



(51) International Patent Classification:

G01S 5/00 (2006.01)

H04W 64/00 (2009.01)

G01S 5/02 (2010.01)

(21) International Application Number:

PCT/SE2019/050797

(22) International Filing Date:

27 August 2019 (27.08.2019)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicant: **TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)** [SE/SE]; 164 83 Stockholm (SE).

(72) Inventors: **DWIVEDI, Satyam**; Dalbovägen 6B, SE-191 45 Sollentuna (SE). **VYAS, Avneesh**; Brogatan 2, SE-174 41 SUNDBYBERG (SE). **ASPLUND, Henrik**; Borgargatan 16, SE-117 34 STOCKHOLM (SE). **LIN, Xingqin**; 2755 Augustine Drive, SANTA CLARA, California 95054 (US).

(74) Agent: **BOU FAICAL, Roger**; Ericsson AB, Patent Unit Kista RAN 1, 164 80 Stockholm (SE).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

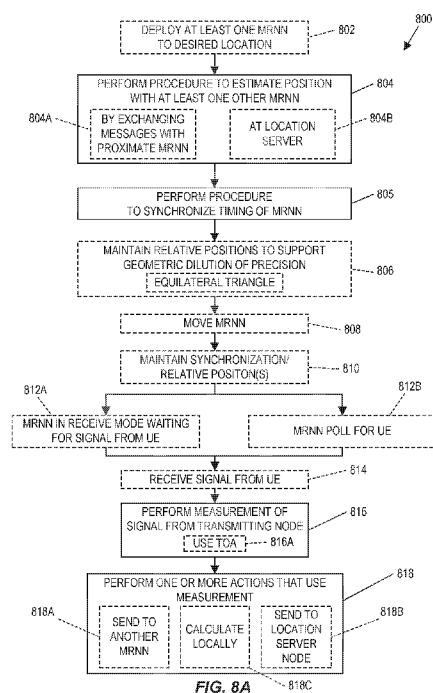
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: POSITION ESTIMATION FOR EMITTERS OUTSIDE LINE OF SIGHT OF FIXED NETWORK NODES



(57) Abstract: Systems and processes for position estimation for emitters outside of line of sight of fixed network nodes are disclosed. The positions of the mobile nodes are determined and the mobile nodes are time synchronized. Then, locations of one or more user equipments (UEs) are determined. The mobile radio network nodes may be air, land, or water-borne (e.g., mounted on drones, trains, boats, planes, automobiles, or the like). The UEs to be located may be a wide range of devices such as emergency transmitters, mobile phones, simple sensor nodes, and other Internet of Things (IoT) devices.

POSITION ESTIMATION FOR EMITTERS OUTSIDE LINE OF SIGHT OF FIXED NETWORK NODES

Technical Field

5 The present disclosure relates to a wireless communication network, and, in particular, to obtaining positioning measurements for user equipment through at least one mobile node of the wireless communication network.

Background

10 Wireless communication networks, such as cellular networks, enable various human- and machine-centric services, including providing positioning measurement reporting of user devices for various purposes. Future wireless communication networks will include mobile base stations and/or network access points (e.g., aerial base stations with adaptive altitudes, and/or base stations mounted on ground vehicles, as non-limiting examples) to
15 provide radio connectivity. Such mobile radio network nodes can extend radio coverage to areas in which accessing mobile networks with fixed access points is difficult or impossible at present. Mobile radio network nodes are also relevant for locations and scenarios in which network access demand varies significantly over time (e.g., in a stadium, a shopping mall, a factory, an underground mine, a seaport, or a remote natural resource exploration
20 and extraction site). Such mobile radio network nodes can also be useful to meet special quality of service (QoS) demands of users requiring accurate positioning and localization and/or users requiring communications that are highly secure, extremely reliable, and/or very high-speed communication.

25 The network of mobile radio network nodes can also include moving relays, which extend access to users that are difficult to reach otherwise in a cost-efficient way. Current wireless communication networks already provide relays, and enable links between relays in a manner similar to device-to-device (D2D) and vehicle-to-vehicle (V2V) sidelinks. Additionally, D2D and V2V positioning techniques and technologies are presently emerging.

30 Future networks will also provide connectivity to humans and devices aloft, such as drones and/or passengers in an airplane, as non-limiting examples. Positioning of such users is also important. To this end, the 3rd Generation Partnership Project (3GPP) has

approved a new study item on enhanced support for aerial vehicles in its Technical Specification Group (TSG) Radio Access Network (RAN) #75 plenary meeting. In terms of Long-Term Evolution (LTE) enhancements, positioning for aerial vehicles is one objective of the study item.

5 Small-cell solutions have traditionally targeted enhancing mobile network data rates in dense urban areas (mainly indoor locations such as stadiums, shopping malls, and the like) with high capacity demands. Motivated by operator obligations to reach 100% coverage in rural areas, another approach to the use of small cells has emerged. In this approach, mobile small cells (e.g., drones and/or balloons) are used, with drones being
10 more suited to situations requiring fast deployment and/or situations where there are only a limited number of subscribers, while balloons may be appropriate in situations in which a slower deployment is acceptable, but a better deployment footprint is required.

Positioning in LTE is supported by the architecture illustrated in Figure 1. As seen in Figure 1, direct interactions between a user equipment (UE) 100 and a location server (i.e.,
15 an Evolved Serving Mobile Location Center, or E-SMLC) 102 are enabled via the LTE Positioning Protocol (LPP) (defined in 3GPP Technical Specification (TS) 36.355 [1]), as indicated by arrow 104. Moreover, there are also interactions between the E-SMLC 102 and the eNodeB (eNB) 106 via the LPPa protocol (defined in 3GPP TS 36.455 [2]), as indicated by arrow 108. The interactions between the E-SMLC 102 and the eNB 106 may
20 be supported to some extent by interactions between the eNB 106 and the UE 100 using an LTE-Uu interface via the Radio Resource Control (RRC) protocol (defined by 3GPP TS 36.331 [3]), as indicated by arrow 110. Additionally, the E-SMLC 102 and mobility management entity (MME) 112 interact using an SL_s interface via the Location Services Application (LCS-AP) protocol (defined in 3GPP TS 29.171 [4]), as indicated by arrow 114.
25 Likewise, the MME 112 and a gateway mobile location center (GMLC) 116 interact using an SL_g interface (defined in 3GPP TS 29.172 [5]), as indicated by arrow 118.

In addition to the protocols and interfaces shown in Figure 1, the following positioning techniques are considered in LTE, as described in 3GPP TS 36.305 [6]:

- Enhanced Cell ID, which provides cell identifier (ID) information to associate a UE with a serving area of a serving cell, and also provides additional information to determine a finer granularity position;
- Assisted Global Navigation Satellite System (GNSS), in which GNSS information is retrieved by a UE and supported by assistance information provided to the UE from an E-SMLC.
- Observed Time Difference of Arrival (OTDOA), in which a UE estimates the time difference of reference signals from different base stations, and sends time difference data to an E-SMLC for multilateration; and
- Uplink Time Difference of Arrival (UTDOA), in which a UE is requested to transmit a specific waveform that is detected by multiple location measurement units (e.g., an eNB) at known positions, which then forward the measurements to an E-SMLC for multilateration.

However, non-line-of-sight (NLOS) situations are known to present challenges in the context of wireless positioning. There are presently no commercial solutions available to address such challenges and still provide sufficiently precise positioning, particularly in view of the tight expected positioning requirements in 5G wireless communication networks, such as a New Radio (NR) network. Additionally, in rural areas, one challenging issue for wireless communication network positioning is the sparse network deployment resulting in very large inter-site distance (ISD) between macro cells. While GNSS positioning may provide initial positioning functionality, GNSS receivers often are expensive in terms of cost and energy consumption. Further, the precision GNSS positioning provides may be too imprecise to manage a UE whose only network connectivity is through one or more mobile access points.

Summary

Embodiments of a method implemented in a mobile radio network node are disclosed herein. In some embodiments, the method implemented in the mobile radio network node comprises performing, together with two or more additional nodes, at least one of which is another mobile radio network node, one or more procedures. The one or

more procedures estimate a position of the mobile radio network node and positions of the two or more additional nodes. The one or more procedures also synchronize timing of the mobile radio network node relative to the two or more additional nodes. The method further comprises performing a measurement on a signal from a transmitting node, the measurement being a time of arrival (TOA) of the signal at the mobile radio network node. The method further comprises performing one or more actions that use the measurement.

In some embodiments, the position of the mobile radio network node and the positions of the two or more additional nodes comprise relative positions. In some embodiments, the position of the mobile radio network node and the positions of the two or more additional nodes comprise absolute positions.

In some embodiments, performing the one or more actions comprises providing the measurement to at least one other node for the at least one other node to calculate a position of the transmitting node. In some embodiments, performing the one or more actions comprises providing the measurement to a location server for the location server to calculate a position of the transmitting node.

In some embodiments, performing the one or more actions comprises receiving additional measurements from the two or more additional nodes. In some embodiments, performing the one or more actions also comprises calculating a time difference of arrival (TDOA) measurement based on the measurement and the additional measurements. In some embodiments, performing the one or more actions also comprises calculating a position of the transmitting node.

In some embodiments, the one or more procedures to estimate the position and synchronize the timing comprise a precision time protocol (PTP) measurement procedure to make PTP measurements. In some embodiments, the one or more procedures to estimate the position and synchronize the timing comprise using the PTP measurements to estimate clock skew between the mobile radio network node and one of the two or more additional nodes, estimate a time offset between the mobile radio network node and the one of the two or more additional nodes, and determine a distance between the mobile radio network node and the one of the two or more additional nodes.

In some embodiments, the signal from the transmitting node is time synchronized with the mobile radio network node. In some embodiments, the signal from the transmitting node is not time synchronized with the mobile radio network node. In some embodiments, the transmitting node is a user equipment (UE).

5 In some embodiments, the mobile radio network node is one of a drone, an automobile, a train, a vehicle, or an airplane. In some embodiments, the two or more additional nodes are mobile radio network nodes. In some embodiments, the another mobile radio network node is one of a drone, an automobile, a train, a vehicle, or an airplane. In some embodiments, the two or more additional nodes are drones.

10 In some embodiments, the method further comprises positioning the mobile radio network node relative to two of the two or more additional nodes such that an equilateral triangle is approximately formed. In some embodiments, the method further comprises moving the mobile radio network node after performing the one or more procedures. In some embodiments, the method further comprises maintaining relative positions between
15 the mobile radio network node and the two or more additional nodes while moving. In some embodiments, the signal comprises an ultrawideband (UWB) signal.

Embodiments of a mobile radio network node configured to communicate with a UE are also disclosed. In some embodiments, the mobile radio network node configured to communicate with the UE comprises a network interface and a processor configured to
20 cause the mobile radio network node to perform the method implemented in a mobile radio network node disclosed herein.

Embodiments of a method implemented in a mobile radio network node to locate a UE are also disclosed herein. In some embodiments the method comprises establishing a position estimate relative to at least two other network nodes. The method further
25 comprises synchronizing a time estimate with the at least two other network nodes. The method further comprises transmitting a position signal from the mobile radio network node to the UE. The method further comprises receiving a responsive position signal from the UE.

In some embodiments, the responsive position signal includes a calculated position
30 of the UE. In some embodiments, the responsive position signal includes a measurement

of the position signal and the method further comprises calculating at the mobile radio network node the position of the UE. In some embodiments, the responsive position signal includes a measurement of the position signal and the method further comprises sending the responsive position signal to a location server to calculate the position of the UE.

Embodiments of a mobile radio network node configured to communicate with a UE are also disclosed. In some embodiments, the mobile radio network node configured to communicate with the UE comprises a network interface and a processor configured to perform the method implemented in a mobile radio network node to locate a UE disclosed herein.

Brief Description of the Drawings

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

Figure 1 is a block diagram illustrating exemplary protocols and interfaces employed by Long-Term Evolution (LTE) wireless communication networks for providing architectural support for positioning;

Figure 2 illustrates one example of a cellular communication network according to some embodiments of the present disclosure;

Figure 3 is a block diagram illustrating establishment of a multi-hop route between fixed base stations and a user equipment (UE) using multiple mobile radio network nodes;

Figure 4 is a simplified diagram of a cellular network using Observed Time Difference of Arrival (OTDOA) multilateration to determine positions of a UE within the cellular network;

Figure 5 is a simplified diagram of a cellular network using uplink TDOA multilateration to determine positions of a UE within the cellular network;

Figure 6 is a simplified diagram of a cellular network with mobile nodes practicing time synchronization and relative positioning to determine a position of a UE within the cellular network;

Figure 7 is a simplified illustration of multilateration location of a UE using plural mobile nodes that are time synchronized and whose relative positions are known;

Figures 8A and 8B are flowcharts of alternate processes used by mobile nodes of a cellular network to assist in determining a position of a UE;

5 Figures 9A-9C are flowcharts of alternate processes used by a UE to assist in determining a position of the UE with mobile nodes of a cellular network;

Figure 10 is a schematic block diagram of a radio access node according to some embodiments of the present disclosure;

10 Figure 11 is a schematic block diagram that illustrates a virtualized embodiment of the radio access node of Figure 10 according to some embodiments of the present disclosure;

Figure 12 is a schematic block diagram of the radio access node of Figure 10 according to some other embodiments of the present disclosure;

15 Figure 13 is a schematic block diagram of a UE according to some embodiments of the present disclosure; and

Figure 14 is a schematic block diagram of the UE of Figure 13 according to some other embodiments of the present disclosure.

Detailed Description

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

Radio Node: As used herein, a "radio node" is either a radio access node or a wireless device.

Radio Access Node: As used herein, a "radio access node" or "radio network node" is any node in a radio access network of a cellular communications network that
30 operates to wirelessly transmit and/or receive signals. Some examples of a radio access

node include, but are not limited to, a base station (e.g., a New Radio (NR) base station (gNB) in a Third Generation Partnership Project (3GPP) Fifth Generation (5G) NR network or an enhanced or evolved Node B (eNB) in a 3GPP Long-Term Evolution (LTE) network), a high-power or macro base station, a low-power base station (e.g., a micro base station, a pico base station, a home eNB, or the like), and a relay node. It should be appreciated that a radio access node can be in a fixed location such as a cellular tower with associated base station or may be mobile such as a drone with base station functionality associated therewith. As used herein, such mobile radio access nodes are referred to as "mobile radio network nodes."

Core Network Node: As used herein, a "core network node" is any type of node in a core network or any node that implements a core network function. Some examples of a core network node include, e.g., a Mobility Management Entity (MME), a Packet Data Network Gateway (PGW), a Service Capability Exposure Function (SCEF), a Home Subscriber Server (HSS), or the like. Some other examples of a core network node include a node implementing a Access and Mobility Function (AMF), a UPF, a Session Management Function (SMF), an Authentication Server Function (AUSF), a Network Slice Selection Function (NSSF), a Network Exposure Function (NEF), a Network Repository Function (NRF), a Policy Control Function (PCF), a Unified Data Management (UDM), or the like.

Wireless Device: As used herein, a "wireless device" is any type of device that has access to (i.e., is served by) a cellular communications network by wirelessly transmitting and/or receiving signals to a radio access node(s). Some examples of a wireless device include, but are not limited to, a User Equipment device (UE) in a 3GPP network and a Machine Type Communication (MTC) device.

Network Node: As used herein, a "network node" is any node that is either part of the radio access network or the core network of a cellular communications network/system.

Note that the description given herein focuses on a 3GPP cellular communications system and, as such, 3GPP terminology or terminology similar to 3GPP terminology is oftentimes used. However, the concepts disclosed herein are not limited to a 3GPP system.

Note that, in the description herein, reference may be made to the term "cell"; however, particularly with respect to 5G NR concepts, beams may be used instead of cells and, as such, it is important to note that the concepts described herein are equally applicable to both cells and beams.

5 Systems and methods for position estimation for emitters outside line of sight of fixed network nodes are disclosed herein. Before addressing particulars of the present disclosure, an overview of cellular networks in which such systems and methods may be used is provided as well as an explanation of multilateration techniques such as time of arrival (TOA) and time difference of arrival (TDOA) with reference to Figures 2 through 5.
10 A discussion of exemplary aspects of the present disclosure begins below with reference to Figure 6.

 In this regard, Figure 2 illustrates one example of a wireless communication network 200 (e.g., a cellular communication network) according to some embodiments of the present disclosure. In some embodiments, the wireless communication network 200 is an
15 LTE network or a 5G NR network. In this example, the wireless communication network 200 includes base stations 202-1 and 202-2, which in LTE are referred to as eNBs and in 5G NR are referred to as gNBs, controlling corresponding macro cells 204-1 and 204-2. The base stations 202-1 and 202-2 are generally referred to herein collectively as base stations 202 and individually as base station 202. The base stations 202 are network
20 nodes as well as radio access nodes. It should be appreciated that in many instances the base stations 202 are fixed and thus may be referred to as a fixed radio access node or fixed network node. Likewise, the macro cells 204-1 and 204-2 are generally referred to herein collectively as macro cells 204 and individually as macro cell 204. The wireless communication network 200 may also include a number of low-power nodes 206-1 through
25 206-4 controlling corresponding small cells 208-1 through 208-4. The low-power nodes 206-1 through 206-4 can be small base stations or Remote Radio Heads, or the like. Notably, while not illustrated, one or more of the small cells 208-1 through 208-4 may alternatively be provided by the base stations 202. The low-power nodes 206-1 through 206-4 are generally referred to herein collectively as low-power nodes 206 and individually
30 as low-power node 206. Likewise, the small cells 208-1 through 208-4 are generally

referred to herein collectively as small cells 208 and individually as small cell 208. The base stations 202 are connected to a core network 210.

The base stations 202 and the low-power nodes 206 provide service to wireless devices 212-1 through 212-5 in the corresponding cells 204 and 208. The wireless devices 212-1 through 212-5 are generally referred to herein collectively as wireless devices 212 and individually as wireless device 212. In many situations, the wireless devices 212 are mobile terminals owned and/or operated by users, and thus, the wireless devices 212 are also sometimes referred to herein as user equipment or UEs. As noted above, the wireless devices 212 are radio nodes. The base stations 202 may also be communicatively coupled to a location server (i.e., an Evolved Serving Mobile Location Center, or E-SMLC), such as the location server 216. The location server 216 is configured to collect positioning measurements and other location information from, e.g., the base stations 202, the wireless devices 212, and/or other devices within the wireless communication network 200, and assisting the devices with positioning measurements and estimations.

To address the challenges described above with respect to, e.g., non-line-of-sight (NLOS) scenarios and/or sparse network deployment with large inter-site distance (ISD) between macro cells, one or more mobile radio network nodes 214 (e.g., mobile radio network nodes 214-1 and 214-2, also sometimes referred to as a mobile network node or as simply a mobile node) are provided for positioning purposes. Each of the mobile radio network nodes 214 is equipped with a small cell and is connected via wireless backhaul to the wireless communication network 200 (e.g., via a macro cell, or via another of the mobile radio network nodes 214). The mobile radio network nodes 214 each provide a relay between base stations (e.g., the base stations 202) and mobile units (i.e., the wireless devices 212) for positioning purposes, and thus can provide mobile node positioning in spite of an NLOS link between mobile units and base stations. In some embodiments, multiple mobile radio network nodes 214 may connect to each other in sequence to create a chain of relays providing a multi-hop route between the base stations 202 and the wireless devices 212. Multi-hop routes and factors affecting their establishment and positioning measurements are discussed in greater detail below with respect to Figure 3.

The use of a set of mobile radio network nodes 214 acting as moving access points and/or moving relays enables the degree of freedom in their mobility to be used to accurately determine a position of a particular user or group of users of the wireless devices 212 and/or a position of other moving access points and relays. For example, a multi-hop connection can be established between moving access points and relays, taking into account positioning requirements of users, relays, and access points, their sensing and measuring capabilities, and other quality of service (QoS) requirements that may exist. An illustration is shown in Figure 3, which illustrates establishment of a multi-hop route between fixed base stations 300-1 through 300-3 and a UE 302 using multiple mobile radio network nodes 304-1 through 304-3 (e.g., the mobile radio network nodes 214 of Figure 2, as non-limiting examples).

The accuracy of radio-based positioning techniques (e.g., based on time of arrival and angle of arrival of radio signals) relies heavily on the reception of sufficiently strong line-of-sight (LOS) signals at the receiving device or node. Consequently, positioning accuracy may be significantly degraded in the absence of LOS signal reception. This is different from other QoS requirements, where absence of LOS is often not a major issue because several reflected signals, when combined properly, can enhance performance.

Therefore, a multi-hop route, such as that illustrated in Figure 3, that is established with positioning requirements in mind may be very different from a multi-hop route that is established to satisfy other QoS requirements for communication. The criteria for establishing (and dynamically re-establishing) a multi-hop route between mobile radio network nodes may include consideration of the following:

- Required positioning accuracy of the mobile radio network nodes to be positioned;
- Radio propagation conditions (e.g., achieving LOS signal receptions between mobile radio network nodes);
- Sensing capabilities of mobile radio network nodes (e.g., provision of different sensors and their measurement performance, wherein the sensors can be of various types such as sensors for vision, radio signal reception, inertial, magnetic field measurement, and/or air pressure measurement, and the like);

- Radio signal transmission and reception capabilities (e.g., transceivers equipped with different antenna capabilities for transmission and/or reception);
- Availability of anchor points in the environment (e.g., signatures placed in the environment to support highly accurate positioning of some mobile radio network nodes in the multi-hop route, through sensors such as cameras);
- Constraints associated with mobility of mobile radio network nodes, given that some mobile radio network nodes have higher flexibility (e.g., flying mobile radio network nodes in the air);
- Network geometry (e.g., geometric dilution of precision for trilateration-based techniques like the Observed Time Difference of Arrival (OTDOA) positioning method employed in LTE);
- Diversity and density of mobile radio network nodes to be positioned;
- Availability of reliable power source to mobile radio network nodes (e.g., battery life and battery recharge capability using techniques such as energy harvesting);
- and
- Other QoS requirements.

Once a multi-hop route is established, positioning measurements can be reported to the wireless communication network in various ways. Selection of an appropriate measurement reporting protocol can depend on factors such as the following:

- Which mobile radio network nodes in the network accurately know their own position;
- Whether a positioning request is initiated by the wireless communication network (e.g., the wireless communication network wants to know where mobile radio network nodes and/or UE are located), by a mobile radio network node that is requesting to be positioned (e.g., a mobile radio network node wants to know where it is located), or by an external entity (e.g., a UE may request to be positioned);
- Whether a multi-hop route can be reconfigured before measurement reporting is complete (which would require checking that reporting is done even if route is reconfigured); and

- Any positioning requirements that impact granularity of the measurement report and reliability of the reporting protocol.

In some wireless communication networks, various types of multilateration processes may be employed to assist in determining location. Multilateration is a positioning technique based on measurement of time of arrival (TOA) of energy waves having a known propagation speed. The time it takes a signal to arrive from an emitter multiplied by the known propagation speed results in an approximate range in a circle around the emitter. When a second emitter, spaced apart from the first emitter, is added to the system, the respective range circles may intersect at one or more locations. The receiver must necessarily be present at one of these intersections. By extension, a two-dimensional location can be isolated with three emitters, and a three-dimensional location can be isolated with four emitters.

A brief overview of multilateration is provided with reference to Figure 4. Specifically, if there is a network 400 with at least three synchronized transmitting nodes 402(1)-402(3) (here the transmitting nodes 402(1)-402(3) are radio access nodes or base stations such as base stations 212) and a UE (synchronized with the transmitting nodes 402(1)-402(3)) at position 404, the position 404 may be determined. In particular, it takes time τ_1 for a signal 406(1) to travel from the transmitting node 402(1) to position 404. If the propagation speed of the signal 406(1) is known, this time τ_1 corresponds to a distance (or radius) from the transmitting node 402(1). The UE at the position 404 may determine τ_1 if the transmitting node 402(1) includes a transmission start time in the signal 406(1). Similarly, it takes time τ_2 for signal 406(2) to travel from the transmitting node 402(2) to the position 404. Time τ_2 multiplied by the propagation speed of the signal 406(2) corresponds to a second distance (or radius) from the transmitting node 402(2). The UE at the position 404 may determine τ_2 if the transmitting node 402(2) includes a transmission start time in the signal 406(2). The circles intersect in two locations. Similarly, it takes time τ_3 for signal 406(3) to travel from the transmitting node 402(3) to the position 404. Time τ_3 multiplied by the propagation speed of the signal 406(3) corresponds to a third distance (or radius) from the transmitting node 402(3). The UE at the position 404 may determine τ_3 if the transmitting node 402(3) includes a transmission start time in the signal

406(3). This third distance allows position 404 to be discriminated between the two intersections of the first two circles.

Alternatively, instead of just simple TOA measurements, observed time difference of arrival (OTDOA or sometimes just TDOA) measurements can be made by the UE at position 404. The UE measures TOA for the signals 406(1)-406(3) and subtracts measured TOA values from that of a reference (in this case τ_1) to calculate the TDOA. Each TDOA corresponds to a hyperbola (e.g., H1 and H2, respectively) in two dimensions. Due to various signaling noises, there is some uncertainty in the measurements, and therefore, H1 and H2 are thought to have some uncertain region, denoted by the dotted lines in Figure 4. As with the TOA, the intersection, in this case the intersection of hyperbolas H1 and H2, identifies the region of the UE's location.

As illustrated in Figure 5, some systems use uplink TDOA for position determination instead of the downlink TDOA illustrated in Figure 4. One such uplink TDOA system is a system 500, which includes three receiving network nodes 502(1)-502(3). The receiving network nodes 502(1)-502(3) are radio access nodes or base stations such as base stations 212. A UE 504 is at position 506 and sends signals 508(1)-508(3) to the three receiving network nodes 502(1)-502(3). The receiving network nodes 502(1)-502(3) can perform TOA measurements on the signals 508(1)-508(3) to determine how far the UE 504 is from a given receiving network node 502(1)-502(3) (e.g., circles C1, C2, and C3) to determine the intersection of the circles C1, C2, and C3. Alternatively, the TOA measurements may be provided to a central location server (e.g., the location server 216 of Figure 2) and TDOA calculations performed to determine the position 506.

The benefit of doing a measurement at the receiving network nodes 502(1)-502(3) is that the UE 504 does not require LTE or GPS functionality, which allows a broader range of UEs to be located. Further, note that in an uplink multilateration system, the UE 504 does not have to be synchronized with the network because the TDOA measurements (sometimes referred as TDOA calculations) can still correct for such lack of certainty.

While TOA and TDOA solutions are capable of providing a first order position estimate, these solutions are limited by the fact that the base stations may not be capable of providing a precise emitter location. Further, the base stations may not have line-of-

sight to a UE, may have bad channels, or there may be other effects such as geometric-dilution-of-precision (GDOP) (i.e., error propagation as a mathematical effect of device topology on positional measurement precision). Still further, there are many places where wireless networks have less than complete coverage (e.g., forests, national parks, oceans, or the like). As noted, there may be instances where mobile radio network nodes such as drones can act as anchor nodes, relay nodes, or base stations. However, to get proper position estimates from such mobile radio network nodes, they must be time synchronized and know each other's relative position. For example, each nanosecond loss of time synchronization translates into thirty centimeters (30 cm) of positioning estimation error. A time precision error of more than a few hundred nanoseconds is common in commercially-deployed mobile networks.

It should be appreciated that performance when positioning through a mobile radio network node depends on environmental conditions such as signal hearability and propagation channel conditions. For example, even in regions of high coverage, multipath reception of a signal at the UE or lack of a clear line-of-sight may reduce the position estimate accuracy.

Exemplary aspects of the present disclosure focus on knowing the positions of the mobile nodes with sufficient precision such that the mobile radio network nodes accurately know their own absolute position as well as their position relative to other mobile nodes to assist in location services for UEs and particularly for rescue services. In exemplary aspects, the positions of the mobile radio network nodes are determined and the mobile radio network nodes are time synchronized. Then, locations of UEs are determined. The mobile radio network nodes may be air, land, or water-borne (e.g., mounted on drones, trains, boats, planes, automobiles, or the like). The UE to be located may be a wide range of devices such as emergency transmitters, mobile phones, simple sensor nodes, and other Internet of Things (IoT) devices.

While the present disclosure contemplates that the network nodes (e.g., fixed, mobile, radio access, or otherwise) that are being used to locate a target UE be time synchronized, the present disclosure does not require the target UE to be time synchronized with the network. This non-requirement allows accurate positioning of

simpler low-power emitters. Further, processing may be done in the mobile radio network node or other mobile node and thus does not require any backhaul infrastructure for time synchronization. Still further, coordinated mobility between the network nodes, and particularly among the mobile radio network nodes, allows relative positioning to maximize time synchronization precision for improved positioning of emitter nodes. Note also that the processes disclosed herein may be deployed as a stand-alone service or as an add-on to any existing positioning techniques already available such as LTE or GNSS positioning. Thus, positioning may be made available where no mobile or GNSS coverage exists or a coverage area of an existing positioning service may be extended.

One specifically contemplated use case is, as noted, rescue services. Rescue personnel may have UEs that transmit and receive according to the present disclosure to facilitate tracking the rescue personnel in remote areas or areas where conditions are such that conventional positioning solutions are inadequate.

While more detail is provided below with reference to Figure 8, a brief overview of how exemplary aspects of the present disclosure work are provided with reference to Figures 6 and 7. To facilitate the positioning of the present disclosure, a system 600 of mobile radio network nodes 602(1)-602(N) (generically mobile radio network node 602) is deployed as illustrated in Figure 6. A UE 604 is positioned within the system 600. Initially, the mobile radio network nodes 602(1)-602(N) determine their positions relative to one another. That is, each mobile radio network node 602 should be able to estimate a position of other mobile radio network nodes within line-of-sight with respect to itself. The positioning can be absolute as in the GNSS and longitude/latitude or relative such that the mobile radio network nodes know where they are positioned relative to one another without a specific external reference point. The position estimations may be performed using TOA measurements and/or TDOA calculations based on TOA measurements between the mobile radio network nodes 602(1)-602(N) or other positioning technique as needed or desired. In an exemplary aspect, the mobile radio network nodes 602 may be connected to a wireless network and the wireless network can play a role in determining positions by providing fixed network nodes (e.g., base stations 202) that may use multilateration or other similar technique to locate the mobile radio network nodes 602.

In addition, the mobile radio network nodes 602 may be able to perform over-the-air time synchronization.

Alternatively, both positioning estimation and time synchronization may be accomplished using precision time protocol (PTP) with measurements shared between the mobile radio network nodes 602. Using PTP operates as follows: the mobile radio network node 602(1) and mobile radio network node 602(2) run PTP. From the PTP measurements, the parameters α_{12} , β_{12} , ρ_{12} can be estimated. α_{12} is the clock skew between clocks of the mobile radio network node 602(1) and the mobile radio network node 602(2). β_{12} is the time offset between the mobile radio network node 602(1) and the mobile radio network node 602(2) when the PTP measurements were taken, and ρ_{12} is the distance between the mobile radio network node 602(1) and the mobile radio network node 602(2).

PTP measurements are repeated sequentially between mobile radio network nodes 602(1)-602(N) pairwise. The set of parameters available after the PTP is run pairwise among three mobile radio network nodes 602 are summarized in Table 1 below:

Table 1

Nodes 1 and 2	Nodes 1 and 3	Nodes 2 and 3
$\alpha_{12}, \beta_{12}, \rho_{12}$	$\alpha_{13}, \beta_{13}, \rho_{13}$	$\alpha_{23}, \beta_{23}, \rho_{23}$

Mobile radio network nodes 602 communicate and share their measurements with each other in a distributed setup where the mobile radio network nodes 602 run the positioning algorithms. In a centralized setting, the mobile radio network nodes 602 communicate the measurements to a central server such as the location server 216 through a connected base station such as base station 202-1. While it is contemplated that mobile radio network nodes 602 take the PTP measurements, one (or more) of the nodes involved in taking such PTP measurements may be fixed.

Knowing all the respective distances in the network, the relative positions of the mobile radio network nodes 602 can be estimated in a distributed fashion or in a centralized fashion (e.g., at the location server 216). The relative positions can be estimated using any of the several known techniques like least squares minimization,

maximum likelihood techniques, or the like. One of the mobile radio network nodes 602 can be the reference zero coordinate, and positions of the other mobile radio network nodes 602 can be estimated with respect to that reference zero coordinate. Thus, knowing the relative positions as used herein means knowing positions relative to one another. This relative position fix is contrasted with an absolute position which, as used herein is defined to be an absolute position on a predefined coordinate system such as longitude/latitude or the like.

Once the relative positions and the relative time parameters of all the mobile radio network nodes 602 are estimated, the mobile radio network nodes 602 are ready to receive the measurements from an emitter, namely UE 604 whose location needs to be estimated. To this end, the mobile radio network nodes 602 may move from an initial position (e.g., a hangar or garage where the mobile radio network nodes 602 are recharged, refueled, have maintenance performed, or the like) to a second region in the vicinity of the location where the UE 604 is expected to be found (e.g., a national park where someone is lost, a collapsed building, or the like to continue the rescue services example).

The UE 604 may periodically emit or transmit a signal. This signal does not have to be defined for the present disclosure to work. However, the signal may be a periodic signal at a fixed frequency such as might be created by a diode transmitter.

Alternatively, the signal may be a modulated signal that has information embedded therein such as an identifier. The precise nature of the signal is not critical to the present disclosure. Likewise, this signal does not have to be synchronized with any signaling scheme used by the network. For the sake of illustration, this signal may be a PING. Each of the mobile radio network nodes 602(1)-602(N) that is within line-of-sight should receive the PING from the UE 604. On receipt, each of the mobile radio network nodes 602(1)-602(N) may measure the time of arrival with respect to an internal clock. For the sake of example, these measurements are toa_1 , toa_2 , and toa_3 .

Time difference of arrival (TDOA) measurements (sometimes referred to as TDOA calculations) are generated from the TOA measurements. The TDOA measurements are corrected with the relative clock parameters. As shown below:

$$tdoa_{12} = toa_1 - toa_2 - \alpha_{12} \Delta - \beta_{12}$$

$$tdoa_{13} = toa_1 - toa_3 - \alpha_{13} \Delta - \beta_{13}$$

$$tdoa_{23} = toa_2 - toa_3 - \alpha_{23} \Delta - \beta_{23}$$

5 From the TDOA measurements, an estimated position of the UE 604 may be calculated as generally shown in Figure 7, where hyperbolas 700(1)-700(3) intersect at UE node 702 that corresponds to a location of the UE 604 (Figure 6). It should be appreciated that there are many conventional techniques for determining location from TDOA measurements.

10 It should be appreciated that the present disclosure embraces the concept of first locating the mobile radio network nodes 602, and then locating the UE. Thus, there are two uses of position estimation algorithms. As noted, the initial use is to locate the mobile radio network nodes 602(1)-602(N) relative to one another and then to estimate the position of the UE 604.

15 While the above description provides one way that the location of a UE 604 may be determined, Figures 8A and 8B illustrate through flowcharts processes 800 and 850, respectively, for position determination. Process 800 assumes that the mobile radio network nodes 602 (abbreviated MRNN in Figures 8A and 8B) do the calculations, and the process 850 assumes that the UE 604 does some of the position calculations.

20 In this regard, the process 800 of Figure 8A begins with one or more mobile radio network nodes 602(1)-602(N) being deployed to a desired location (block 802). In an exemplary aspect, the desired location is a location under rescue (i.e., subject to search and rescue operations). While the mobile radio network nodes 602(1)-602(N) are being deployed or after, the mobile radio network node 602(1) performs a procedure to estimate
 25 a position with at least one other mobile radio network node 602(2) (block 804). As noted above, this position estimation may be made by exchanging messages with proximate mobile radio network nodes (block 804A) or by passing location information and/or messages received from other mobile network nodes to a location server (e.g., location server 216) (block 804B). Note that, as explained above, while three nodes are generally
 30 required for two-dimensional positioning, the present disclosure contemplates that one or

more of the nodes used to help provide positioning may be fixed, and therefore, block 804 contemplates position calculation with just at least one other mobile radio network node 602(2). It should also be appreciated that all the network nodes involved in the position calculation may be mobile network nodes. As used herein, estimating a position at block 5 804 also covers the situation where one of the nodes participating in the position estimation is fixed and "knows" its absolute position. However, even when an absolute position is known, a relative position may still be calculated as needed or desired. Note further that while the process 800 describes position calculation with at least one other mobile radio network node 602(2), it should be appreciated that the position calculation 10 may be done with nodes that are more properly characterized as UE (albeit not the one to be located). For example, a cellular phone or some other UE may have its location determined by GPS, and this cellular phone may provide that GPS derived location to a mobile node as part of the mobile node's position calculations.

The network nodes including the mobile radio network node 602(1) then perform a 15 procedure to synchronize timing therebetween (block 805). As noted above, this may be done through a procedure such as using PTP or other time synchronizing process.

Once the relative positions are known, in an exemplary aspect, the mobile radio network nodes 602(1)-602(N) may optionally maintain relative positions to support a geometric dilution of precision (GDOP) (e.g., in an ideal situation three mobile radio 20 network nodes 602(1)-602(N) form approximately an equilateral triangle) (block 806). As used herein, approximately an equilateral triangle means a triangle having at least one interior angle between fifty and seventy degrees. What should be avoided, if possible, is a line configuration, where three or more nodes are in a line or in a "flat" such that two of the interior angles of such a triangle are both less than fifteen degrees. Such a line or flat 25 triangle configuration introduces greater uncertainty in position determination and is more likely to suffer from single object blockages which prevent line of sight to a UE whose position is to be determined.

It should be appreciated that the mobile radio network nodes 602(1)-602(N) may move (block 808) after synchronization, either in response to environmental conditions, to 30 be closer to an area of interest, or for other reasons. However, the mobile radio network

nodes 602(1)-602(N) may maintain timing synchronization and relative positions (block 810). Alternatively, if relative positions cannot be maintained (e.g., some environmental or geographical feature precludes maintaining the relative positions), the mobile radio network nodes 602(1)-602(N) may update the position calculations such that the mobile radio network nodes 602(1)-602(N) still "know" respective positions so that further position calculations may be performed in furtherance of locating the UE. Note that movement may occur at any time during the process 800 or the process 850.

Regardless of movement, in a first exemplary aspect of the process 800, the mobile radio network nodes 602(1)-602(N) are in a receive mode waiting for a signal from the UE 604 (block 812A). This signal may be PING as previously described, a wideband, and/or an ultrawideband (UWB) signal. Alternatively, one or more of the mobile radio network nodes 602(1)-602(N) may poll for the UE to respond (block 812B).

The transmitting node of the device or person to be located (e.g., UE 604) may send a signal, and the mobile radio network node 602(1) receives the signal from the transmitting node (e.g., UE 604) (block 814) and performs a measurement of the signal from the transmitting node (block 816). In an exemplary aspect the measurement is a TOA measurement (block 816A) of the signal.

The process 800 continues by the mobile radio network node 602(1) performing one or more actions that use the measurement of the signal (block 818). In a first exemplary aspect, the mobile radio network node 602(1) sends the measurement of the signal to another mobile radio network node (block 818A). Alternatively, the mobile radio network node 602(1) may send the measurement of the signal to a location server node (e.g., location server 216) (block 818B). In these two possibilities, the other node (e.g., a different mobile radio network node 602(N) or the location server 216) may perform additional calculations such as calculating a TDOA measurement and calculate a position of the UE 604 therefrom. As a third option, the action of the mobile radio network node 602(1) is to receive further measurements of signals from other network nodes and calculate the position of the UE 604 locally (i.e., in the mobile radio network node 602(1)) (block 818C).

The process 850 of Figure 8B is similar in that the mobile radio network nodes initially follow the same steps of blocks 802-810 as process 800. However, in process 850, the UE 604 handles some of the processing required to calculate a position. Thus, while process 800 may use an uplink time difference of arrival (U-TDOA) technique (see for example, 3GPP REL-11) to locate the UE 604, the process 850 is more similar to an observed time difference of arrival (OTDOA) technique (see for example, 3GPP REL-9). Thus, in the process 850, the mobile radio network node 602 transmits a signal (referred to herein as a position signal) to the UE 604 (block 852). The position signal may include information about the mobile radio network node 602 such as an identifier, a time that the signal was sent relative to a system clock, or other information as needed or desired. The UE 604 performs a measurement on the position signal from the mobile radio network node 602 and sends back a responsive position signal to the mobile radio network node 602, which receives the responsive position signal from the UE 604 (block 854). At its simplest, the UE 604 may act like a radio frequency identifier tag and merely parrot back any received position signal, potentially appending or prepending a UE identifier if needed or desired. In such a case, it is readily apparent that the precise nature of the position signal is not critical to the present disclosure. In a second exemplary aspect, the UE 604 may decode incoming signals and/or derive sufficient information to take a TOA measurement from one or more mobile radio network nodes 602(1)-602(N) and from these TOA measurements, calculate a TDOA between incoming signals, which coupled with position information from the mobile radio network nodes 602(1)-602(N) may allow the UE 604 to calculate the UE 604 position (block 854A). In this exemplary aspect, the responsive position signal is the position of the UE 604. Again, this may be very similar to the OTDOA technique set forth in 3GPP REL-9. In a third exemplary aspect, the UE 604 may still decode incoming signals and/or derive sufficient information to take a TOA measurement from one or more mobile radio network nodes 602(1)-602(N) and from these TOA measurements, may calculate a TDOA between incoming signals. In this exemplary aspect, the responsive position signal merely includes information about the measurement taken by the UE 604 (block 854B) (e.g., the TOA measurements or the calculated TDOA measurements).

In the latter case, the mobile radio network node 602 may calculate the UE 604 position (block 856A) or may pass the information about the measurement to a location server for calculation of the position (block 856B).

On the other side, there are a variety of ways the UE 604 may operate as illustrated by flowcharts in Figures 9A-9C. In this regard, Figure 9A illustrates a process 900 where the UE transmitter transmits a signal or signals at regular intervals to the mobile radio network nodes 602 (block 902), and the mobile radio network nodes 602 further process the signal for location determination (block 904). This situation corresponds to block 804A.

In an alternate aspect, illustrated in Figure 9B, in process 910, the UE transmitter transmits a signal or signals responsive to a mobile radio network node's polling (block 912). The mobile radio network nodes 602 receive the signal(s) transmitted by the UE and perform further processing for location determination (block 914). This situation corresponds to block 804B.

In still another alternate aspect, illustrated in Figure 9C, in process 930, the UE 604 receives signals from multiple mobile radio network nodes 602 (block 932). The UE 604 may optionally calculate its position based on the received signals (block 934) and return a signal having information about the calculated position to the mobile radio network nodes 602 (block 936), or the UE 604 may merely return information about the received signals to the mobile radio network nodes at block 936. If the UE 604 did not calculate a position, the mobile radio network nodes 602 may calculate a position of the UE based on the returned signal (block 938) or may pass the signals to a location server for position determination (block 940).

It should be appreciated that while the above discussion assumes that the various signals exchanged are cellular type signals, the present disclosure is not so limited. Bluetooth, WIFI, and the like may also be used. Further, range finding lasers may also be used among the mobile network nodes to help find relative positions therebetween. Such alternate arrangement may be particularly useful in areas with no other positioning methods (e.g., basements, mines, or deep building interiors).

In still another possible aspect, the mobile radio network nodes may be initialized at manufacturing or in a preliminary controlled environment (e.g., a lab) before sending them

out. Such approach may be appropriate for simpler mobile network nodes which may not have over the air (OTA) time synchronization capabilities. Likewise, this approach may be appropriate for mobile network nodes equipped with a high-quality oscillator with a good holdover capability so that drift is minimized.

5 In still another aspect, the mobile radio network nodes 602(1)-602(N) and one or more self-backhauled mobile radio network nodes may perform TDOA measurements to position other mobile phones/UE within the vicinity. As is understood in the cellular industry, backhaul is a term used to refer to getting data back to the core network. Thus, a self-backhauled node is capable of getting data back to the core network. Thus, one
10 exemplary such self-backhauled mobile radio network node would be a mobile radio network node with base station capabilities that has line of sight to a fixed network node that is part of the core network. This approach may allow existing networks to employ already positioned UEs or self-backhauled nodes to further locate a wider range of emitter nodes (e.g., Bluetooth nodes) without positioning capability.

15 Figure 10 is a schematic block diagram of a radio access node 1000 according to some embodiments of the present disclosure. The radio access node 1000 may be, for example, a base station 202, 206, or any of the mobile radio network nodes 602. As illustrated, the radio access node 1000 includes a control system 1002 that includes one or more processors 1004 (Application Specific Integrated Circuits, Field Programmable Gate
20 Arrays, and/or the like), memory 1006, and a network interface 1008. The one or more processors 1004 are also referred to herein as processing circuitry. In addition, the radio access node 1000 includes one or more radio units 1010 that each include one or more transmitters 1012 and one or more receivers 1014 coupled to one or more antennas 1016. The radio units 1010 may be referred to as, or be part of, radio interface circuitry. In some
25 embodiments, the radio unit(s) 1010 is external to the control system 1002 and connected to the control system 1002 via, e.g., a wired connection. However, in some other embodiments, the radio unit(s) 1010 and potentially the antenna(s) 1016 are integrated together with the control system 1002. The one or more processors 1004 operate to provide one or more functions of a radio access node 1000 as described herein. In some

embodiments, the function(s) are implemented in software that is stored, e.g., in the memory 1006 and executed by the one or more processors 1004.

Figure 11 is a schematic block diagram that illustrates a virtualized embodiment of the radio access node 1000 according to some embodiments of the present disclosure.

5 This discussion is equally applicable to other types of network nodes. Further, other types of network nodes may have similar virtualized architectures.

As used herein, a "virtualized" radio access node is an implementation of the radio access node 1000 in which at least a portion of the functionality of the radio access node 1000 is implemented as a virtual component(s) executing on a physical processing node(s) in a network(s). As illustrated, in this example, the radio access node 1000 includes the control system 1002 that includes the one or more processors 1004, the memory 1006, and the network interface 1008, and the one or more radio units 1010 that each includes the one or more transmitters 1012 and the one or more receivers 1014 coupled to the one or more antennas 1016, as described above. The control system 1002 is connected to the radio unit(s) 1010 via, for example, an optical cable or the like. The control system 1002 is connected to one or more processing nodes 1100 coupled to or included as part of a network(s) 1102 via a network interface 1108. Each processing node 1100 includes one or more processors 1104, memory 1106, and a network interface 1108.

In this example, functions 1110 of the radio access node 1000 described herein (e.g., the location services) are implemented at the one or more processing nodes 1100 or distributed across the control system 1002 and the one or more processing nodes 1100 in any desired manner. In some particular embodiments, some or all of the functions 1110 of the radio access node 1000 described herein are implemented as virtual components executed by one or more virtual machines implemented in a virtual environment(s) hosted by the processing node(s) 1100. As will be appreciated by one of ordinary skill in the art, additional signaling or communication between the processing node(s) 1100 and the control system 1002 is used in order to carry out at least some of the desired location determination functions 1110. Notably, in some embodiments, the control system 1002 may not be included, in which case the radio unit(s) 1010 communicates directly with the processing node(s) 1100 via an appropriate network interface(s).

In some embodiments, a computer program including instructions which, when executed by at least one processor, cause the at least one processor to carry out the functionality of the radio access node 1000 or a node implementing one or more of the functions 1110 of the radio access node 1000 in a virtual environment according to any of the embodiments described herein is provided. In some embodiments, a carrier comprising the aforementioned computer program product is provided. The carrier is one of an electronic signal, an optical signal, a radio signal, or a non-transitory computer readable storage medium.

Figure 12 is a schematic block diagram of the radio access node 1000 (which as noted above may be a base station 202, 206, or any of the mobile radio network nodes 602) according to some other embodiments of the present disclosure. The radio access node 1000 includes one or more module(s) 1200, each of which is implemented in software. The module(s) 1200 provide the functionality of the radio access node 1000 described herein. This discussion is equally applicable to the processing node(s) 1100 of Figure 11 where the module(s) 1200 may be implemented at one of the processing nodes 1100 or distributed across multiple processing node(s) 1100 and/or distributed across the processing node(s) 1100 and the control system 1002.

Figure 13 is a schematic block diagram of a UE 1300 according to some embodiments of the present disclosure. The UE 1300 may be the UE 604. As illustrated, the UE 1300 includes one or more processors 1302, memory 1304, and one or more transceivers 1306 each including one or more transmitters 1308 and one or more receivers 1310 coupled to one or more antennas 1312. The transceiver(s) 1306 includes radio-front end circuitry connected to the antenna(s) 1312 that is configured to condition signals communicated between the antenna(s) 1312 and the processor(s) 1302, as will be appreciated by one of ordinary skill in the art. The one or more processors 1302 are also referred to herein as processing circuitry. The transceivers 1306 are also referred to herein as radio circuitry. In some embodiments, the functionality of the UE 1300 described above may be fully or partially implemented in software that is, e.g., stored in the memory 1304 and executed by the processor(s) 1302. Note that the UE 1300 may include additional components not illustrated in Figure 13 such as, e.g., one or more user interface

components, and/or the like and/or any other components for allowing input of information into the UE 1300 and/or allowing output of information from the UE 1300, a power supply, etc.

In some embodiments, a computer program including instructions which, when
5 executed by at least one processor, causes the at least one processor to carry out the functionality of the UE 1300 according to any of the embodiments described herein is provided. In some embodiments, a carrier comprising the aforementioned computer program product is provided. The carrier is one of an electronic signal, an optical signal, a radio signal, or a computer readable storage medium.

10 Figure 14 is a schematic block diagram of the UE 1300 according to some other embodiments of the present disclosure. The UE 1300 includes one or more module(s) 1400, each of which is implemented in software. The module(s) 1400 provide the functionality of the UE 1300 described herein.

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

While processes in the figures may show a particular order of operations performed by certain embodiments of the present disclosure, it should be understood that such order

is exemplary (e.g., alternative embodiments may perform the operations in a different order, combine certain operations, overlap certain operations, etc.).

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).

- 3GPP Third Generation Partnership Project
- 5G Fifth Generation
- AP Access Point
- ASIC Application Specific Integrated Circuit
- BSC Base Station Controller
- BTS Base Transceiver Station
- CD Compact Disk
- COTS Commercial Off-the-Shelf
- CPE Customer Premise Equipment
- CPU Central Processing Unit
- D2D Device-to-Device
- DAS Distributed Antenna System
- DSP Digital Signal Processor
- DVD Digital Video Disk
- eNB Enhanced or Evolved Node B
- E-SMLC Evolved Serving Mobile Location Center
- FPGA Field Programmable Gate Array
- GHz Gigahertz
- gNB New Radio Base Station
- GSM Global System for Mobile Communications
- IoT Internet of Things
- IP Internet Protocol
- LEE Laptop Embedded Equipment
- LME Laptop Mounted Equipment

	•	LTE	Long Term Evolution
	•	M2M	Machine-to-Machine
	•	MANO	Management and Orchestration
	•	MCE	Multi-Cell/Multicast Coordination Entity
5	•	MDT	Minimization of Drive Tests
	•	MIMO	Multiple Input Multiple Output
	•	MME	Mobility Management Entity
	•	MSC	Mobile Switching Center
	•	MSR	Multi-Standard Radio
10	•	MTC	Machine Type Communication
	•	NB-IoT	Narrowband Internet of Things
	•	NFV	Network Function Virtualization
	•	NIC	Network Interface Controller
	•	NR	New Radio
15	•	O&M	Operation and Maintenance
	•	OSS	Operations Support System
	•	OTT	Over-the-Top
	•	PDA	Personal Digital Assistant
	•	P-GW	Packet Data Network Gateway
20	•	RAM	Random Access Memory
	•	RAN	Radio Access Network
	•	RAT	Radio Access Technology
	•	RF	Radio Frequency
	•	RNC	Radio Network Controller
25	•	ROM	Read Only Memory
	•	RRH	Remote Radio Head
	•	RRU	Remote Radio Unit
	•	SCEF	Service Capability Exposure Function
	•	SOC	System on a Chip
30	•	SON	Self-Organizing Network

- UE User Equipment
- USB Universal Serial Bus
- V2I Vehicle-to-Infrastructure
- V2V Vehicle-to-Vehicle
- 5 • V2X Vehicle-to-Everything
- VMM Virtual Machine Monitor
- VNE Virtual Network Element
- VNF Virtual Network Function
- VoIP Voice over Internet Protocol
- 10 • WCDMA Wideband Code Division Multiple Access
- WiMax Worldwide Interoperability for Microwave Access

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

Claims

What is claimed is:

1. A method implemented in a mobile radio network node (602) of a wireless
5 communication network (600), the method comprising:
performing, together with two or more additional nodes, at least one of which is
another mobile radio network node (602(2)), one or more procedures that:
estimate (804) a position of the mobile radio network node and positions of
the two or more additional nodes; and
10 synchronize timing (805) of the mobile radio network node relative to the two
or more additional nodes;
performing (816) a measurement on a signal from a transmitting node (604), the
measurement being a time of arrival, TOA, of the signal at the mobile radio network node;
and
15 performing (818) one or more actions that use the measurement.
2. The method of claim 1, wherein the position of the mobile radio network node and
the positions of the two or more additional nodes comprise relative positions.
- 20 3. The method of claim 1, wherein the position of the mobile radio network node and
the positions of the two or more additional nodes comprise absolute positions.
4. The method of any one of claims 1 to 3, wherein performing the one or more
actions comprises providing (818A) the measurement to at least one other node for the at
25 least one other node to calculate a position of the transmitting node.
5. The method of any one of claims 1 to 3, wherein performing the one or more
actions comprises providing (818B) the measurement to a location server for the location
server to calculate a position of the transmitting node.

6. The method of any one of claims 1 to 3, wherein performing the one or more actions comprises:

receiving additional measurements from the two or more additional nodes;

calculating a time difference of arrival, TDOA, measurement based on the

5 measurement and the additional measurements; and

calculating a position of the transmitting node (818C).

7. The method of any one of claims 1 to 6, wherein the one or more procedures to estimate the position and synchronize the timing comprise a precision time protocol, PTP,
10 procedure to make PTP measurements.

8. The method of claim 7, wherein the one or more procedures to estimate the position and synchronize the timing comprise using the PTP measurements to estimate clock skew between the mobile radio network node and one of the two or more additional nodes,
15 estimate a time offset between the mobile radio network node and the one of the two or more additional nodes, and determine a distance between the mobile radio network node and the one of the two or more additional nodes.

9. The method of any one of claims 1 to 8, wherein the signal from the transmitting
20 node is time synchronized with the mobile radio network node.

10. The method of any one of claims 1 to 8, wherein the signal from the transmitting node is not time synchronized with the mobile radio network node.

25 11. The method of any one of claims 1 to 10, wherein the transmitting node is a user equipment, UE (604).

12. The method of any one of claims 1 to 11, wherein the mobile radio network node is one of a drone, an automobile, a train, a vehicle, or an airplane.

13. The method of any one of claims 1 to 12, wherein the two or more additional nodes are mobile radio network nodes (602(2), 602(N)).

14. The method of any one of claims 1 to 13, wherein the another mobile radio network
5 node is one of a drone, an automobile, a train, a vehicle, or an airplane.

15. The method of any one of claims 1 to 14, wherein the two or more additional nodes are drones.

10 16. The method of any one of claims 1 to 15, further comprising positioning the mobile radio network node relative to two of the two or more additional nodes such that an equilateral triangle is approximately formed (806).

17. The method of any one of claims 1 to 16, further comprising moving (808) the
15 mobile radio network node after performing the one or more procedures.

18. The method of claim 17, further comprising maintaining (806) relative positions between the mobile radio network node and the two or more additional nodes while moving.
20

19. The method of any one of claims 1 to 18, wherein the signal comprises an ultrawideband, UWB, signal.

20. A mobile radio network node (602(1)) configured to communicate with a user
25 equipment, UE (604), the mobile radio network node comprising a network interface (1008) and a processor (1004) configured to cause the mobile radio network node to:
perform the method of any of the claims 1 to 19.

21. A method implemented in a mobile radio network node (602) to locate a User Equipment, UE (604), comprising:

establishing (804) a position estimate relative to at least two other network nodes (602(2), 602(N));

5 synchronizing (805) a time estimate with the at least two other network nodes;

transmitting (852) a position signal from the mobile radio network node to the UE;
and

receiving (854) a responsive position signal from the UE.

10 22. The method of claim 21, wherein the responsive position signal includes a calculated position of the UE (854A).

23. The method of claim 21, wherein the responsive position signal includes a measurement of the position signal (854B), the method further comprising calculating, at
15 the mobile radio network node, the position of the UE (856A).

24. The method of claim 21, wherein the responsive position signal includes a measurement of the position signal (854B), the method further comprising sending the responsive position signal to a location server (216) to calculate the position of the UE
20 (856B).

25. A mobile radio network node (602(1)) configured to communicate with a user equipment, UE (604), the mobile radio network node comprising a network interface (1008) and a processor (1004) configured to cause the mobile radio network node to:
25 perform the method of any of claims 21 through 24.

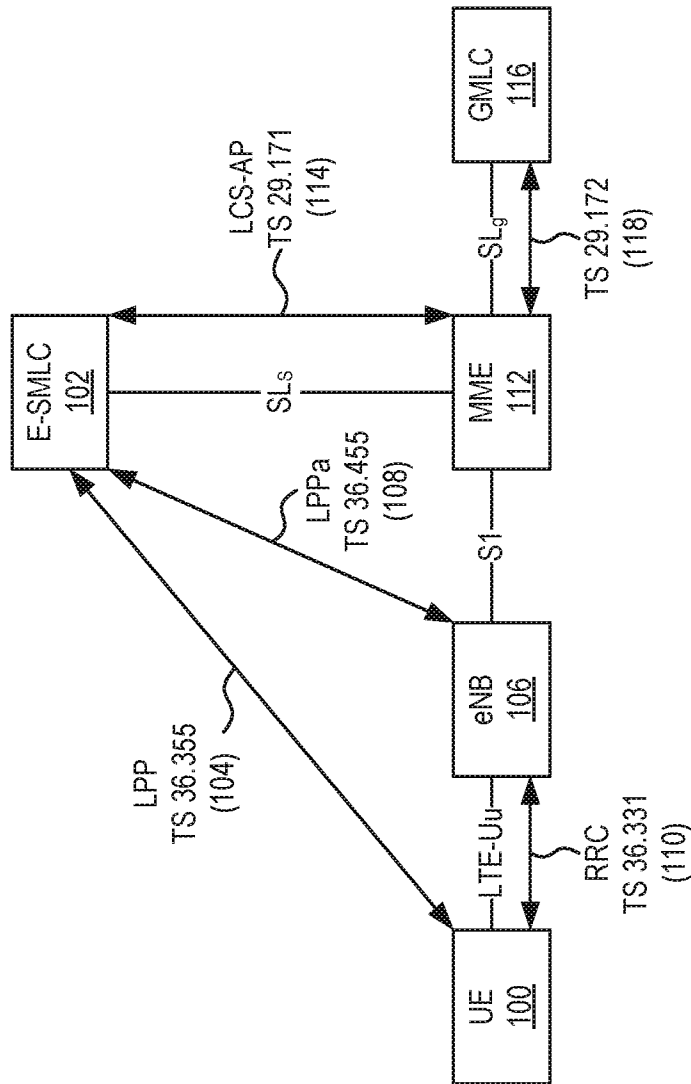


FIG. 1

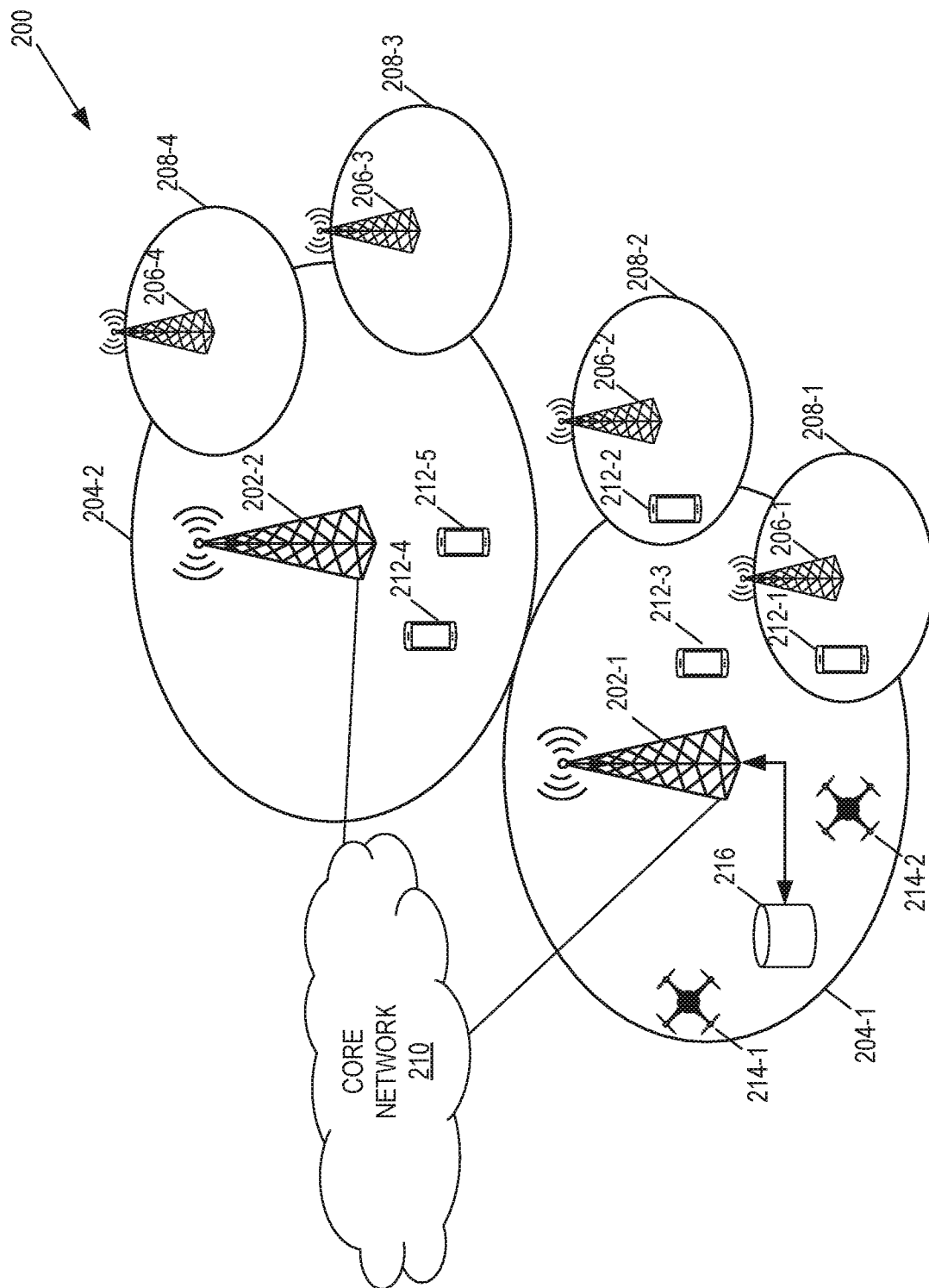


FIG. 2

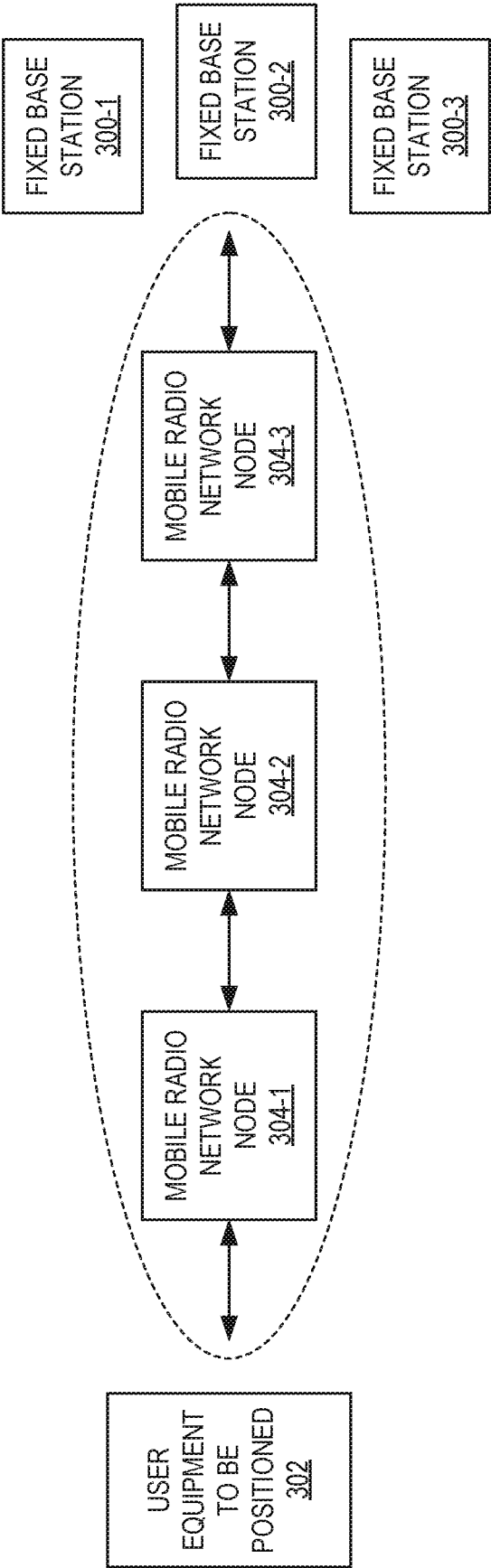


FIG. 3

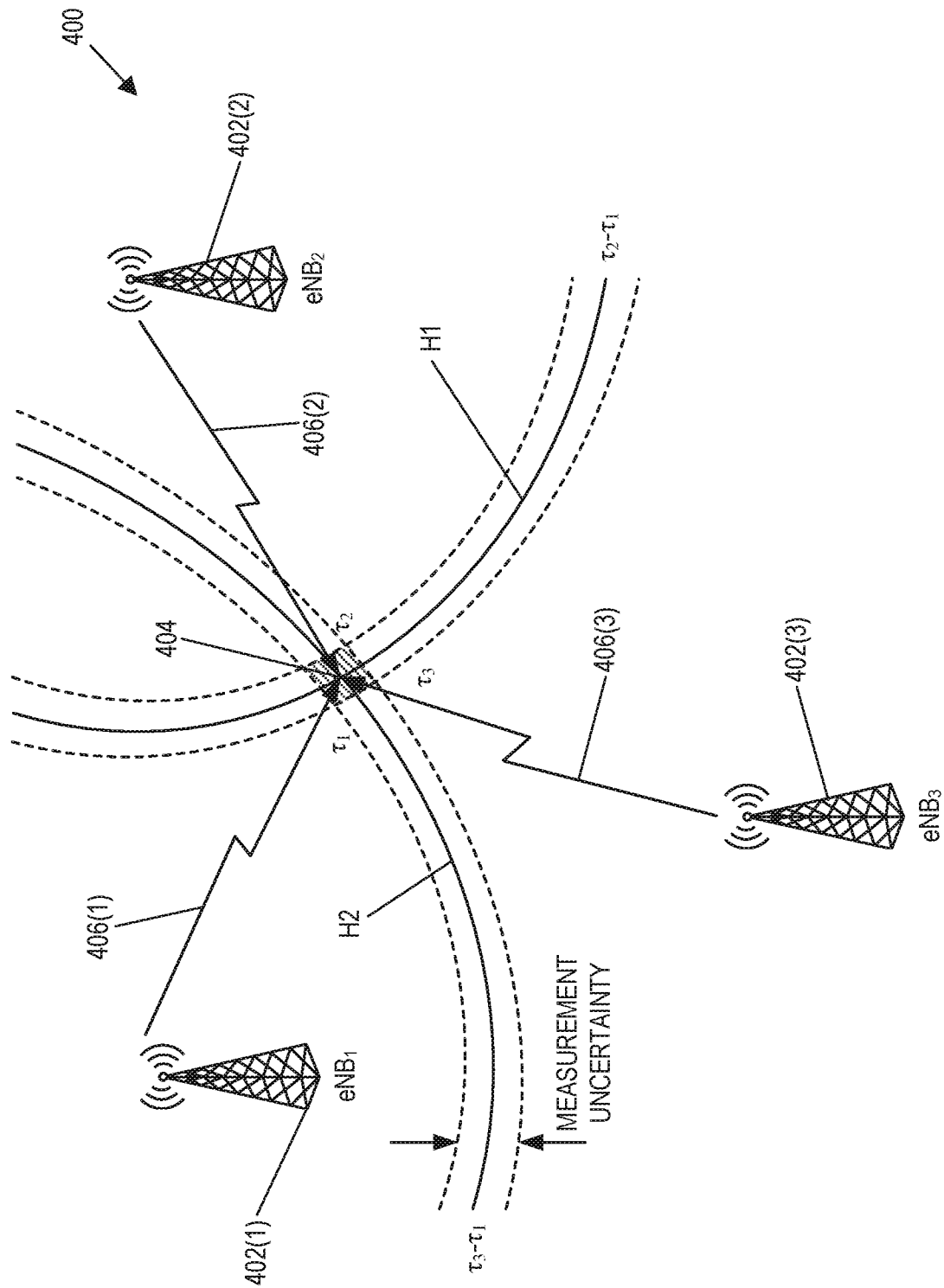


FIG. 4

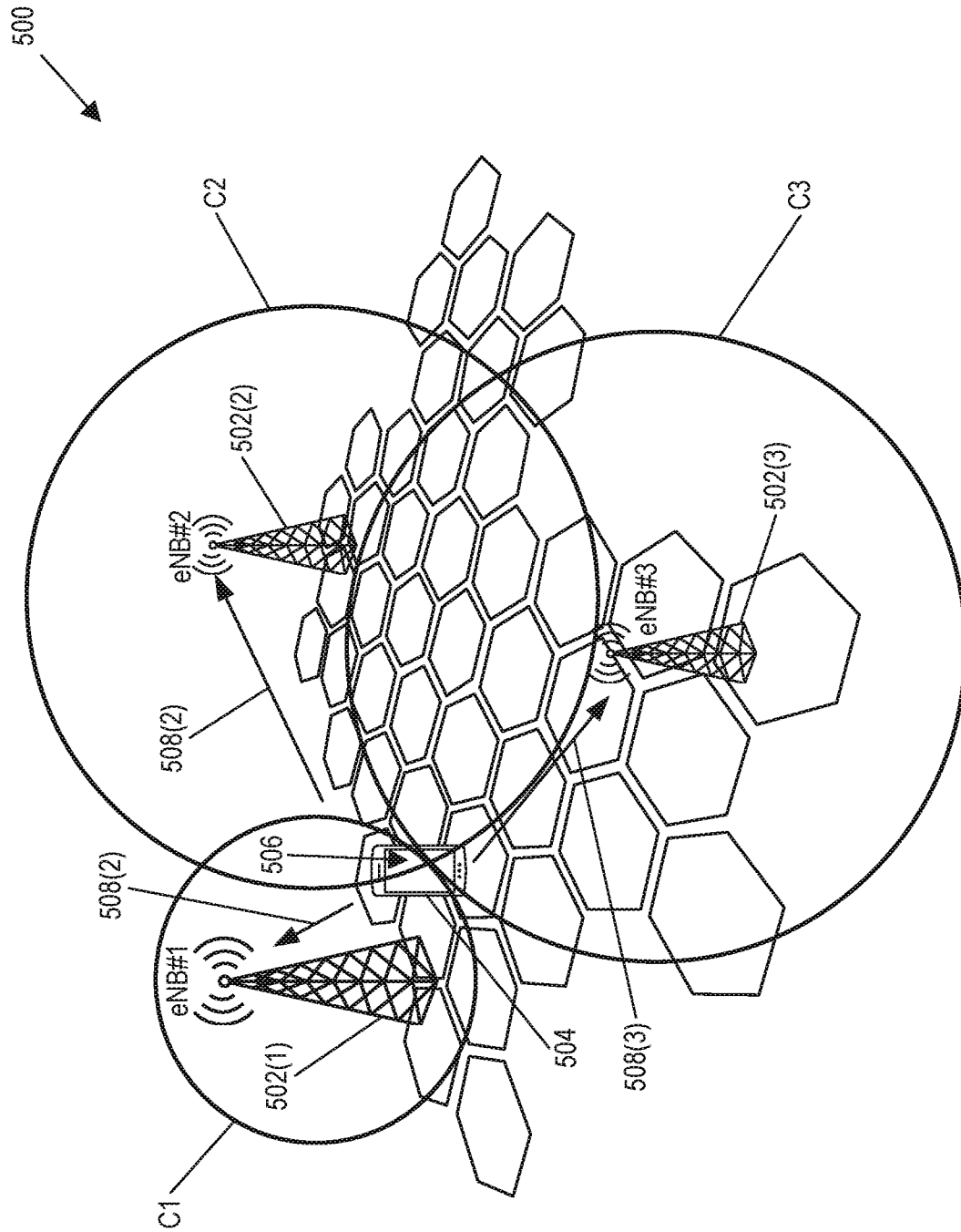


FIG. 5

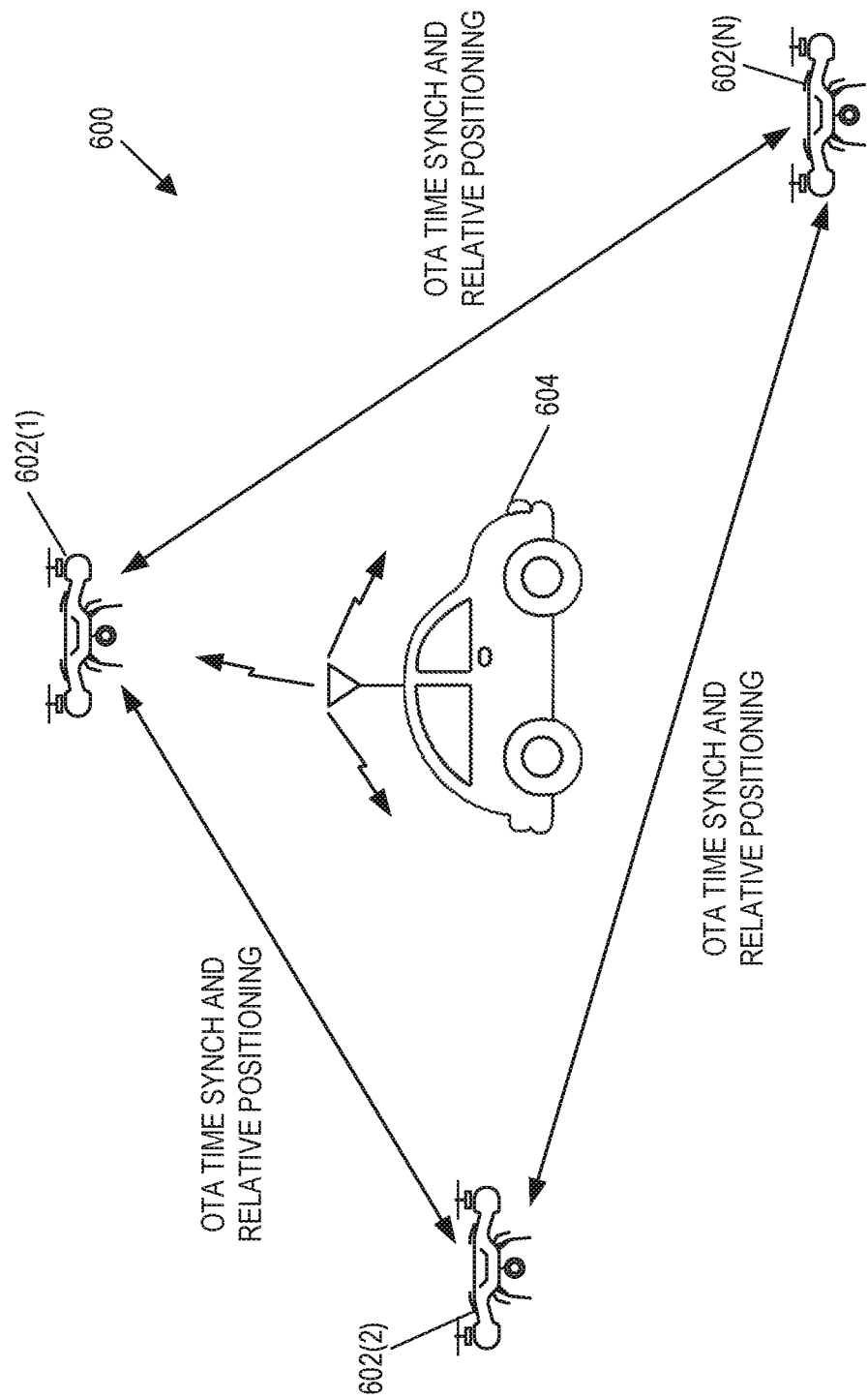


FIG. 6

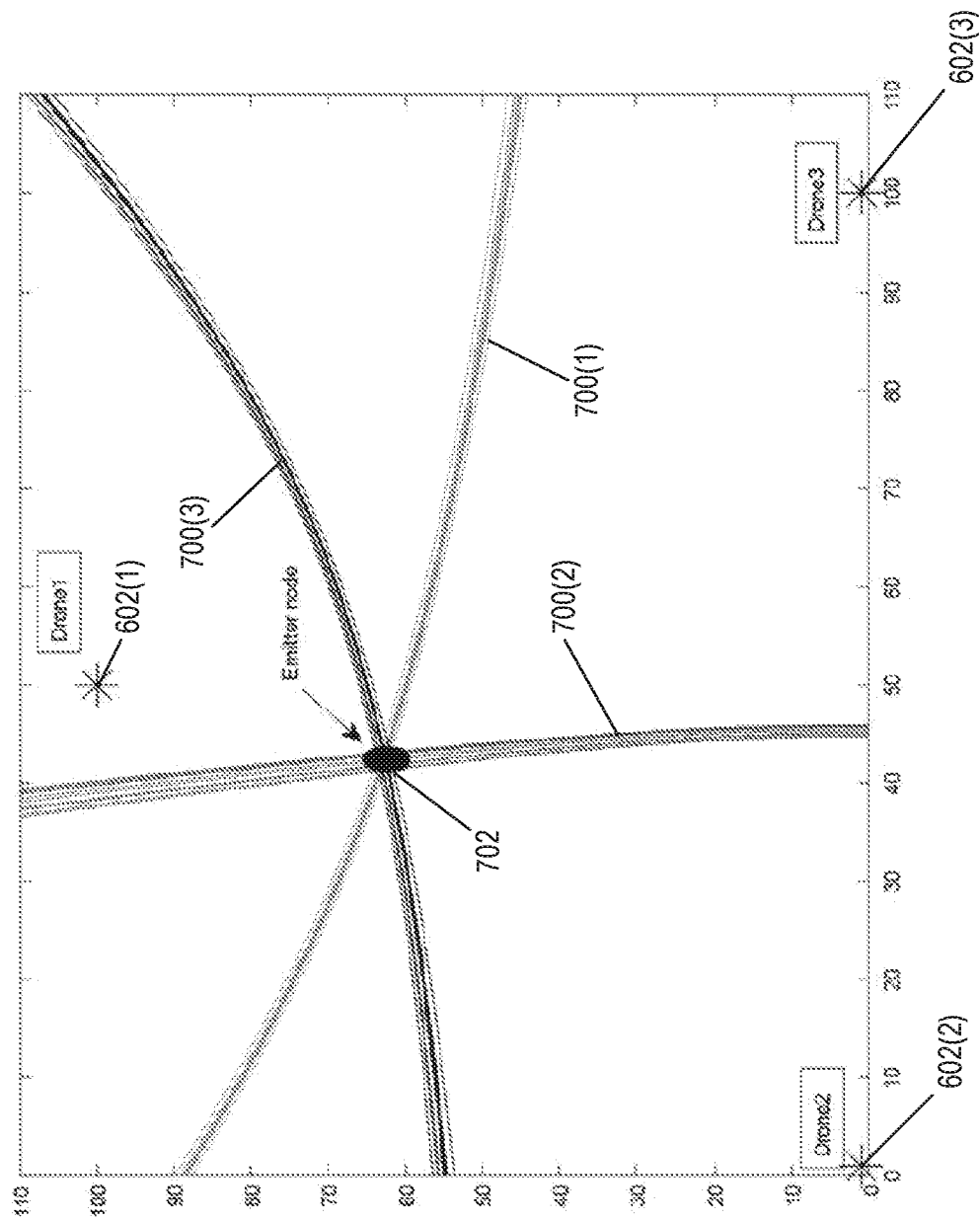


FIG. 7

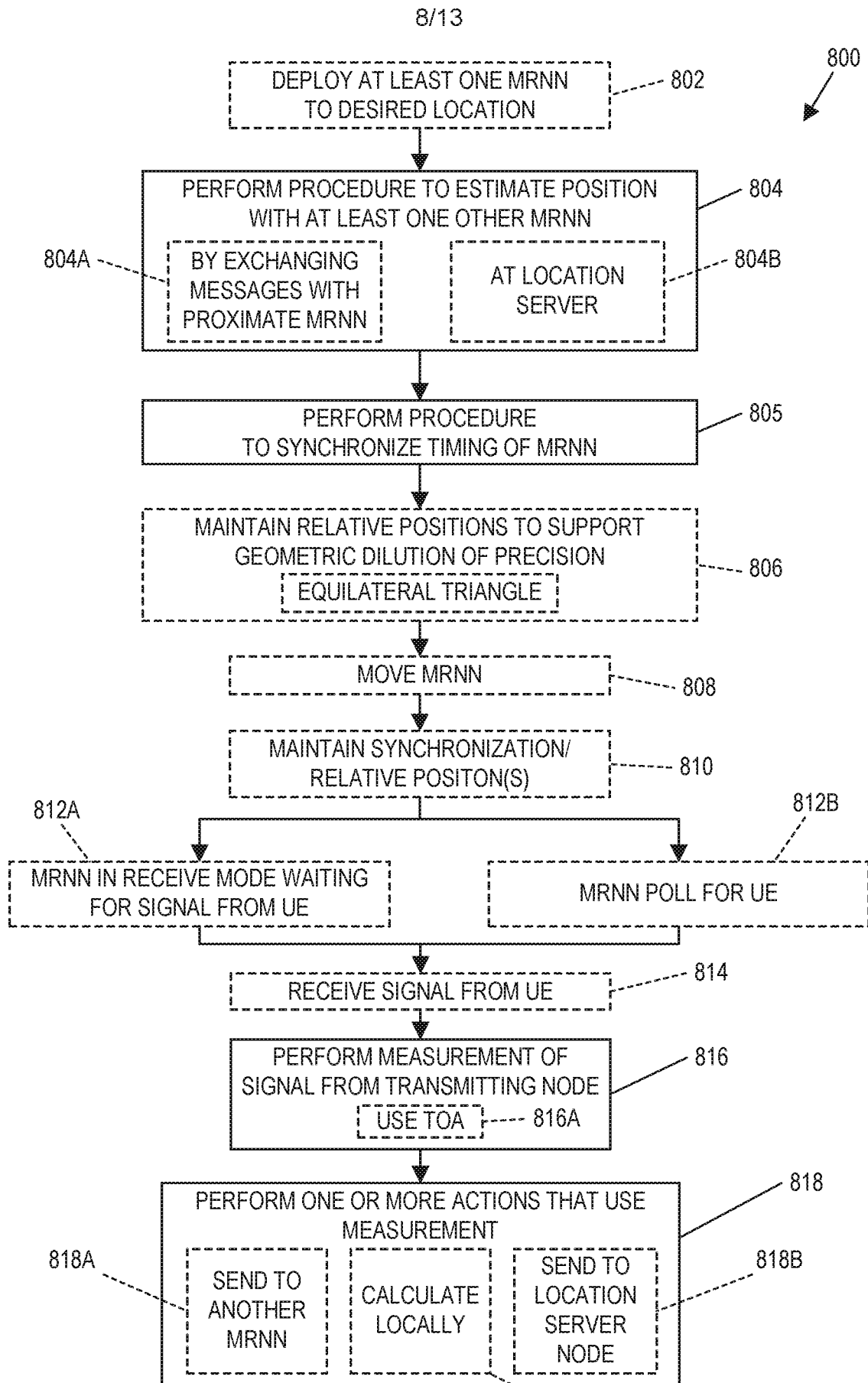
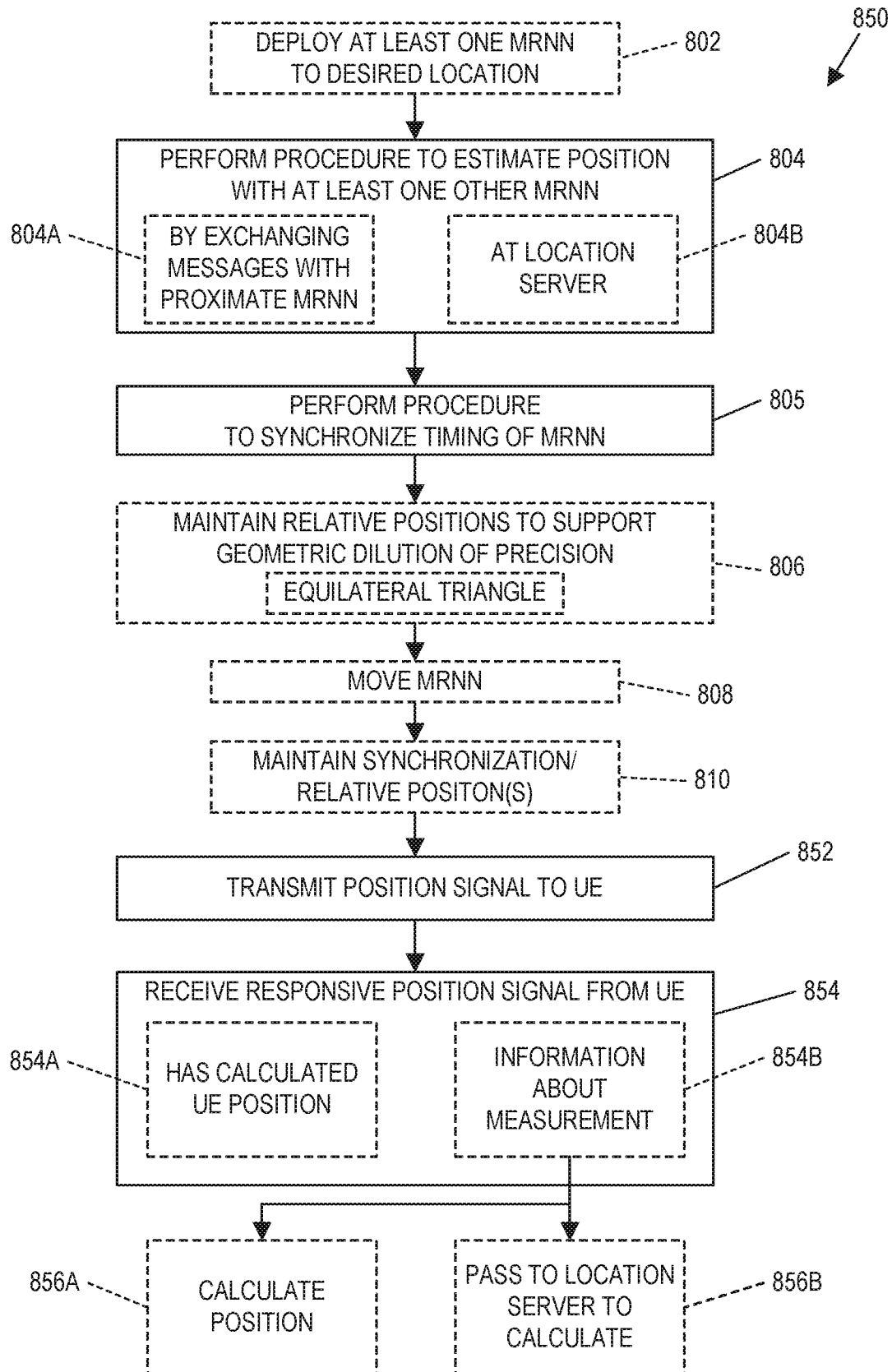
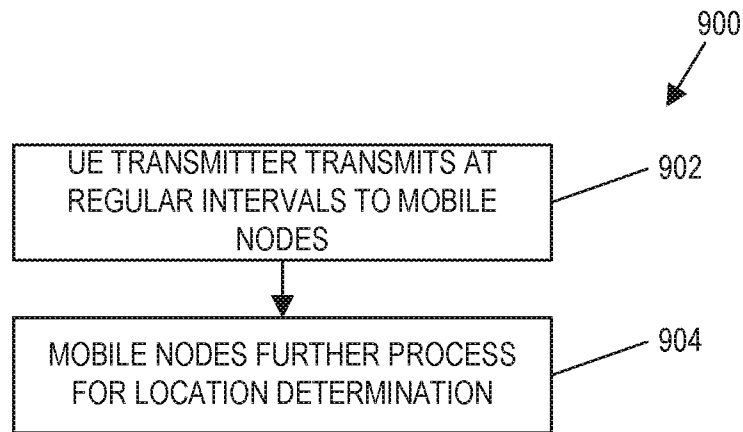
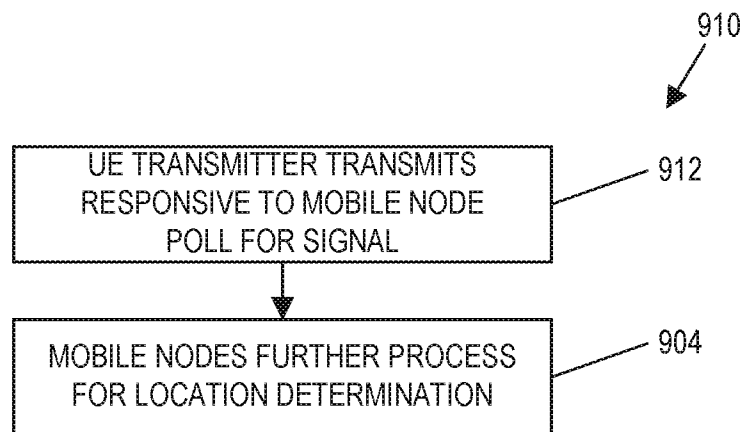
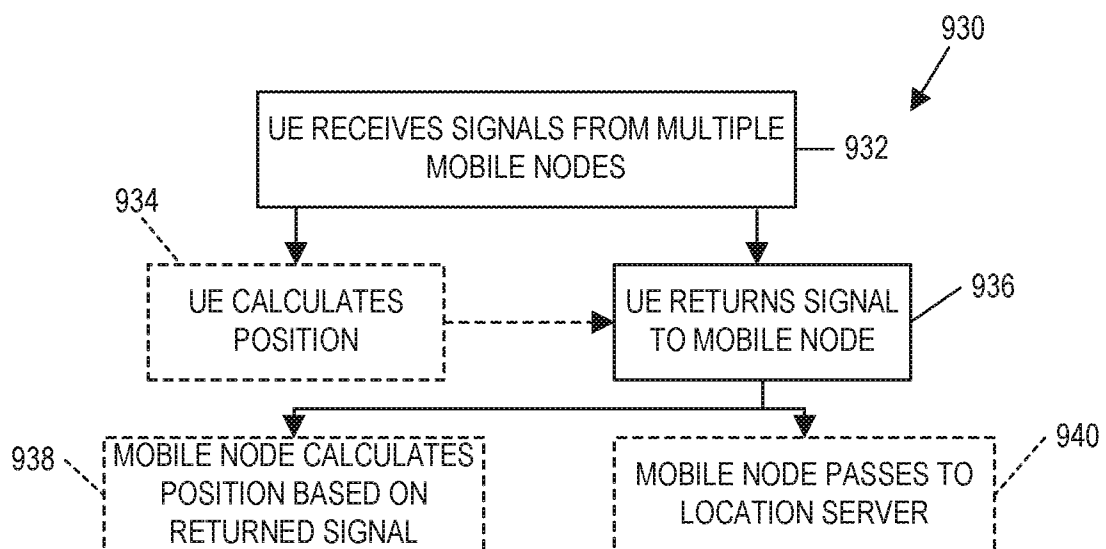


FIG. 8A

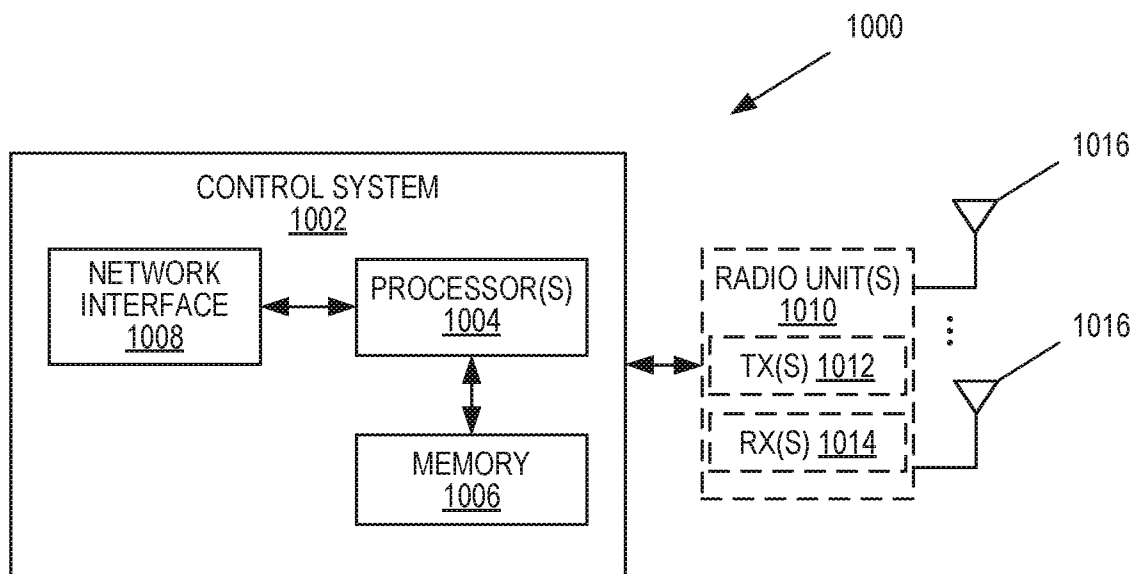
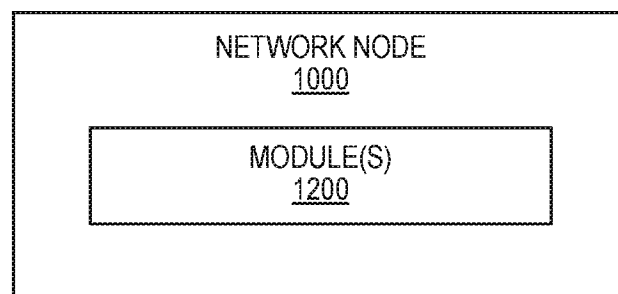
9/13

**FIG. 8B**

10/13

**FIG. 9A****FIG. 9B****FIG. 9C**

11/13

**FIG. 10****FIG. 12**

12/13

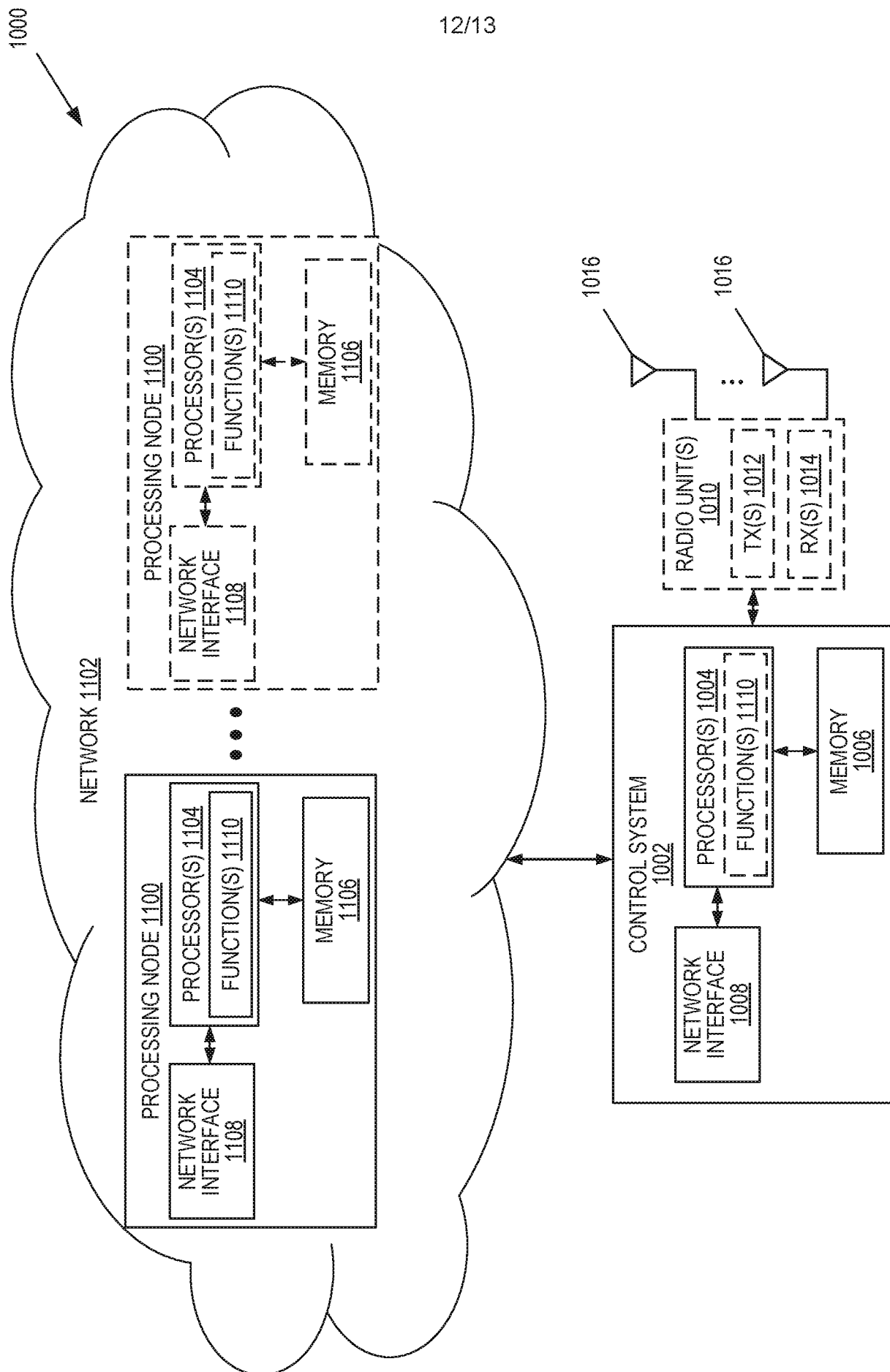
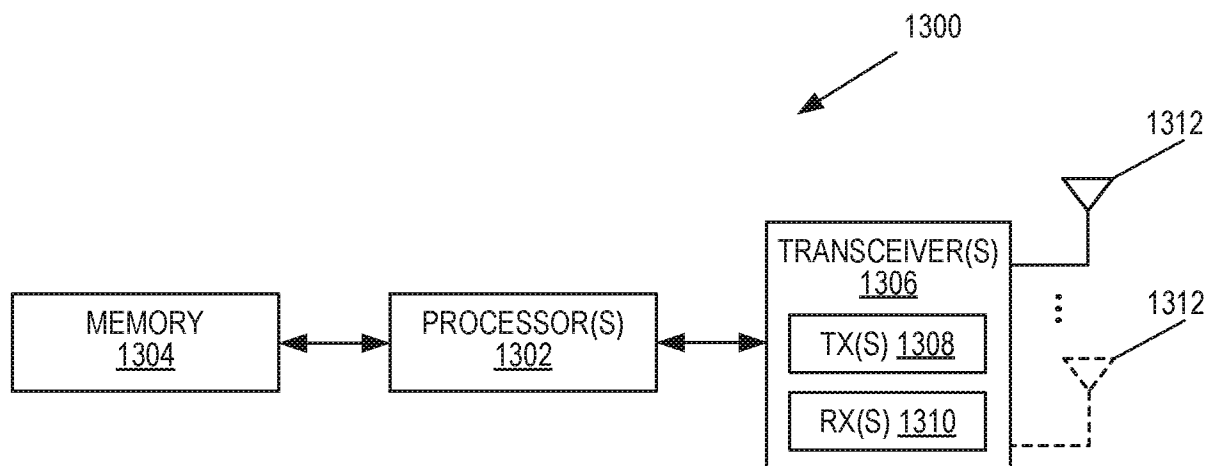
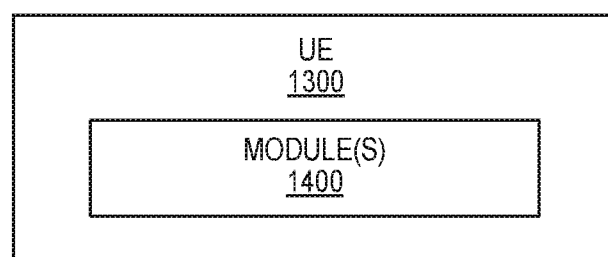


FIG. 11

13/13

**FIG. 13****FIG. 14**

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2019/050797

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01S5/00 G01S5/02 H04W64/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01S 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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/103696 A1 (CHEOK KA C [US] ET AL) 1 May 2008 (2008-05-01) abstract paragraph [0008] paragraphs [0028] - [0031] paragraphs [0036] - [0037] paragraphs [0059] - [0064] paragraphs [0076] - [0078] paragraph [0080]; figure 3 paragraph [0095]; figure 4 -----	1-25
Y	WO 2004/019559 A2 (BLUESOFT LTD [IL]; ALJADJEFF DANIEL [IL] ET AL.) 4 March 2004 (2004-03-04) abstract page 9, line 9 - page 11, line 15; figure 1 ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

23 April 2020

Date of mailing of the international search report

12/05/2020

Name and mailing address of the ISA/

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

Authorized officer

Möll, Hans-Peter

INTERNATIONAL SEARCH REPORT

International application No

PCT/SE2019/050797

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/143770 A1 (CHARBIT GILLES [GB] ET AL) 16 June 2011 (2011-06-16) abstract paragraph [0022]; figure 1 -----	21-25

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/SE2019/050797

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008103696 A1	01-05-2008	CA 2554417 A1	01-09-2005
		EP 1721186 A1	15-11-2006
		KR 20070015513 A	05-02-2007
		US 2005215269 A1	29-09-2005
		US 2008103696 A1	01-05-2008
		US 2008167051 A1	10-07-2008
		WO 2005081012 A1	01-09-2005

WO 2004019559 A2	04-03-2004	AU 2003250521 A1	11-03-2004
		EP 1547318 A2	29-06-2005
		JP 2005536944 A	02-12-2005
		US 2004072582 A1	15-04-2004
		US 2004203870 A1	14-10-2004
		WO 2004019559 A2	04-03-2004

US 2011143770 A1	16-06-2011	CN 102143578 A	03-08-2011
		US 2011143770 A1	16-06-2011
