Host Application
515 HW
516 Communication Interface
518 Processing Circuitry
520 Base Station
521 SW
525 HW
526 Communication Interface
527 Radio Interface
528 Processing Circuitry
530 UE
531 SW
532 Client Application
535 HW
537 Radio Interface
538 Processing Circuitry
560
570
550
500

Fig. 9

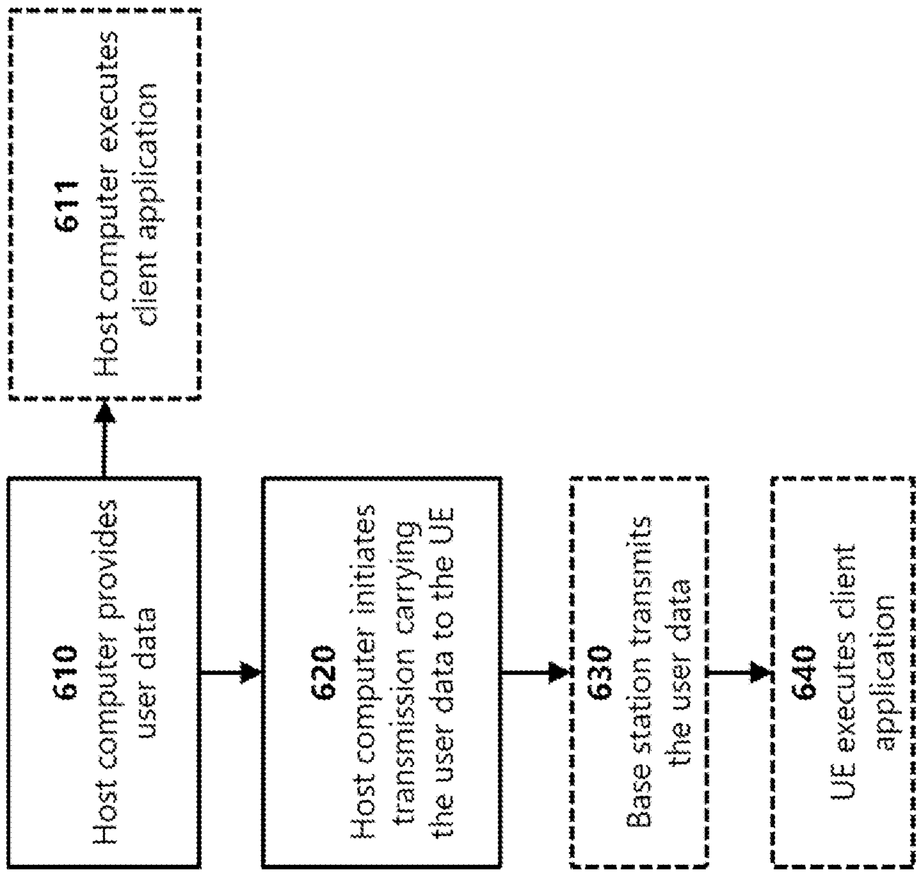
610
Host computer provides user data
611
Host computer executes client application
620
Host computer initiates transmission carrying the user data to the UE
630
Base station transmits the user data
640
UE executes client application

Fig. 10

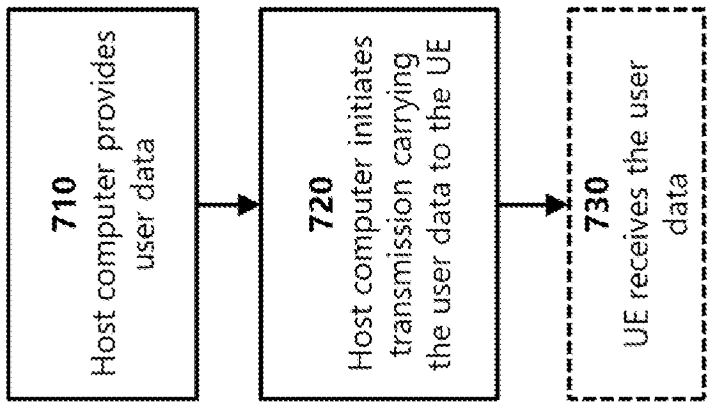
710
Host computer provides user data
720
Host computer initiates transmission carrying the user data to the UE
730
UE receives the user data

Fig. 11

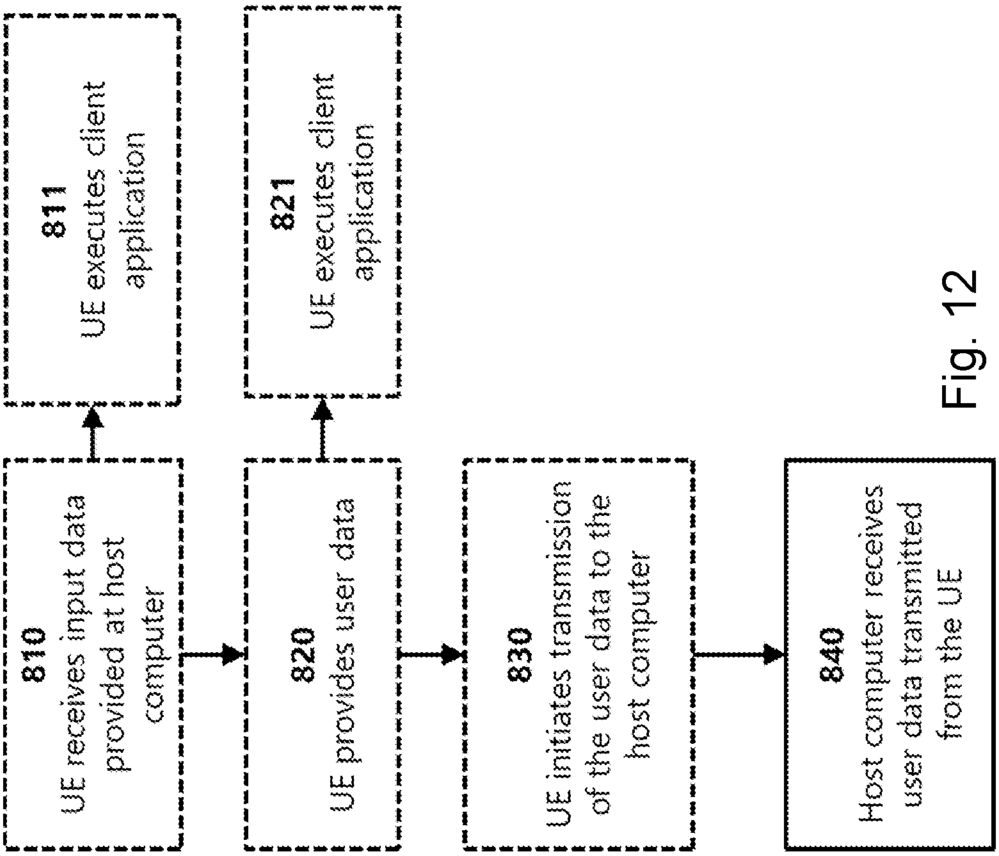
810
UE receives input data provided at host computer
811
UE executes client application
820
UE provides user data
821
UE executes client application
830
UE initiates transmission of the user data to the host computer
840
Host computer receives user data transmitted from the UE

Fig. 12

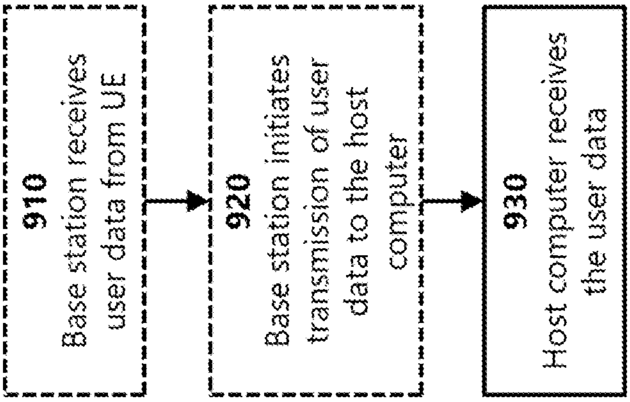
910
Base station receives user data from UE
920
Base station initiates transmission of user data to the host computer
930
Host computer receives the user data

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/058189

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W74/08
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W

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

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	the whole document	8,18
A		5,15

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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	Date of mailing of the international search report
22 November 2019	29/11/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Heinrich, Dietmar

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/058189

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	the whole document	8,18
A		5,15
Y	US 2017/237837 A1 (SAMMOUR MOHAMMED [JO] ET AL) 17 August 2017 (2017-08-17)	8,18
A	paragraph [0003] - paragraph [0048] paragraph [0070] - paragraph [0071]	1-7, 9-17, 19-21
E	WO 2019/184483 A1 (SHARP KK [JP]; CHANG NINGJUAN [CN]) 3 October 2019 (2019-10-03) paragraph [0036] paragraph [0042] paragraph [0056] paragraph [0062] paragraph [0067] - paragraph [0078] abstract	1-4,6, 9-14,16, 19-21

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Information on patent family members

International application No
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