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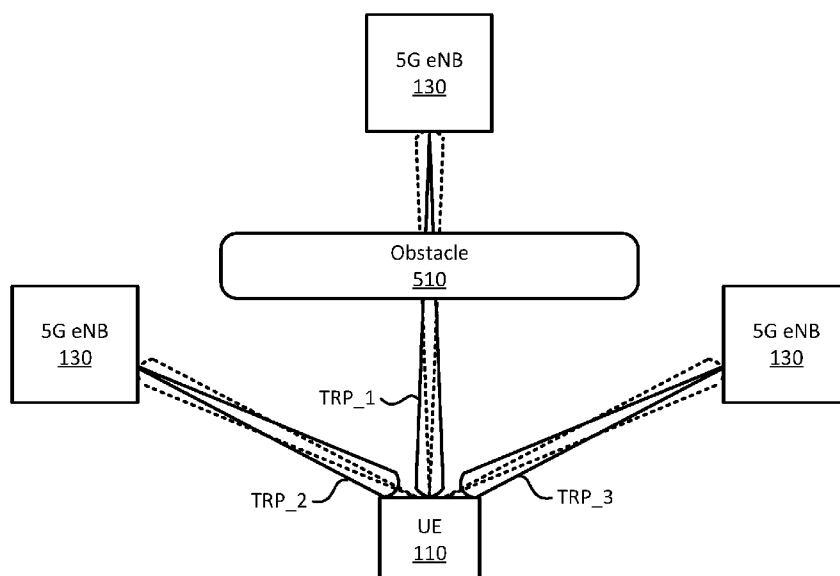
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**Fig. 5**

(57) **Abstract:** A User Equipment (UE) may use beamforming technologies to communicate with a base station of a wireless telecommunication network. The UE may monitor a quality of the signals between the UE and the network in order to determine if/when signal degradation has occurred. The UE may analyze the signal in order to determine a reason for the signal degradation. For instance, the UE may determine whether the signal degradation was due to a physical rotation of the UE, an object moving in between the UE and the base station, the UE moving from one location to another, etc. Additionally, the UE may perform one or more of a variety of signal recovery operations in order to recover from the signal degradation, such as updating the direction of the signal, engaging in a handover procedure involving a more appropriate base station, etc.



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## SIGNAL DEGRADATION DETECTION AND RECOVERY

RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Patent Application No. 62/374,637, which was filed on August 12, 2016, the contents of which are hereby incorporated  
5 by reference as though fully set forth herein.

BACKGROUND

Wireless telecommunication networks often include a Core Network (CN) that is connected to Radio Access Networks (RANs) that may include one or more base stations. The RANs may enable User Equipment (UE), such as smartphones, tablet computers, laptop  
10 computers, etc., to obtain wireless services by connecting to the CN. An example of a wireless telecommunication network may include an Evolved Packet System (EPS) that operates based on the 3rd Generation Partnership Project (3GPP) Communication Standards.

An EPS may include an Evolved Packet Core (EPC) network that is connected to one or more Long-Term Evolution (LTE) RANs (e.g., Evolved Universal Mobile Telecommunication  
15 System (UMTS) Terrestrial Radio Access Networks (E-UTRANs)). Each LTE RAN may include one or more base stations some, or all of which, may take the form of enhanced Node Bs (eNBs). UEs may communicate with the EPC network via the LTE RANs. LTE RANs and EPCs are often referred to as 4th Generation (4G) networks of the 3GPP Communication Standards.

20 5<sup>th</sup> Generation (5G) technologies, for wireless telecommunications, are currently under consideration and development. An objective of 5G technologies is to increase the overall wireless data rates that may exist between base stations and UEs. A technique for doing so, that is currently under considerations, is beamforming (BF), whereby a base station and a UE may establish a direction-specific connection with one another. As such, UEs at different locations,  
25 with respect to a particular base station, may use the same, or similar resources (e.g., Radio Frequency (RF) channel, numerology, etc.) for connecting to, and communicating with, the base station.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 1 is a diagram of an example system in which systems and/or methods described herein may be implemented;

Fig. 2 is a diagram of an example of a Core Network (CN);

Fig. 3 is a diagram of an example process for detecting and recovering from signal degradation;

Fig. 4 is a diagram of an example of signal degradation due to blockage;

5 Fig. 5 is a diagram of an example for detecting blockage as a source of signal degradation;

Fig. 6 is a graph of an example of data throughput for a 5<sup>th</sup> Generation (5G) beamforming (BF) connection experiencing blockage;

10 Fig. 7 is a diagram of an example of signal degradation due to User Equipment (UE) rotation;

Fig. 8 is a diagram of another example of signal degradation due to UE rotation;

Fig. 9 is a diagram of an example of signal degradation due to UE movement;

Fig. 10 is a signal diagram illustrating Radio Resource Control (RRC) signaling for an example setup procedure; and

15 Fig. 11 illustrates, for one embodiment, example components of an electronic device; and

Fig. 12 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

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

The techniques described herein may be used to detect and recover from signal degradation in a wireless telecommunication network that is implementing beamforming (BF) between User Equipment (UE) and base stations. For example, a UE may use BF to establish a connection with a base station of a wireless telecommunication network. The UE may monitor the quality of the signals between the UE and the base station. The UE may detect an unacceptable level of signal degradation with respect to the connection. In response, the UE may perform one or more procedures to determine the reason for, and recover from, the signal degradation. For example, the UE may determine whether the signal degradation was due to an

obstruction (e.g., a car, a bus, or another type of physical barrier) between the UE and the base station, a rotation of the UE (such that the direction of the BF signal from the UE is pointed in different direction than toward the base station), or a change in a geographic location of the UE (e.g., the UE moving without reorientation of the direction of the BF signal from the UE to the base station). In response to determining the reason for the signal degradation, the UE may implement a signal recovery procedure to ensure that the UE may continue communicating with the network (which may include the serving base station or another base station (when appropriate)).

Fig. 1 is a diagram of an example system 100 in which systems and/or methods described herein may be implemented. As shown, system 100 may include a telecommunication network that includes different types of RANs (e.g., 4G RANs, 5G RANs, etc.) that are connected to one or more Core Networks (CNs) 130. The RANs may include one or more LTE eNBs 120 and one or more 5G eNBs 130 (referred to collectively as eNBs 120 and 130), which may enable UEs 110 to connect to one or more of the CNs. In some implementations, eNBs 130 (and UEs 110) may implement BF technology that enables a direction-specific connection (referred to herein as a 5G BF connection, a 5G connection, or a BF connection) to be established between eNB 130 and UE 110. By contrast, 4G eNBs 120 may, for example, establish connections to UEs 110 in accordance with Long-Term Evolution (LTE) technologies as provided by the 3<sup>rd</sup> Generation Partnership Project (3GPP) Communication Standards.

CNs 140 may include a 4<sup>th</sup> Generation (4G) CN (e.g., an Evolved Packet Core (EPC)), a 5G CN (e.g., a CN capable of supporting 5G technologies), an Internet-of-Things (IoT) CN (e.g., a CN dedicated to supporting IoT devices), etc. In some implementations, the telecommunication network may include a single CN that is capable of supporting 4G, 5G, and IoT services. While some of the techniques described herein may be primarily implemented by 5G eNBs 130 and/or UEs 110, depending on the implementations, CNs 140 (and the devices implemented therein) may be used to support, participate, and/or otherwise enable one or more of the techniques described herein. A detailed example of the functions and devices that may be included in CN 140 is described below with reference to Fig. 2.

UE 110 may include a portable computing and communication device, such as a personal digital assistant (PDA), a smartphone, a cellular phone, a laptop computer with connectivity to the wireless telecommunications network, a tablet computer, etc. UE 110 may also include a computing and communication device that may be worn by a user (also referred to as a wearable device) such as a watch, a fitness band, a necklace, glasses, an eyeglass, a ring, a belt, a headset, or another type of wearable device. In some implementations, UE 110 may include a communication device installed in another mobile device, such as a vehicle, a robot, etc. In

some implementations, UE 110 may also include an IoT device, an example of which may include an electronic appliance, a utilities meter, a vending machine, etc. UE 110 may establish a connection with LTE eNB 120 and/or 5G eNB 130. In addition, UE 110 may communicate and otherwise cooperate with 5G eNB 130 to help detect signal degradations between UE 110 and 5G eNB 130 and/or recover from said signal degradations.

eNBs 120 and 130 may include one or more network devices that receives, processes, and/or transmits traffic destined for and/or received from UE 110 via an air interface. eNBs 120 and 130 may be connected to a network device, such as a site router, that functions as an intermediary for information communicated between eNBs 120 and 130, and CN 140. LTE eNBs 120 may implement 4G technologies for connecting and providing services to UEs 110. Such connections may utilize 4G radio resources as defined by the 3GPP Communications Standards. 5G eNBs 130 may implement 5G technologies for connecting and providing services to UEs 110. 4G technologies and 5G technologies, as described herein, may include connections that use different Radio Frequency (RF) channels, numerologies (e.g., frame sizes and times slots, etc.). As a particular example, 4G technologies implemented by 4G eNBs 120 may not include BF capabilities; whereas 5G technologies implemented by 5G eNBs 130 may include BF capabilities.

As such, 5G eNBs 130 may include signal degradation detection and recovery (SDDR) unit 140. In some implementations, each 5G eNB 130 may include a SDDR unit 140, while in other implementations a single SDDR unit 140 may be provided for multiple 5G eNBs 130. SDDR unit 140 may be an internal component of 5G eNB 130, while in other implementations, SDDR unit 140 may be implemented by an external device (e.g., a server device) connected to one or more 5G eNBs 130. SDDR unit 140 may perform one or more of the techniques described herein, such as detecting signal degradation between 5G eNB 130 and UE 110, determining the reason for the signal degradation (e.g., an obstruction, UE rotation, UE movement, etc.), and recovering the signal between the network and UE 110. SDDR unit 140 may be implemented in many different forms of software, firmware, and hardware. For example, SDDR unit 140 may be implemented as a non-transitory computer-readable medium containing program instructions for causing one or more processors of eNB 130 to perform operations, processes, etc., as described herein. The actual software code and/or hardware used to implement aspects of SDDR unit 140 should not be construed as limiting.

Fig. 2 is a diagram of an example of a CN. As shown, the CN may include an Evolved Packet Core (EPC) (labeled as "Core Network" in Fig. 2) that includes Serving Gateway (SGW) 210, PDN Gateway (PGW) 220, Mobility Management Entity (MME) 230, Home Subscriber Server (HSS) 240, and/or Policy and Charging Rules Function (PCRF) 250. The CN may be

connected to 4G RANs (e.g., LTE RANs) and 5G RANs (as shown in Fig. 1). The CN may also be connected to an external network, such as a Public Land Mobile Networks (PLMN), a Public Switched Telephone Network (PSTN), and/or an Internet Protocol (IP) network (e.g., the Internet).

5 SGW 210 may aggregate traffic received from one or more eNBs and may send the aggregated traffic to the external network or device via PGW 220. Additionally, SGW 210 may aggregate traffic received from one or more PGWs 220 and may send the aggregated traffic to one or more eNBs. SGW 210 may operate as an anchor for the user plane during inter-eNB handovers and as an anchor for mobility between different telecommunication networks.

10 PGW 220 may include one or more network devices that may aggregate traffic received from one or more SGWs 210, and may send the aggregated traffic to an external network. PGW 220 may also, or alternatively, receive traffic from the external network and may send the traffic toward UE 110 (via SGW 140 and/or eNBs 120 and 130). PGW 220 may be responsible for providing charging data for each communication session to PCRF 240 to help ensure that  
15 charging policies are properly applied to communication sessions with the wireless telecommunication network.

MME 230 may include one or more computation and communication devices that act as a control node for eNBs 120 and 130, and/or other devices that provide the air interface for the wireless telecommunications network. For example, MME 230 may perform operations to  
20 register UE 110 with the wireless telecommunications network, to establish bearer channels (e.g., traffic flows) associated with a session with UE 110, to hand off UE 110 to a different eNB, MME, or another network, and/or to perform other operations. MME 230 may perform policing operations on traffic destined for and/or received from UE 110.

HSS 240 may include one or more devices that may manage, update, and/or store, in a  
25 memory associated with HSS 240, profile information associated with a subscriber (e.g., a subscriber associated with UE 110). The profile information may identify applications and/or services that are permitted for and/or accessible by the subscriber; a Mobile Directory Number (MDN) associated with the subscriber; bandwidth or data rate thresholds associated with the applications and/or services; and/or other information. The subscriber may be associated with  
30 UE 110. Additionally, or alternatively, HSS 240 may perform authentication, authorization, and/or accounting operations associated with the subscriber and/or a communication session with UE 110.

PCRF 250 may receive information regarding policies and/or subscriptions from one or more sources, such as subscriber databases and/or from one or more users. PCRF 250 may  
35 provide these policies to PGW 220 or another device so that the policies can be enforced. As

depicted, in some embodiments, PCRF 250 may communicate with PGW 220 to ensure that charging policies are properly applied to locally routed sessions within the telecommunications network. For instance, after a locally routed session is terminated, PGW 220 may collect charging information regarding the session and provide the charging information to PCRF 250 for enforcement.

The quantity of devices and/or networks, illustrated in Figs. 1 and 2, is provided for explanatory purposes only. In practice, there may be additional devices and/or networks; fewer devices and/or networks; different devices and/or networks; or differently arranged devices and/or networks than illustrated in Figs. 1 and 2. Alternatively, or additionally, one or more of the devices of Figs. 1 and 2 may perform one or more functions described as being performed by another one or more of the devices of Figs. 1 and 2. Furthermore, while "direct" connections are shown in Figs. 1 and 2, these connections should be interpreted as logical communication pathways, and in practice, one or more intervening devices (e.g., routers, gateways, modems, switches, hubs, etc.) may be present.

Fig. 3 is a diagram of an example process 300 for detecting and recovering from signal degradation. Process 300 may be implemented by UE 110. In some implementations, one or more of the operations of process 300 may be implemented by another device, such as 5G eNB 130. Fig. 3 is described below with references to Figs. 4-9.

As shown, process 300 may include establishing a 5G BF connection with 5G eNB 130 (block 310). For example, UE 110 may establish a connection with UE 110 using 5G technologies, which may include BF technologies (in addition to RF channels numerologies, etc., that are specified by the 3GPP for 5G connections). Due to the nature of BF technologies, the connection between 5G eNB 130 and UE 110 may be such that the connection is specific to the locations of UE 110 and 5G eNB 130, and the orientation/configuration of the antennas of UE 110 and 5G eNB 130.

Process 300 may also include detecting signal degradation corresponding to the connection with 5G eNB 130 (block 320). For instance, 5G eNB 130 may monitor a quality, strength, etc., of a connection (and/or signal) between 5G eNB 130 and UE 110. If/when the signal from 5G eNB 130 drops below a particular degree, level, percentage, amount, threshold, etc., UE 110 may determine that the signal has experienced a signal degradation to an unacceptable degree.

Process 300 may also include determining a reason for the signal degradation (block 330). For example, UE 110 130 may analyze the communications to/from 5G eNB 130 in order to determine a reason for the signal degradation detected. As described below, UE 110 may determine that the signal degradation is due to signal blockage, UE rotation, and/or UE mobility.



Fig. 4 is a diagram of an example of signal degradation due to blockage. As shown, a connection between 5G eNB 130 and UE 110 may include BF signals to and from each of 5G eNB 130 and UE 110. However, due to the directionally specific nature of a BF connection, an obstacle (e.g., a vehicle, wall, building, hill, etc.) may obstruct or otherwise interfere with the BF connection between 5G eNB 130 and UE 110. Such an obstruction may cause a reduction (or degradation) of the signal quality between 5G eNB 130 and UE 110. As described in further detail below, if/when UE 110 is not moving and/or the signal degradation extends beyond a pre-designated duration, UE 110 may conclude that the signal degradation is due to a blockage.

Fig. 5 is a diagram of an example for detecting blockage as a source of signal degradation. For example, UE 110 may maintain measurements for multiple Transmission Reception Points (TRPs) (e.g., TRP\_1, TRP\_2, and TRP\_3), where each eNB may implement one or more TRPs. Examples of such measurements may include a Signal-to-Noise Ratio (SNR), a strength or quality of a reference signal (e.g., Reference Signal Receive Power (RSRP), Reference Signal Received Quality (RSRQ), etc.), a packet loss rate, an estimated data rate, etc., for Transmissions (Tx), Receptions (Rx), and/or Tx Rx pairs for each TRP. As such, when UE 110 detects signal degradation corresponding to a serving TRP (e.g., TRP\_1, the TRP through which UE 110 may attach to the network), UE 110 may determine whether the signal degradation is due to blockage (e.g., obstacle 510) by taking measurements for the serving TRP (e.g., TRP\_1) and comparing the measurements to the measurements of other TRPs (e.g., TRP\_2 and/or TRP\_3) maintained by UE 110. If the difference between the respective TRP measurements exceeds a pre-selected (or pre-designated) threshold, UE 110 may determine that the signal degradation of the serving 5G eNB 130 is due to blockage.

Fig. 6 is a graph of an example of data throughput for a 5G BF connection experiencing blockage. A horizontal axis of the table may be directed to time, while a vertical axis of the table may be directed to throughput measured as bits per second. The table may correspond to an example of downloading a 100-megabit (MB) file over File Transport Protocol (FTP) using a 5G BF connection. Generally, the table of Fig. 5 indicates that while a short-term blockage may be adequately handled by procedures, such as Radio Link Control (RLC) retransmissions), moderate to longer-term blockages may cause more serious throughput (or signal degradation) problems, such as Transmission Control Protocol (TCP) timeout events. In some implementations, UE 110 may determine whether signal blockage is occurring by comparing a reference signal from the serving 5G eNB 130 with a signal reference from another 5G eNB 130. For example, UE 110 may compare the signal quality of a signal corresponding to the serving 5G eNB 130 to a signal quality of a signal corresponding to another 5G eNB 130; and verify whether the relative qualities are consistent with a determined distance between UE 110

and the serving 5G eNB 130 and a distance between 110 UE and the other 5G eNB 130. For instance, if the signal of the serving 5G eNB 130 is weaker than the signal from the other 5G eNB 130, even though the serving eNB is much closer, UE 110 may determine that there is an object (e.g., an obstruction) weakening or otherwise interfering with the signal between UE 110 and the serving 5G eNB 130. In some implementations, distances between UE 110 and each 5G eNB 130 may be initially established via a Radio Resource Control (RRC) message or another type of initial setup message.

Fig. 7 is a diagram of an example of signal degradation due to UE rotation. As shown, UE 110 may initially establish a 5G BF connection with 5G eNB 130 (at 7.1). Additionally, UE 110 may derive a beam direction, corresponding to the 5G BF connection, based on a combination of a current rotational position (e.g., via a gyroscope of UE 110) and a global coordinate system reading (e.g., a Global Positioning System (GPS) reading) taken by UE 110. At some point thereafter, the user of UE 110 may change the rotational orientation of UE 110 (at 7.2 and 7.3). For instance, the user may tilt his or her head during a call, the user may rotate his or her wrist while interfacing with UE 110, etc. In such a scenario, if the gyroscope detects a rotational shift of UE 110, without a corresponding change in the global coordinate system reading of UE 110, then UE 110 may determine that signal degradation has resulted from UE rotation.

Fig. 8 is a diagram of another example of signal degradation due to UE rotation. As shown, in response to detecting a signal degradation, UE 110 may perform a sweep for TRPs (TRP\_1, TRP\_2, TRP\_3, etc.) and determine an angular position of each TRP. UE 110 may determine whether the signal degradation is due to UE rotation by comparing the relative angular shifts of two or more TRPs. For example, if an angular offset between TRP\_1 and TRP 1' is equal to an angular offset between TRP\_3 and TRP\_3', UE 110 may determine that the signal degradation is due to UE rotation since both reference signals (TRP\_1 and TRP\_3) experienced a similar angular offset. Additionally, or alternatively, UE 110 may recover the link with 5G eNB 130 by rotation (e.g., a beam sweep) and determine the blockage is due to rotation. In some implementations, the network may become aware of the UE rotation by keeping a retransmission count (e.g., a number of times the network retransmits a signal without receiving a response from UE 110), noticing that a data rate from UE 110 is low, and/or receiving a status report from UE 110).

Fig. 9 is a diagram of an example of signal degradation due to UE movement. As shown, UE 110 may initially establish a 5G BF connection with 5G eNB 130 (at geographic location 9.1). However, as UE 110 may be a mobile device, UE 110, may move (e.g., from geographic location 9.1 to geographic location 9.2). As depicted, due to the location and/or

directionally specific nature of BF signals, the connection (and/or signals) between 5G eNB 130 and UE 110 may experience degradation if/when UE 110 move from one geographic location to another geographic location. As such, if/when UE 110 detects signal degradation in combination with a change in geographic location (and/or without rotation), UE 110 may  
5 determine that the signal degradation is due to UE movement.

In some implementations, UE 110 may consider factors, such as UE velocity, signal degradation over time (e.g., gradual signal degradation versus abrupt signal degradation), relative signal strength of non-serving TRPs (e.g., eNBs 130 not serving UE 110) etc., in order to distinguish between signal degradation that is due to blockage (see, e.g., Figs. 4 and 5) and  
10 signal degradation that due to UE movement. For example, if/when UE 110 experiences consistent and gradual signal strength reduction from the serving TRP and consistent signal strength increase from a neighbor TRP over time, then the signal degradation may be due to UE movement. If/when UE 110 is stationary and signal degradation is abrupt, the signal degradation may be due to blockage (e.g., a bus that as parked between UE 110 and eNB 130).  
15 If/when UE 110 is moving and signal degradation is gradual, the signal degradation may be due to UE movement (e.g., UE 110 gradually moving away from eNB 130).

Returning to Fig. 3, process 300 may also include recovering from the signal degradation (block 340). For instance, UE 110 may be capable of performing one or more recovery procedures in order to restore, re-establish, and/or maintain a connection with the wireless  
20 telecommunication network. For example, UE 110 may re-configure a 5G BF signal, from UE 110 to the serving eNB 130, to point in a new direction (e.g., a direction that properly accounts for a rotation and/or movement of UE 110). In another example, UE 110 may identify other 5G eNBs 130 in the vicinity, compare an option of reconnecting to the serving 5G eNB 130 (e.g., by re-configuring the original signal from UE 110) with an option to connect to another 5G eNB  
25 130, initiate and/or participate in a handover procedure towards a more appropriate 5G eNB 130, etc. The types of recovery procedures performed by UE 110 may depend on the reason(s) for the signal degradation, whether other 5G eNBs 130 are located in the vicinity, etc. In some implementations, prior to re-establishing a BF connection with 5G eNB 130, UE 110 may communicate with a new RAN (e.g., a LTE/5G macro RAN) using a wide beam signal or  
30 performing a fallback procedure, and the new RAN may notify the serving 5G eNB TRP regarding the status of UE 110. A wide beam signal may include a beamforming signal with a broader direction angle than a more typical beamforming signal. In some implementations, if/when the network has discovered that signal degradation has occurred (whether by UE rotation, blockage, and/or UE movement), 5G eNB 130 may respond by transmitting a wider

beam and increase the angular coverage of the transmission to improve signal quality for link recovery.

Fig. 10 is a diagram of an example process 1000 for detecting and recovering from signal degradation. In some implementations, process 1000 may be performed by UE 110. In some  
5 implementations, process 100 may be performed by a combination of UE 110 and eNB 130.

As shown, process 1000 may include detecting signal degradation (block 1005). For example, UE 110 may monitor, measure, etc., a quality of signal and/or connection between UE 110 and 5G eNB 130. In some implementations, UE 110 may do so by, for example, monitoring a SNR, a signal strength (e.g. RSRP/RSRQ), a packet loss rate, an estimated data rate, etc.,  
10 corresponding to signals between UE 110 and 5G eNB 130. UE 110 may determine that signal degradation has occurred when the measurement(s) or condition(s) of the signal surpass a particular threshold (e.g., a SNR threshold, a signal strength threshold, etc.).

Process 1000 may also include determining a reason for the signal degradation (block 1010). For example, UE 110 may determine whether the signal degradation is due to UE  
15 rotation, examples of which are discussed above with reference to Figs. 7 and 8. When UE 110 rotation is detected (block 1015 – Yes), UE 110 may perform a signal recovery procedure corresponding to the UE rotation. For example, UE 110, may perform a beam sweep for 5G eNB 130. The beam sweep may include an attempt, by UE 110, to locate 5G eNB 130 by creating multiple BF signals sent in different directions (e.g., signals transmitted at different  
20 angles). Upon determining the location of the 5G eNB 130, UE 110 may adjust, redirect, etc., the Rx beam toward the serving 5G eNB 130 in order to recover from the signal degradation. In some implementations, UE 110 may determine the angular rotation, of UE 110, that lead to the signal degradation, determine a corresponding BF correction based on the angular rotation, and re-establish communications with 5G eNB 130 based on the BF correction determined by UE  
25 110. In some implementations, UE 110 may forego a detection of whether rotation has occurred and go straight to a beam sweep procedure since the beam sweep procedure reveals that 5G eNB 130 is at a different angular location than before, making a formal determination that UE rotation has occurred may not be necessary. In some implementations, the beam sweep procedure may be facilitated by a reference signal transmitted by the serving 5G eNB 130.

When UE rotation is not detected (block 1015 – No), UE 110 may determine whether the  
30 signal degradation is due to UE blockage (block 1025). As described in detail with respect to Figs. 3-5, UE 110 may make this determination based on factor such as whether UE 110 is moving (including how fast, how recently, etc.), whether UE 110 is in an area known for UE blockage issues (e.g., an area with hills, canyons, tunnels, buildings, underground roadways, etc.). When UE blockage has been detected (block 1025 – Yes), process 1000 may include  
35

starting a timer (block 1030). As shown, UE 110 may wait for the timer to expire before attempting to proactively improve the signal. In some implementations, UE 110 may perform rotation and/or blockage detection, at a subframe level, based on a dedicated reference signal from eNB 130.

5           For instance, prior to the expiration of the timer (block 1035 – No), process 1000 may include determining whether the signal has improved by itself (block 1040). For example, if a bus is the source of the signal obstruction, the signal quality may improve if/when the bus moves to another location. As such, if the signal improves before the expiration of the timer (block 1040 – Yes), process 1000 may end (block 1045). In the alternative, if the signal does not  
10          improve (block 1040 – No), UE 110 may continue to wait for the expiration of the timer (block 1035). If the signal has not improved on its own, and the timer has expired (block 1035 – Yes), process 1000 may include performing signal recovery for signal blockage (block 1050).

          For example, UE 110 may send a blockage detection report to the network (e.g., via 5G eNB 130 or another base station) and/or begin searching for, and begin communicating with, a  
15          new TRP (e.g., a 4G eNB 120, another 5G eNB 130, etc.). Returning to block 1025, when UE 110 does not detect UE blockage (block 1025 – No), process 1000 may include detecting UE mobility and performing signal recovery for UE move (block 1055). Examples for detecting, and/or recovering from, signal degradation due to UE movement are discussed above with reference to Figs. 2 and 9, and may include UE 110 communicating with 5G eNB 130 to request  
20          or otherwise initiate a handover procedure. In some implementations, (e.g., when 5G eNB 130 is unreachable, UE 110 may perform a UE-based handover (e.g., a handover procedure that does not involve UE 110 communicating directly with 5G eNB 130, but may, for example, involve UE 110 communicating with 5G eNB 130 indirectly (e.g., via another base station in the area)).

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

          Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Fig. 11 illustrates, for one embodiment, example components of an electronic device 1100. Electronic device 1100 may be an example of UE 110  
35          and/or eNB 130. In embodiments, the electronic device 1100 may be a mobile device, a RAN

node, a network controller, a subscription repository, a data gateway, a service gateway, or an application server. In some embodiments, the electronic device 1100 may include application circuitry 1102, baseband circuitry 1104, Radio Frequency (RF) circuitry 1106, front-end module (FEM) circuitry 1108 and one or more antennas 1160, coupled together at least as shown. In  
5 embodiments in which a radio interface is not needed for electronic device 1100 (e.g., a data gateway, network controller, etc.), the RF circuitry 1106, FEM circuitry 1108, and antennas 1160 may be omitted. In other embodiments, any of said circuitries can be included in different devices.

Application circuitry 1102 may include one or more application processors. For  
10 example, the application circuitry 1102 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various  
15 applications and/or operating systems to run on the system. The memory/storage may include, for example, computer-readable medium 1103, which may be a non-transitory computer-readable medium. Application circuitry 1102 may, in some embodiments, connect to or include one or more sensors, such as environmental sensors, cameras, etc.

Baseband circuitry 1104 may include circuitry such as, but not limited to, one or more  
20 single-core or multi-core processors. The baseband circuitry 1104 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1106 and to generate baseband signals for a transmit signal path of the RF circuitry 1106. Baseband processing circuitry 1104 may interface with the application circuitry 1102 for generation and processing of the baseband signals and for controlling  
25 operations of the RF circuitry 1106. For example, in some embodiments, the baseband circuitry 1104 may include a second generation (2G) baseband processor 1104a, third generation (3G) baseband processor 1104b, fourth generation (4G) baseband processor 1104c, and/or other baseband processor(s) 1104d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 11G, etc.). The baseband circuitry 1104  
30 (e.g., one or more of baseband processors 1104a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1106. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some implementations, the functionality of baseband circuitry 1104 may be wholly or partially implemented by memory/storage devices

configured to execute instructions stored in the memory/storage. The memory/storage may include, for example, a non-transitory computer-readable medium 1104h.

In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1104 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1104 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry 1104 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), radio resource control (RRC) elements, and/or Non-Access Stratum (NAS) elements. A central processing unit (CPU) 1104e of the baseband circuitry 1104 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers, and/or NAS. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1104f. The audio DSP(s) 1104f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

Baseband circuitry 1104 may further include memory/storage 1104g. The memory/storage 1104g may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 1104. Memory/storage 1104g may particularly include a non-transitory memory. Memory/storage for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 1104g may include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. The memory/storage 1104g may be shared among the various processors or dedicated to particular processors.

Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1104 and the application circuitry 1102 may be implemented together such as, for example, on a system on a chip (SOC).

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

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

In some embodiments, the RF circuitry 1106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1106 may include mixer circuitry 1106a, amplifier circuitry 1106b and filter circuitry 1106c. The transmit signal path of  
20 the RF circuitry 1106 may include filter circuitry 1106c and mixer circuitry 1106a. RF circuitry 1106 may also include synthesizer circuitry 1106d for synthesizing a frequency for use by the mixer circuitry 1106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1108 based on the synthesized frequency  
25 provided by synthesizer circuitry 1106d. The amplifier circuitry 1106b may be configured to amplify the down-converted signals and the filter circuitry 1106c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals.

Output baseband signals may be provided to the baseband circuitry 1104 for further  
30 processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 1106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 1106a of the transmit signal path may be  
35 configured to up-convert input baseband signals based on the synthesized frequency provided by



the synthesizer circuitry 1106d to generate RF output signals for the FEM circuitry 1108. The baseband signals may be provided by the baseband circuitry 1104 and may be filtered by filter circuitry 1106c. The filter circuitry 1106c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

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

15 In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the  
20 baseband circuitry 1104 may include a digital baseband interface to communicate with the RF circuitry 1106.

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

25 In some embodiments, the synthesizer circuitry 1106d may be a fractional-N synthesizer or a fractional N/N+6 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

30 The synthesizer circuitry 1106d may be configured to synthesize an output frequency for use by the mixer circuitry 1106a of the RF circuitry 1106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1106d may be a fractional N/N+6 synthesizer.

In some embodiments, frequency input may be provided by a voltage-controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by

either the baseband circuitry 1104 or the applications processor 1102 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 1102.

Synthesizer circuitry 1106d of the RF circuitry 1106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+6 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

In some embodiments, synthesizer circuitry 1106d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 1106 may include an IQ/polar converter.

FEM circuitry 1108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1160, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1106 for further processing. FEM circuitry 1108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1106 for transmission by one or more of the one or more antennas 1160.

In some embodiments, the FEM circuitry 1108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1106). The transmit signal path of the FEM circuitry 1108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1160).

In some embodiments, the electronic device 1100 may include additional elements such as, for example, memory/storage, display, camera, sensors, and/or input/output (I/O) interface. In some embodiments, the electronic device of Fig. 11 may be configured to perform one or more methods, processes, and/or techniques such as those described herein.

5 Fig. 12 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Fig. 12 shows a diagrammatic representation of hardware  
10 resources 1200 including one or more processors (or processor cores) 1210, one or more memory/storage devices 1220, and one or more communication resources 1230, each of which are communicatively coupled via a bus 1240.

The processors 1210 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an  
15 application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 1212 and a processor 1214. The memory/storage devices 1220 may include main memory, disk storage, or any suitable combination thereof.

The communication resources 1230 may include interconnection and/or network  
20 interface components or other suitable devices to communicate with one or more peripheral devices 1204 and/or one or more databases 1206 via a network 1208. For example, the communication resources 1230 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy),  
25 Wi-Fi® components, and other communication components.

Instructions 1250 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1210 to perform any one or more of the methodologies discussed herein. The instructions 1250 may reside, completely or partially, within at least one of the processors 1210 (e.g., within the processor's cache memory),  
30 the memory/storage devices 1220, or any suitable combination thereof. Furthermore, any portion of the instructions 1250 may be transferred to the hardware resources 1200 from any combination of the peripheral devices 1204 and/or the databases 1206. Accordingly, the memory of processors 1210, the memory/storage devices 1220, the peripheral devices 1204, and the databases 1206 are examples of computer-readable and machine-readable media.

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

In a first example, User Equipment (UE) for a wireless telecommunication network may comprise a radio component configured to implement beamforming signaling to establish a  
5 connection with the wireless telecommunication network; and processing circuitry to: monitor a signal quality, of the beamforming signaling, corresponding to the connection; determine that the signal quality has degraded to an unacceptable degree; determine a specific reason for the signal quality having degraded, the specific reason relating to the beamforming signaling including direction-specific signals; identify, based on the specific reason for the signal quality  
10 having degraded, a corrective procedure for the signal quality degradation; and initiate the corrective procedure to improve the connection with the wireless telecommunication network.

In example 2, the subject matter of example 1, or any of the examples herein, wherein the processing circuitry is to determine, based on a gyroscope of the UE, that the specific reason for the signal having degraded is an angular rotation of the UE.

15 In example 3, the subject matter of example 2, or any of the examples herein, wherein the corrective procedure includes reconfiguring a directional orientation of the beamforming signal to account for the angular rotation of the UE.

In example 4, the subject matter of example 2, or any of the examples herein, wherein the corrective procedure includes a beam sweep to determine a location of a serving 5G eNB.

20 In example 5, the subject matter of example 1, or any of the examples herein, wherein the processing circuitry is to determine that the signal quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

In example 6, the subject matter of example 5, or any of the examples herein, wherein, to determine that the signal quality has degraded due to the physical object, the processing circuitry  
25 is, to: initiate a timer in response to determining that the signal quality has degraded; and postpone the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

In example 7, the subject matter of example 5, or any of the examples herein, wherein the processing circuitry is to determine that the signal quality has degraded, due to the physical  
30 object, based a comparison of a reference signal from a Transmission Reception Point (TRP) of the 5G eNB and a reference signal from another base station of the wireless telecommunication network.

In example 8, the subject matter of example 7, or any of the examples herein, wherein the determination that the signal quality has degraded due to a physical object is also based on a

distance between the UE and the 5G eNB and a distance between the UE and the another base station.

In example 9, the subject matter of examples 2 or 5, or any of the examples herein, wherein the specific reason for the signal quality being degraded is based on a Beam Reference  
5 Signal (BRS) periodicity of the wireless telecommunication network.

In example 10, the subject matter of examples 2 or 5, or any of the examples herein, wherein the specific reason for the signal quality being degraded is based on a beam track in a particular subframe of a dedicated reference signal.

In example 11, the subject matter of examples 2 or 5, or any of the examples herein,  
10 wherein the specific reason for the signal quality being degraded is based on a regular data transmission from the 5G eNB to the UE.

In example 12, the subject matter of example 1, or any of the examples herein, wherein the processing circuitry is to determine that the signal quality has degraded based on signal strengths, measured over time, of Transmission Reception Points (TRPs) corresponding to the  
15 5G eNB and at least one other base station of the wireless telecommunication network.

In example 13, the subject matter of example 1, or any of the examples herein, wherein, in response to determining that the signal quality has not degraded due to an angular rotation of the UE or a physical object obstructing the beamforming signal, the processing circuitry is to determine that the signal quality has degraded due to a change in a geographical location of the  
20 UE.

In example 14, the subject matter of example 1, or any of the examples herein, wherein the corrective procedure includes communicating with the 5G eNB in order to initiate a handover, of the UE, to another base station of the wireless telecommunication network.

In example 15, the subject matter of example 1, or any of the examples herein, wherein  
25 the corrective procedure includes a fallback procedure to another Radio Access Network (RAN).

In example 16, the subject matter of example 1, or any of the examples herein, wherein the corrective procedure includes a UE-based handover procedure, wherein the UE identifies and initiates a handover procedure toward another base station, of the wireless telecommunication network, without instructions to do so from a serving 5G eNB.

In example 17, the subject matter of example 1, or any of the examples herein, wherein  
30 the corrective procedure includes communicating with the wireless telecommunication network using a wide beam signal.

In an eighteenth example, an enhanced NodeB (eNB) of a wireless telecommunication network may comprise a radio component configured to implement beamforming signaling to  
35 establish a connection with User Equipment (UE) within a coverage area of the eNB; and

processing circuitry to: cause the radio component to implementing beamforming with respect to a reference signal from the eNB to a particular UE; monitor a signal quality, corresponding to a beamforming signal from the UE to the eNB; determine that the signal quality has degraded to an unacceptable degree; and implement a corrective procedure in order to improve

5 communications with the UE.

In example 19, the subject matter of example 18, or any of the examples herein, wherein, to determine that the signal quality has degraded, the processing circuitry is to determine that the UE has failed to respond to the eNB in a manner anticipated by the eNB.

10 In example 20, the subject matter of example 19, or any of the examples herein, wherein the manner anticipated by the eNB includes receiving a particular acknowledgement message from the UE.

In example 21, the subject matter of example 18, or any of the examples herein, wherein the corrective procedure includes communicating with the UE via a wide beam signal.

15 In a twenty-second example, a computer-readable medium containing program instructions for causing one or more processors, associated with User Equipment (UE) configured to implement beamforming signaling to establish a connection with a wireless telecommunication network, to: monitor a signal quality, of the beamforming signaling, corresponding to the connection; determine that the signal quality has degraded to an unacceptable degree; determine a specific reason for the signal quality having degraded, the  
20 specific reason relating to the beamforming signaling including direction-specific signals; identify, based on the specific reason for the signal quality having degraded, a corrective procedure for the signal quality degradation; and initiate the corrective procedure to improve the connection with the wireless telecommunication network.

25 In example 23, the subject matter of example 22, or any of the examples herein, wherein the program instructions are to cause the one or more processors to, determine, based on a gyroscope of the UE, that the specific reason for the signal having degraded is an angular rotation of the UE.

30 In example 24, the subject matter of example 23, or any of the examples herein, wherein the corrective procedure includes reconfiguring a directional orientation of the beamforming signal to account for the angular rotation of the UE.

In example 25, the subject matter of example 23, or any of the examples herein, wherein the corrective procedure includes a beam sweep to determine a location of a serving 5G eNB.

In example 26, the subject matter of example 22, or any of the examples herein, wherein the program instructions are to cause the one or more processors to determine that the signal

quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

In example 27, the subject matter of example 26, or any of the examples herein, wherein, to determine that the signal quality has degraded due to the physical object, the program  
5 instructions are to cause the one or more processors to: initiate a timer in response to determining that the signal quality has degraded; and postpone the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

In example 28, the subject matter of example 26, or any of the examples herein, wherein the program instructions are to cause the one or more processors to determine that the signal  
10 quality has degraded, due to the physical object, based a comparison of a reference signal from a Transmission Reference Point (TRP) of the 5G eNB and a reference signal from another base station of the wireless telecommunication network.

In example 29, the subject matter of example 28, or any of the examples herein, wherein the determination that the signal quality has degraded due to a physical object is also based on a  
15 distance between the UE and the 5G eNB and a distance between the UE and the another base station.

In example 30, the subject matter of example 22, or any of the examples herein, wherein the program instructions are to cause the one or more processors to determine that the signal quality has degraded based on signal strengths, measured over time, of Transmission Reception  
20 Points (TRPs) corresponding to a serving 5G eNB and at least one other base station of the wireless telecommunication network.

In example 30, the subject matter of example 22, or any of the examples herein, wherein the program instructions are to cause the one or more processors to determine that the signal quality has degraded based on signal strengths, measured over time, of Transmission Reception  
25 Points (TRPs) corresponding to a serving 5G eNB and at least one other base station of the wireless telecommunication network.

In example 31, the subject matter of example 22, or any of the examples herein, wherein, in response to determining that the signal quality has not degraded due to an angular rotation of the UE or a physical object obstructing the beamforming signal, the program instructions are to  
30 cause the one or more processors to determine that the signal quality has degraded due to a change in a geographical location of the UE.

In example 32, the subject matter of example 22, or any of the examples herein, wherein the corrective procedure includes communicating with a serving 5G eNB in order to initiate a handover, of the UE, to another base station of the wireless telecommunication network.

In example 33, the subject matter of example 22, or any of the examples herein, wherein the corrective procedure includes a fallback procedure to another Radio Access Network (RAN).

In example 34, the subject matter of example 22, or any of the examples herein, wherein the corrective procedure includes a UE-based handover procedure, wherein the UE identifies  
5 and initiates a handover procedure toward another base station, of the wireless telecommunication network, without instructions to do so from a serving 5G eNB.

In example 35, the subject matter of example 22, or any of the examples herein, wherein the corrective procedure includes communicating with the wireless telecommunication network using a wide beam signal.

10 In a thirty-sixth example, a method, performed by a User Equipment (UE), may comprise monitoring, by the UE, a signal quality of a beamforming signal, corresponding to a connection to a wireless telecommunication network; determining, by the UE, that the signal quality has degraded to an unacceptable degree; determining, by the UE, a specific reason for the signal quality having degraded, the specific reason relating to the beamforming signaling  
15 including direction-specific signals; identifying, by the UE and based on the specific reason for the signal quality having degraded, a corrective procedure for the signal quality degradation; and initiating, by the UE, the corrective procedure to improve the connection with the wireless telecommunication network.

In example 37, the subject matter of example 36, or any of the examples herein, wherein  
20 determining the specific reason for the signal quality having degraded includes determining, based on a gyroscope of the UE, that the specific reason for the signal having degraded is an angular rotation of the UE.

In example 38, the subject matter of example 37, or any of the examples herein, wherein the corrective procedure includes reconfiguring a directional orientation of the beamforming  
25 signal to account for the angular rotation of the UE.

In example 39, the subject matter of example 37, or any of the examples herein, wherein the corrective procedure includes a beam sweep to determine a location of a serving 5G eNB.

In example 40, the subject matter of example 36, or any of the examples herein, wherein determining the specific reason for the signal quality having degraded includes determining that  
30 the signal quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

In example 41, the subject matter of example 40, or any of the examples herein, wherein, in response to determining that the signal quality has degraded due to the physical object, the method further comprises: initiating a timer in response to determining that the signal quality



has degraded; and postponing the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

In example 42, the subject matter of example 40, or any of the examples herein, wherein determining that the signal quality has degraded, due to the physical object is based on a  
5 comparison of a reference signal from the 5G eNB and a reference signal from another base station of the wireless telecommunication network.

In example 43, the subject matter of example 40, or any of the examples herein, wherein the determination that the signal quality has degraded due to a physical object is also based on a distance between the UE and the 5G eNB and a distance between the UE and the another base  
10 station.

In example 44, the subject matter of example 36, or any of the examples herein, wherein determining that the signal quality has degraded is based on signal strengths, measured over time, of Transmission Reception Points (TRPs) corresponding to a serving 5G eNB and at least one other base station of the wireless telecommunication network.

15 In example 45, the subject matter of example 36, or any of the examples herein, wherein determining the specific reason for the signal quality having degraded includes determining that the signal quality has degraded due to a change in a geographical location of the UE in response to determining that the signal quality has not degraded due to an angular rotation of the UE or a physical object obstructing the beamforming signal.

20 In example 46, the subject matter of example 36, or any of the examples herein, wherein the corrective procedure includes communicating with a serving 5G eNB in order to initiate a handover, of the UE, to another base station of the wireless telecommunication network.

In example 47, the subject matter of example 36, or any of the examples herein, wherein the corrective procedure includes a fallback procedure to another Radio Access Network (RAN).

25 In example 48, the subject matter of example 36, or any of the examples herein, wherein the corrective procedure includes a UE-based handover procedure, wherein the UE identifies and initiates a handover procedure toward another base station, of the wireless telecommunication network, without instructions to do so from a serving 5G eNB.

In example 49, the subject matter of example 36, or any of the examples herein, wherein  
30 the corrective procedure includes communicating with the wireless telecommunication network using a wide beam signal instead of another beamforming signal.

In a fiftieth example, a User Equipment (UE) for a wireless telecommunication network may comprise means for monitoring a signal quality of a beamforming signal, corresponding to a connection to the wireless telecommunication network; means for determining that the signal  
35 quality has degraded to an unacceptable degree; means for determining a specific reason for the

signal quality having degraded, the specific reason relating to the beamforming signaling including direction-specific signals; means for identifying, based on the specific reason for the signal quality having degraded, a corrective procedure for the signal quality degradation; and means for initiating the corrective procedure to improve the connection with the wireless telecommunication network.

In example 51, the subject matter of example 50, or any of the examples herein, wherein the means for determining the specific reason for the signal quality having degraded includes means for determining, based on a gyroscope of the UE, that the specific reason for the signal having degraded is an angular rotation of the UE.

In example 52, the subject matter of example 51, or any of the examples herein, wherein the corrective procedure includes reconfiguring a directional orientation of the beamforming signal to account for the angular rotation of the UE.

In example 53, the subject matter of example 51, or any of the examples herein, wherein the corrective procedure includes a beam sweep to determine a location of a serving 5G eNB.

In example 54, the subject matter of example 50, or any of the examples herein, wherein the means for determining the specific reason for the signal quality having degraded includes means for determining that the signal quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

In example 55, the subject matter of example 54, or any of the examples herein, in response to determining that the signal quality has degraded due to the physical object, means for initiating a timer in response to determining that the signal quality has degraded; and postponing the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

In example 56, the subject matter of example 54, or any of the examples herein, wherein determining that the signal quality has degraded, due to the physical object is based on a comparison of a reference signal from the 5G eNB and a reference signal from another base station of the wireless telecommunication network.

In example 57, the subject matter of example 56, or any of the examples herein, wherein the determination that the signal quality has degraded due to a physical object is also based on a distance between the UE and the 5G eNB and a distance between the UE and the another base station.

In example 58, the subject matter of example 50, or any of the examples herein, wherein determining that the signal quality has degraded is based on signal strengths, measured over time, of Transmission Reception Points (TRPs) corresponding to a serving 5G eNB and at least one other base station of the wireless telecommunication network.

In example 59, the subject matter of example 50, or any of the examples herein, wherein determining the specific reason for the signal quality having degraded includes determining that the signal quality has degraded due to a change in a geographical location of the UE in response to determining that the signal quality has not degraded due to an angular rotation of the UE or a physical object obstructing the beamforming signal.

In example 60, the subject matter of example 50, or any of the examples herein, wherein the corrective procedure includes communicating with a serving 5G eNB in order to initiate a handover, of the UE, to another base station of the wireless telecommunication network.

In example 61, the subject matter of example 50, or any of the examples herein, wherein the corrective procedure includes a fallback procedure to another Radio Access Network (RAN).

In example 62, the subject matter of example 50, or any of the examples herein, wherein the corrective procedure includes a UE-based handover procedure, wherein the UE identifies and initiates a handover procedure toward another base station, of the wireless telecommunication network, without instructions to do so from a serving 5G eNB.

In example 63, the subject matter of example 50, or any of the examples herein, wherein the corrective procedure includes communicating with the wireless telecommunication network using a wide beam signal instead of another beamforming signal.

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

For example, while series of signals and/or operations have been described with regard to Figs. 3 and 10, the order of the signals/operations may be modified in other implementations. Further, non-dependent signals may be performed in parallel.

It will be apparent that example aspects, as described above, may be implemented in many different forms of software, firmware, and hardware in the implementations illustrated in the figures. The actual software code or specialized control hardware used to implement these aspects should not be construed as limiting. Thus, the operation and behavior of the aspects were described without reference to the specific software code—it being understood that software and control hardware could be designed to implement the aspects based on the description herein.

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

of these features may be combined in ways not specifically recited in the claims and/or disclosed in the specification.

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

WHAT IS CLAIMED IS:

1. User Equipment (UE) for a wireless telecommunication network, the UE comprising:

a radio component configured to implement beamforming signaling to establish a connection with the wireless telecommunication network; and

processing circuitry to:

monitor a signal quality, of the beamforming signaling, corresponding to the connection;

determine that the signal quality has degraded to an unacceptable degree;

determine a specific reason for the signal quality having degraded, the specific reason relating to the beamforming signaling including direction-specific signals;

identify, based on the specific reason for the signal quality having degraded, a corrective procedure for the signal quality degradation; and

initiate the corrective procedure to improve the connection with the wireless telecommunication network.

2. The UE of claim 1, wherein the processing circuitry is to determine, based on a gyroscope of the UE, that the specific reason for the signal having degraded is an angular rotation of the UE.

3. The UE of claim 2, wherein the corrective procedure includes reconfiguring a directional orientation of the beamforming signal to account for the angular rotation of the UE.

4. The UE of claim 2, wherein the corrective procedure includes a beam sweep to determine a location of a serving 5G eNB.

5. The UE of claim 1, wherein the processing circuitry is to determine that the signal quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

6. The UE of claim 5, wherein, to determine that the signal quality has degraded due to the physical object, the processing circuitry is, to:

initiate a timer in response to determining that the signal quality has degraded; and

postpone the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

7. The UE of claim 5, wherein the processing circuitry is to determine that the signal quality has degraded, due to the physical object, based a comparison of a reference signal from a Transmission Reception Point (TRP) of the 5G eNB and a reference signal from another  
5 base station of the wireless telecommunication network.

8. The UE of claim 7, wherein the determination that the signal quality has degraded due to a physical object is also based on a distance between the UE and the 5G eNB and a distance between the UE and the another base station.

9. The UE of claim 2 or 5, wherein the specific reason for the signal quality being degraded is based on a Beam Reference Signal (BRS) periodicity of the wireless telecommunication network.

10. The UE of claim 2 or 5, wherein the specific reason for the signal quality being degraded is based on a beam track in a particular subframe of a dedicated reference signal.

11. The UE of claim 2 or 5, wherein the specific reason for the signal quality being degraded is based on a regular data transmission from the 5G eNB to the UE.

12. The UE of claim 1, wherein the processing circuitry is to determine that the signal quality has degraded based on signal strengths, measured over time, of Transmission Reception Points (TRPs) corresponding to the 5G eNB and at least one other base station of the wireless telecommunication network.

13. An enhanced NodeB (eNB) of a wireless telecommunication network, the eNB comprising:

a radio component configured to implement beamforming signaling to establish a connection with User Equipment (UE) within a coverage area of the eNB; and

processing circuitry to:

cause the radio component to implementing beamforming with respect to a reference signal from the eNB to a particular UE;

monitor a signal quality, corresponding to a beamforming signal from the UE to the eNB;

determine that the signal quality has degraded to an unacceptable degree; and

implement a corrective procedure in order to improve communications with the UE.

14. The eNB of claim 13, wherein, to determine that the signal quality has degraded,  
5 the processing circuitry is to determine that the UE has failed to respond to the eNB in a manner anticipated by the eNB.

15. The eNB of claim 14, wherein the manner anticipated by the eNB includes  
receiving a particular acknowledgement message from the UE.

16. The eNB of claim 13, wherein the corrective procedure includes communicating  
with the UE via a wide beam signal.

17. A computer-readable medium containing program instructions for causing one or  
15 more processors, associated with User Equipment (UE) configured to implement beamforming signaling to establish a connection with a wireless telecommunication network, to:

monitor a signal quality, of the beamforming signaling, corresponding to the connection;

determine that the signal quality has dropped below a particular threshold;

20 determine a specific reason for the signal quality having degraded, the specific reason relating to the beamforming signaling including direction-specific signals;

identify, based on the specific reason for the signal quality having degraded, a corrective  
procedure for the signal quality degradation; and

initiate the corrective procedure to improve the connection with the wireless  
telecommunication network.

18. The computer-readable medium of claim 17, wherein the program instructions  
are to cause the one or more processors to, determine, based on a gyroscope of the UE, that the  
specific reason for the signal having degraded is an angular rotation of the UE.

19. The computer-readable medium of claim 18, wherein the corrective procedure  
includes reconfiguring a directional orientation of the beamforming signal to account for the  
angular rotation of the UE.

20. The computer-readable medium of claim 17, wherein the corrective procedure  
35 includes a beam sweep to determine a location of a serving 5G eNB.

18. The computer-readable medium of claim 17, wherein the program instructions are to cause the one or more processors to determine that the signal quality has degraded due to a physical object, between the UE and a serving 5G eNB, obstructing the beamforming signal.

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19. The computer-readable medium of claim 18, wherein, to determine that the signal quality has degraded due to the physical object, the program instructions are to cause the one or more processors to:

initiate a timer in response to determining that the signal quality has degraded; and

10 postpone the determination of the signal quality being degraded due to the physical object until after an expiration of the timer.

20. The computer-readable medium of claim 18, wherein the program instructions are to cause the one or more processors to determine that the signal quality has degraded, due to the physical object, based a comparison of a reference signal from a Transmission Reference Point (TRP) of the 5G eNB and a reference signal from another base station of the wireless telecommunication network.

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21. The computer-readable medium of claim 20, wherein the determination that the signal quality has degraded due to a physical object is also based on a distance between the UE and the 5G eNB and a distance between the UE and the another base station.

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22. The computer-readable medium of claim 17, wherein the program instructions are to cause the one or more processors to determine that the signal quality has degraded based on signal strengths, measured over time, of Transmission Reception Points (TRPs) corresponding to a serving 5G eNB and at least one other base station of the wireless telecommunication network.

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23. The computer-readable medium of claim 17, wherein, in response to determining that the signal quality has not degraded due to an angular rotation of the UE or a physical object obstructing the beamforming signal, the program instructions are to cause the one or more processors to determine that the signal quality has degraded due to a change in a geographical location of the UE.

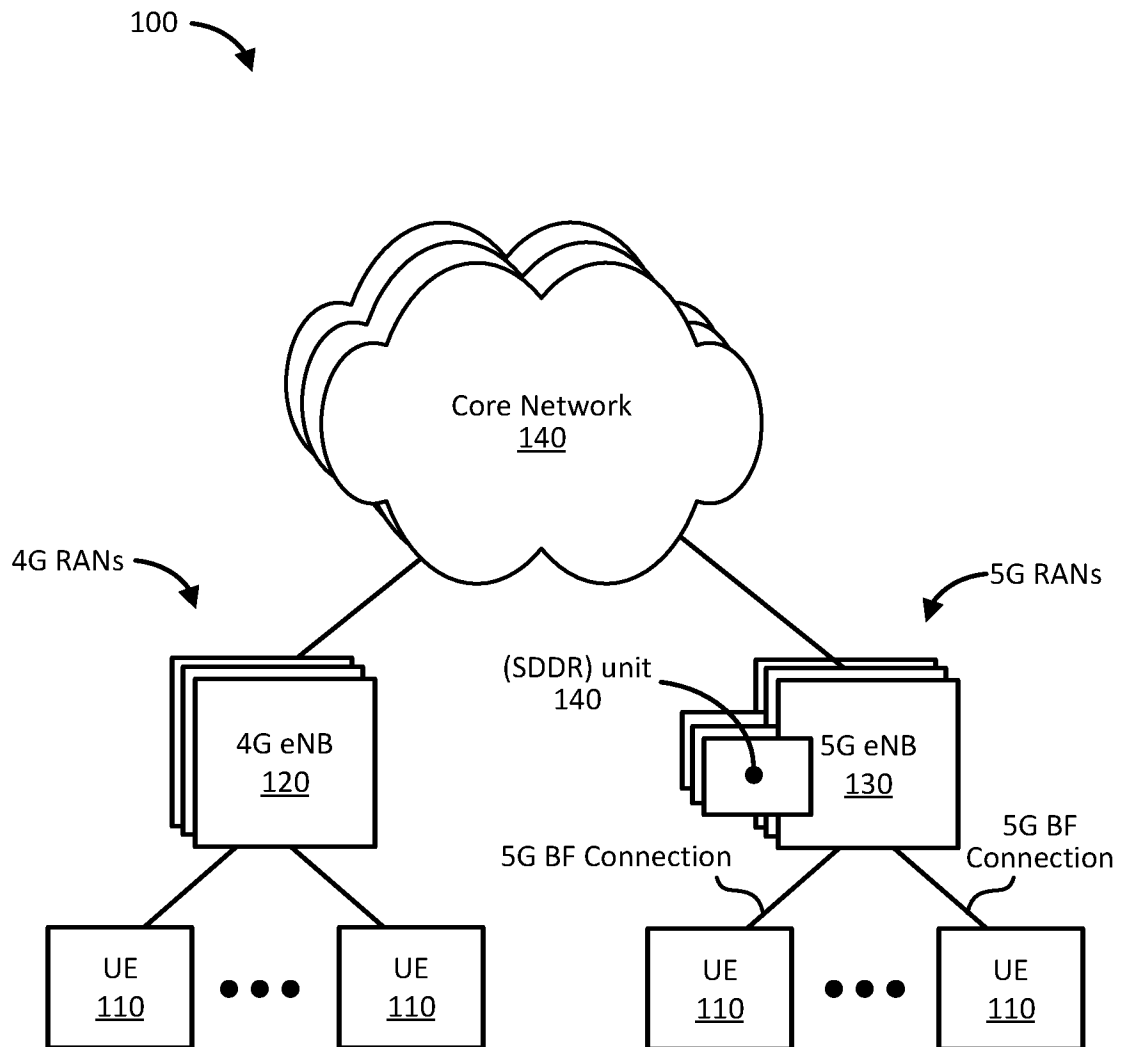
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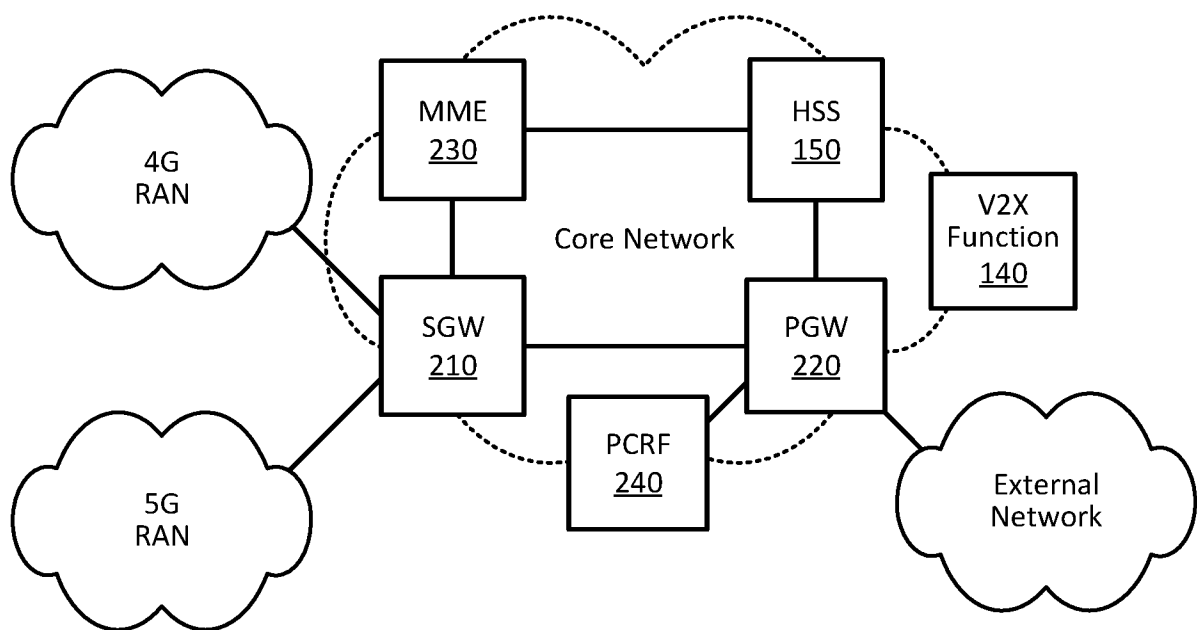
24. The computer-readable medium of claim 17, wherein the corrective procedure includes communicating with a serving 5G eNB in order to initiate a handover, of the UE, to another base station of the wireless telecommunication network.

- 5           25. The computer-readable medium of claim 17, wherein the corrective procedure includes a fallback procedure to another Radio Access Network (RAN).

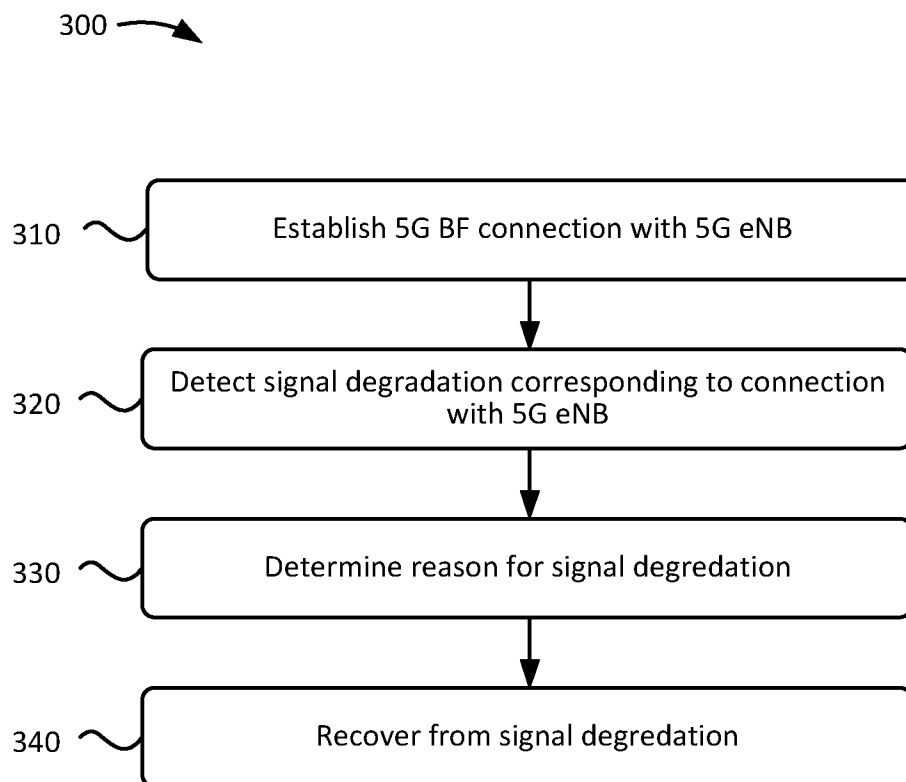
1/12

**Fig. 1**

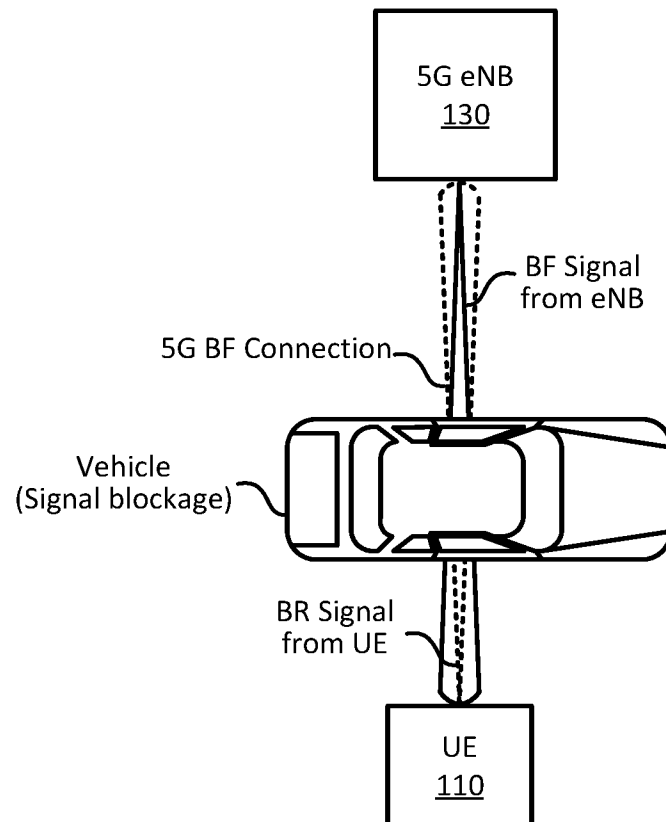
2/12

**Fig. 2**

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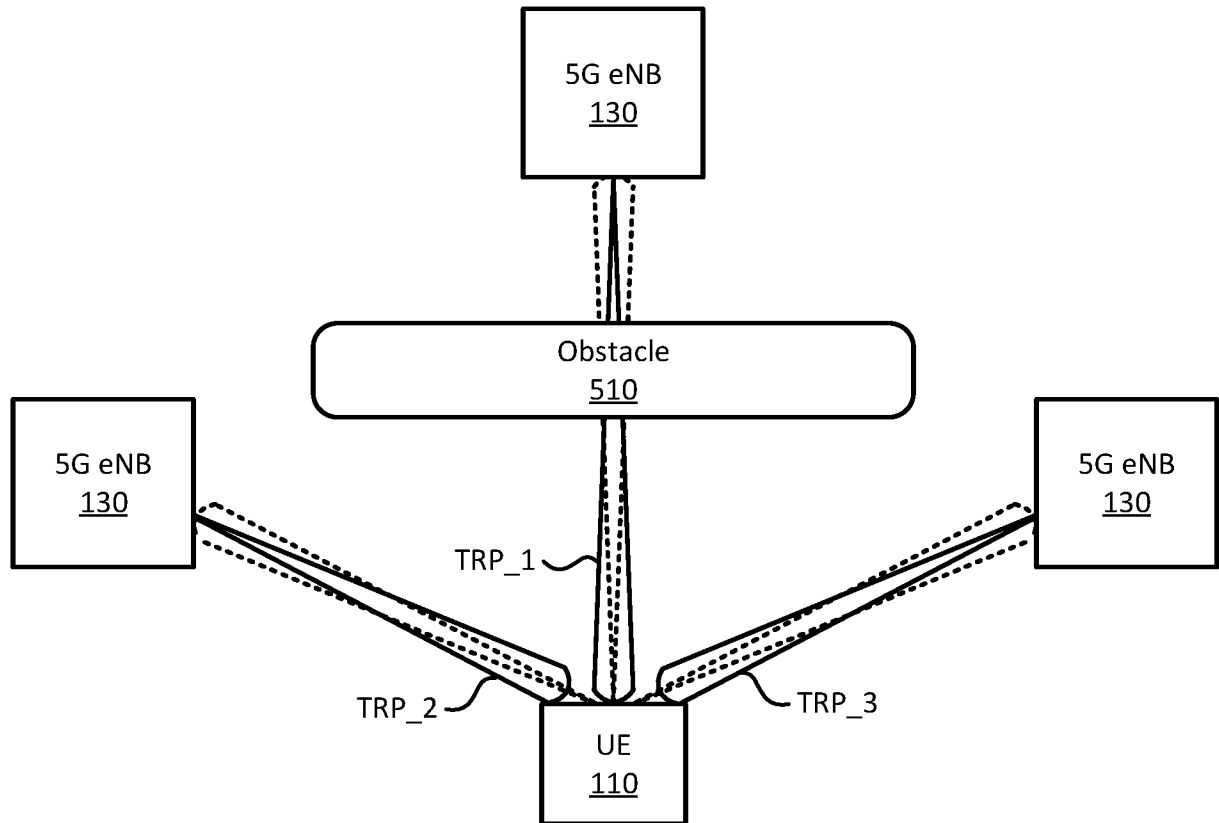
**Fig. 3**

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**Fig. 4**

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**Fig. 5**

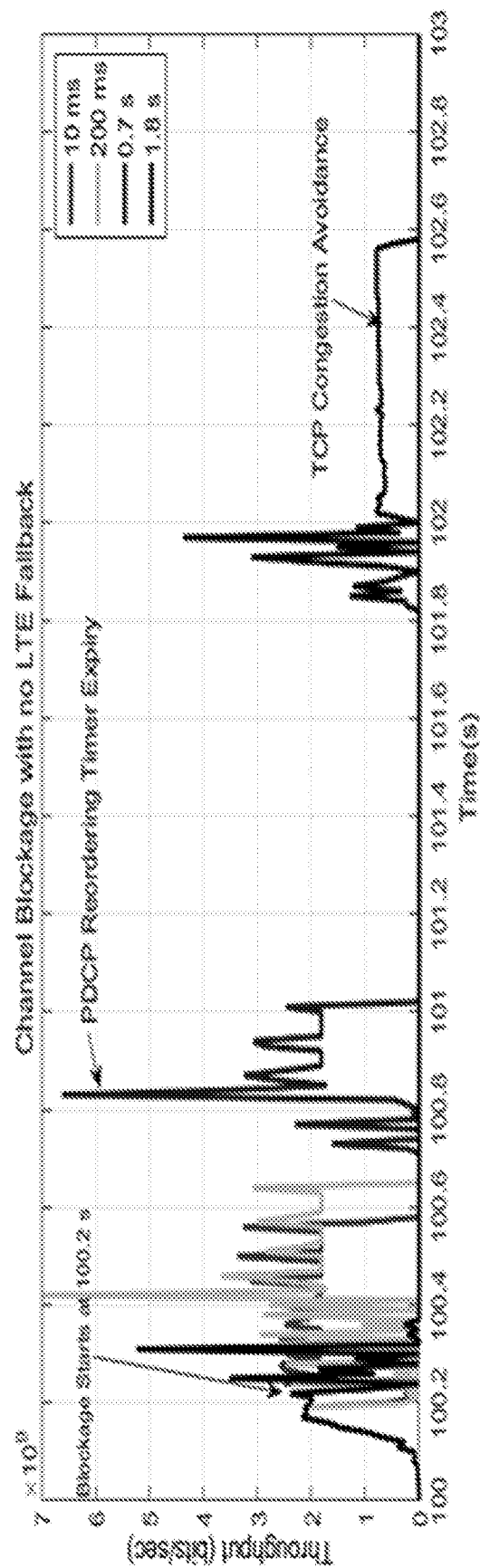
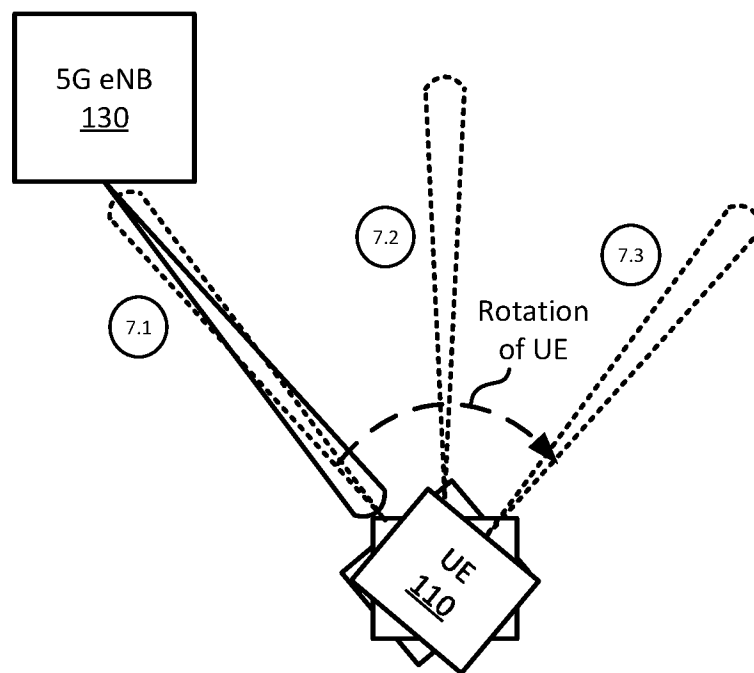


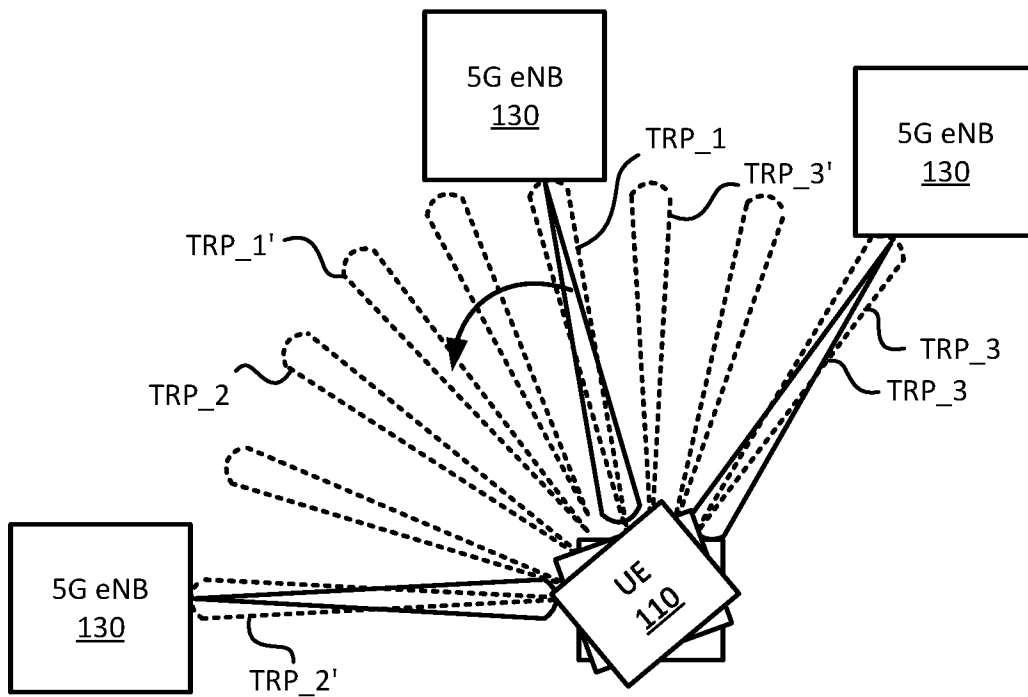
Fig. 6

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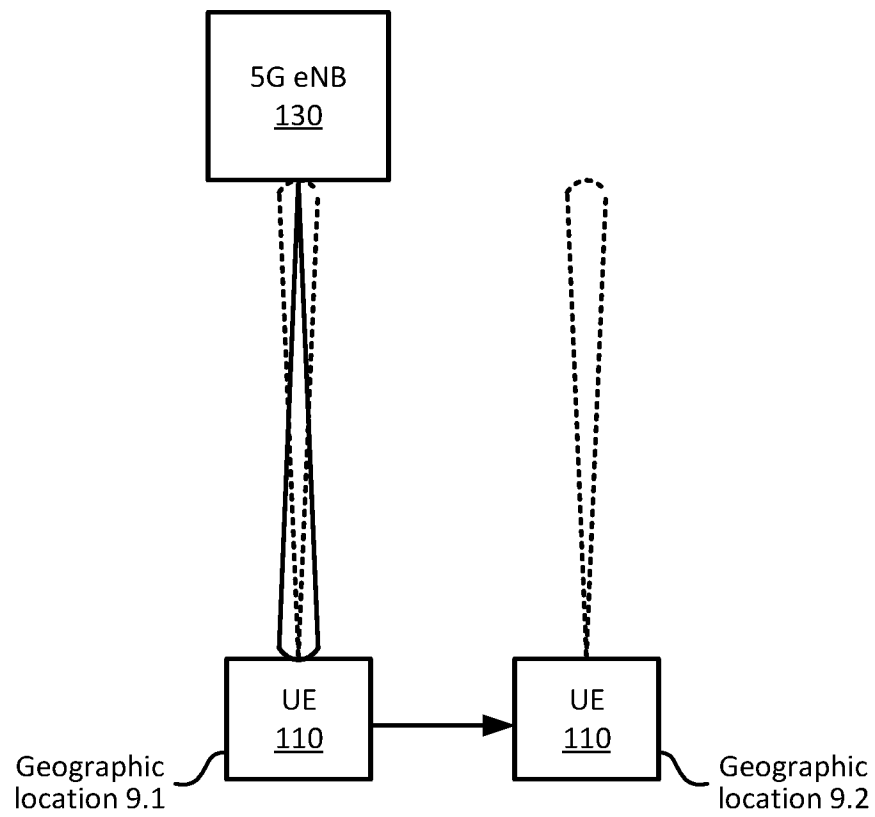
**Fig. 7**



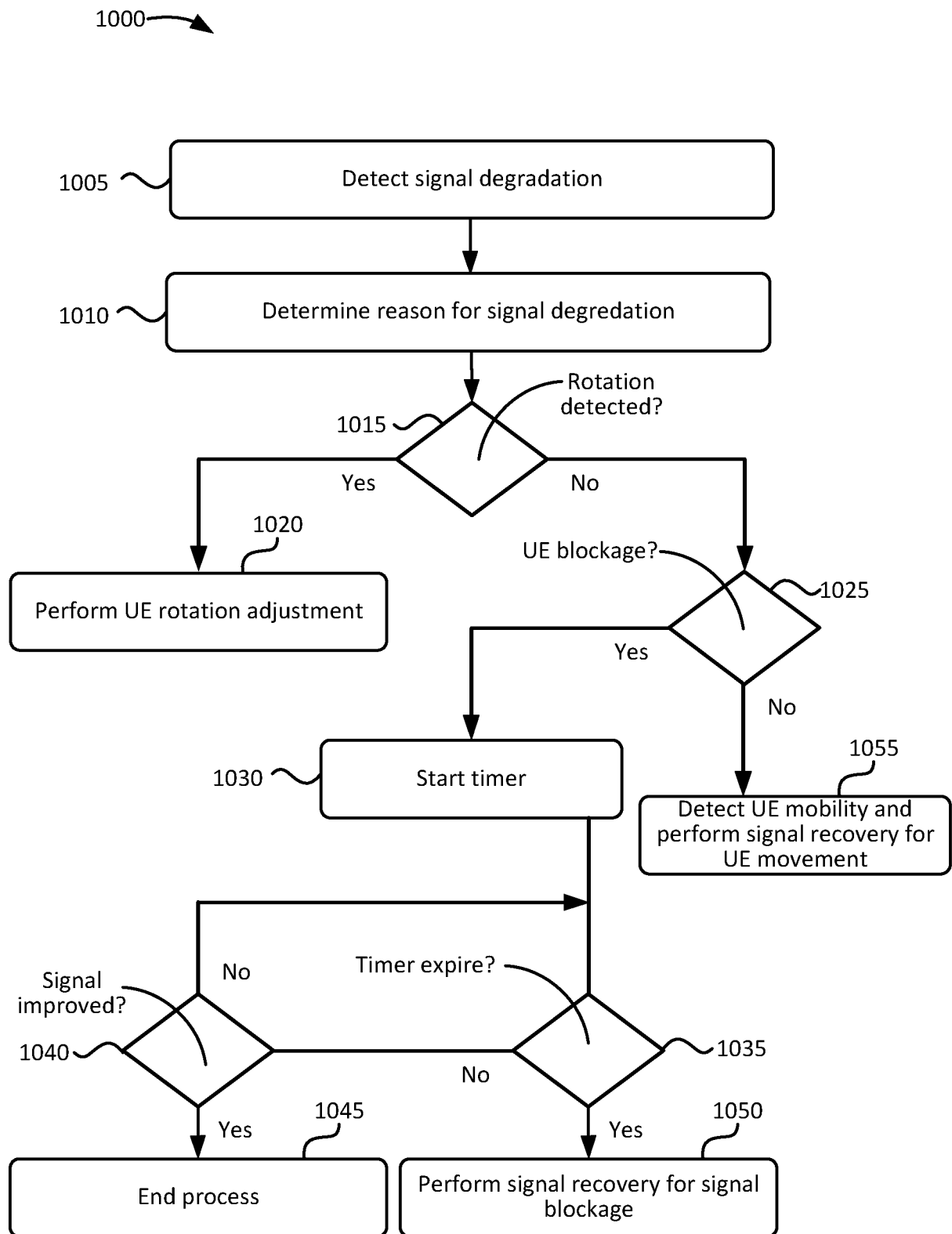
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**Fig. 8**

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**Fig. 9**

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**Fig. 10**

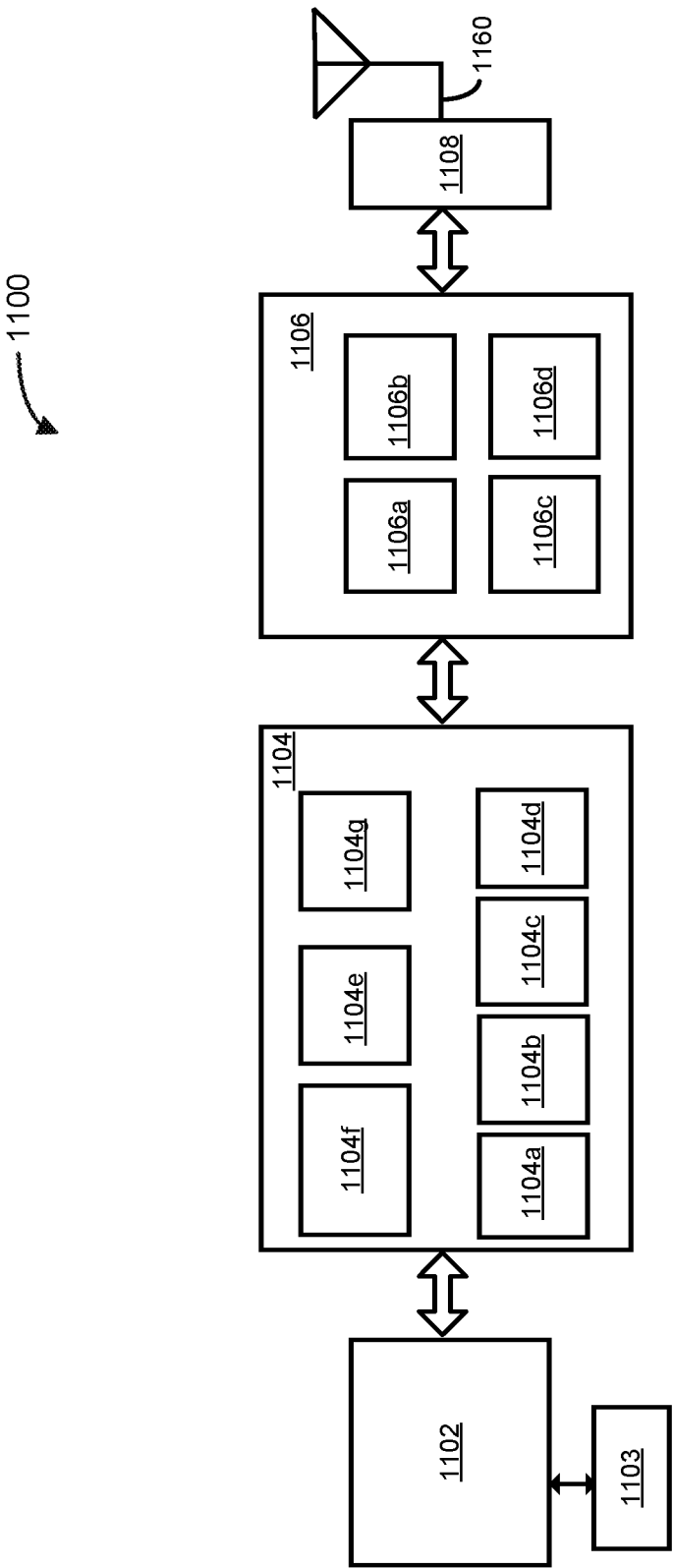
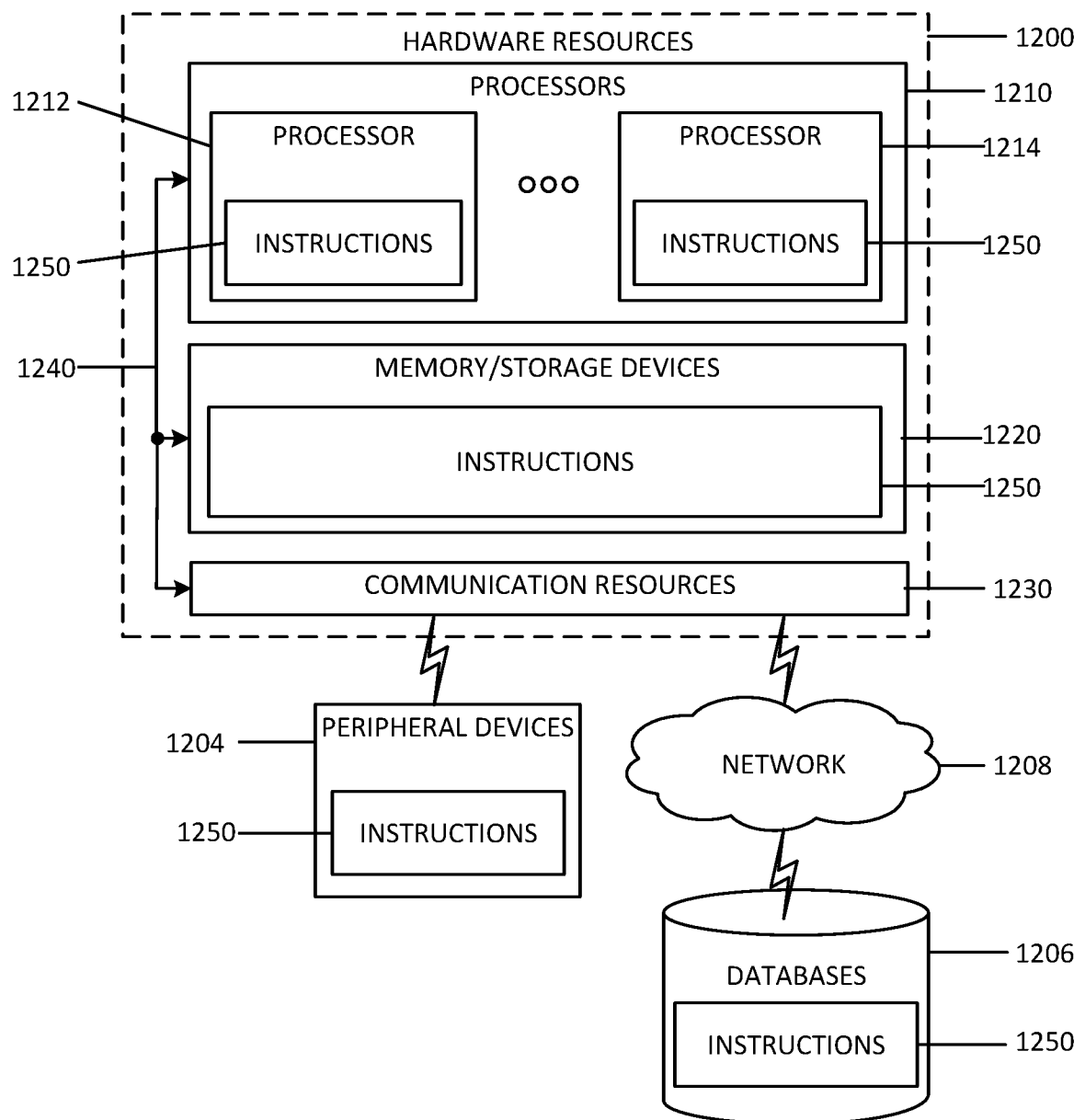


Fig. 11

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**Fig. 12**

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2017/019172

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04B7/06  
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)  
H04B

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

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

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                     | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | BO GAO(TSINGHUA UNIVERSITY): "Proposed text resolution to CID 145 in CC12 ; 11-14-0762-03-00aj-proposed-text-resolution-to-cid-145-in-cc12", IEEE DRAFT; 11-14-0762-03-00AJ-PROPOSED-TEXT-RESOLUTION-TO-CID-145-IN-CC12, IEEE-SA MENTOR, PISCATAWAY, NJ USA, vol. 802.11aj, no. 3, 19 January 2015 (2015-01-19), pages 1-10, XP068082384, [retrieved on 2015-01-19] the whole document | 1-25                  |
| X         | US 2014/055302 A1 (JIA ZHANFENG [US]) 27 February 2014 (2014-02-27) paragraph [0044] - paragraph [0095]<br>-----<br>-/-                                                                                                                                                                                                                                                                | 1-25                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

9 May 2017

Date of mailing of the international search report

17/05/2017

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/019172

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                      |                       |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                   | Relevant to claim No. |
| X                                                    | WO 2013/028171 A1 (INTEL CORP [US]; DINUR NATI [IL]; ALPERT YARON [IL]; SOFFER MENASHE [I] 28 February 2013 (2013-02-28) page 8, line 11 - page 17, line 28<br>----- | 1-25                  |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/019172

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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