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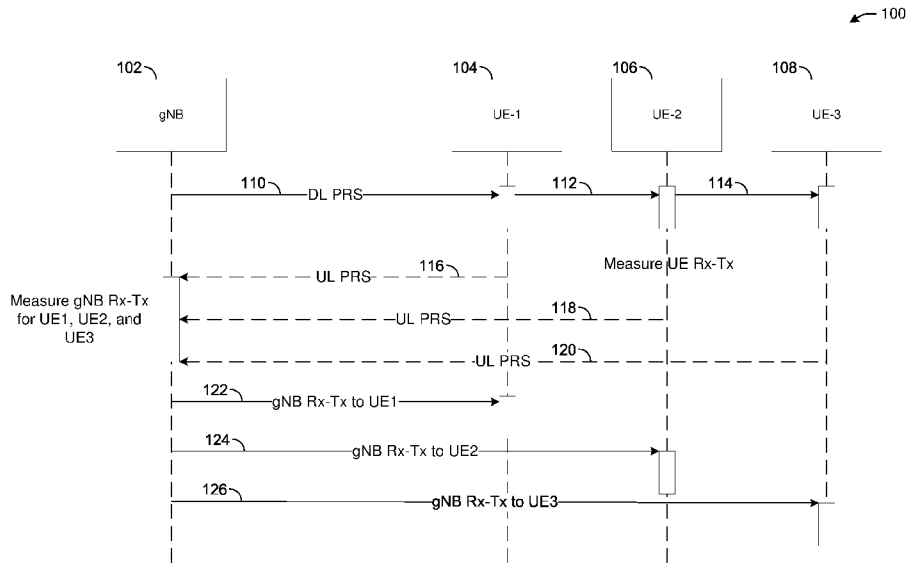


FIG. 1

(57) Abstract: This disclosure describes techniques for time difference indication for accurate propagation delay compensations. An example method may include calculating, by a user equipment (UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station. The example method may also include calculating a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE. The example method may also include determining a propagation delay based on the first time difference and the second time difference. The example method may also include performing a compensation for the propagation delay.

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TECHNIQUES FOR TIME DIFFERENCE INDICATION FOR ACCURATE PROPAGATION DELAY COMPENSATION

CROSS-REFERENCE TO RELATED PATENT APPLICATION(S)

This application claims the benefit of U.S. Provisional Application No. 63/138,093, filed January 15, 2021, the disclosure of which is incorporated by reference as set forth in full.

TECHNICAL FIELD

Various embodiments generally may relate to the field of wireless communications and, more particularly, to techniques for time difference indication for accurate propagation delay compensation.

BACKGROUND

New radio (NR) radio access technology (RAT) may provide ultra-reliable low latency communication (URLLC). URLLC services comprise a wide range of use cases from augmented reality (AR) and/or virtual reality (VR) to industrial automation and may require different levels of quality of service and a different combination of reliability and latency. Besides the flexibility in providing different levels of reliability and latency, it is also important for time-sensitive services to have an accurate absolute time reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is set forth with reference to the accompanying drawings. The use of the same reference numerals indicates similar or identical components or elements; however, different reference numerals may be used as well to indicate components or elements, which may be similar or identical. Various embodiments of the disclosure may utilize elements and/or components other than those illustrated in the drawings, and some elements and/or components may not be present in various embodiments. Depending on the context, singular terminology used to describe an element or a component may encompass a plural number of such elements or components and vice versa.

FIG. 1 illustrates an example flow diagram, in accordance with one or more embodiments of the disclosure.

FIG. 2 illustrates an example flow diagram, in accordance with one or more embodiments of the disclosure.

FIG. 3 illustrates an example flow diagram, in accordance with one or more

embodiments of the disclosure.

FIG. 4 illustrates an example downlink control information (DCI) packet, in accordance with one or more embodiments of the disclosure.

FIG. 5 illustrates an example method, in accordance with one or more embodiments of this disclosure.

FIG. 6 illustrates an example network, in accordance with one or more embodiments of this disclosure.

FIG. 7 illustrates an example wireless network, in accordance with one or more embodiments of this disclosure.

FIG. 8 illustrates an example of a computing system, in accordance with one or more embodiments of this disclosure.

Certain implementations will now be described more fully below with reference to the accompanying drawings, in which various implementations and/or aspects are shown. However, various aspects may be implemented in many different forms and should not be construed as limited to the implementations set forth herein; rather, these implementations are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Like numbers in the figures refer to like elements throughout. Hence, if a feature is used across several drawings, the number used to identify the feature in the drawing where the feature first appeared will be used in later drawings.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail. For the purposes of the present document, the phrases “A or B” and “A/B” mean (A), (B), or (A and B).

From Release-16, the NR specification supports the delivery of reference time information (UTC) to user equipment (UE) with a signaling error of +- 5 ns. Although the

reference time is delivered to a UE, there could be other sources of error that limit the accuracy of the obtained time reference. One example of one of these error sources may include propagation delay. Even if the message with the accurate time is transmitted exactly at the indicated reference time, which is being signaled, the reception of this message may be affected by the propagation delay. Another example may include frame boundary detection accuracy. Besides the propagation delay, the UE may have limited accuracy in detecting when the frame boundary starts with respect to which the reference timing was indicated.

In one or more embodiments, there are several approaches to determining propagation delay. A first approach may include timing advance (TA)-based propagation delay. The TA value may correspond to a length of time a signal takes to reach a base station from a UE. A second approach may include round-trip time (RTT)-based delay compensation. With this second approach, propagation delay estimation may be performed based on a radio access network (RAN)-managed Rx-Tx procedure that may otherwise be intended for time synchronization, for example. Pre-compensation of the reference time information taking into account UE propagation delay may also be performed. A third approach may include pre-compensation of propagation delay at gNB (for example, a base station) and reflecting this in reference timing information.

In one or more embodiments, the RTT-based propagation delay compensation may be performed using a number of different methods. A first example method may involve the UE performing the propagation delay compensation. In this first example method, the UE may receive a message from the gNB and may calculate a time difference between a time at which the message was received by the UE and a time at which the message was transmitted by the gNB. The UE may also send a second message to the gNB, and the gNB may perform a similar calculation. The gNB may then provide an indication of the time difference calculated by the gNB to the UE. Finally, the UE may calculate the propagation delay based on the time difference calculated by the UE and the time difference calculated by the gNB, and may compensate for this propagation delay. This first example method may be illustrated further in FIG. 1.

In one or more embodiments, a second example method may involve the gNB calculating the propagation delay and pre-compensating for propagation delay, rather than the UE calculating the propagation delay. In this example method, the UE may still receive a message from the gNB and may calculate a time difference between a time at which the message was received by the UE and a time at which the message was transmitted by the gNB. Additionally, the UE may still provide an indication of this time difference to the gNB

(alternatively, the UE may simply send another type of message back to the gNB, such as an uplink positioning reference signal (UL PRS), as is described in additional detail below with respect to FIG. 2). The gNB may still also perform its own time difference calculation. However, instead of sending an indication of this time difference back to the UE and the UE calculating the propagation delay, the gNB itself may instead calculate the propagation delay and pre-compensate for this calculated propagation delay. This second example method may be illustrated further in FIG. 2.

In one or more embodiments, a third example method may involve a combination of the first example method and the second example method. This second example method may be illustrated further in FIG. 3. Although these three example approaches for determining and/or compensating for the RTT propagation delay are described herein, any other method may also be used.

In one or more embodiments, the UE time difference (for example, the difference between a time at which the UE receives a message from a gNB and a time at which the gNB transmits that message) may be calculated as $T_{UE\text{-}RX} - T_{UE\text{-}TX}$. $T_{UE\text{-}RX}$ may refer to the UE received timing of downlink subframe #i from a transmission point (TP), defined by the first detected path in time. $T_{UE\text{-}TX}$ may refer to the UE transmit timing of uplink subframe #j that is closest in time to the subframe #i received from the TP. These terms may also be defined in clause 5.1.30 of the TS 38.215 3GPP standard. Multiple downlink positioning reference signal (DL PRS) resources can be used to determine the start of one subframe of the first arrival path of the TP.

In one or more embodiments, the gNB time difference (for example, the difference between a time at which the gNB receives a message from a UE and a time at which the UE transmits that message) may be calculated as $T_{gNB\text{-}RX} - T_{gNB\text{-}TX}$. $T_{gNB\text{-}RX}$ may refer to the Transmission and Reception Point (TRP) received timing of uplink subframe #i containing SRS associated with UE, defined by the first detected path in time. $T_{gNB\text{-}TX}$ may refer to the TRP transmit timing of downlink subframe #j that is closest in time to the subframe #i received from the UE. The terms used in these calculations may also be defined clause 5.2.3 of the TS 38.215 3GPP standard. Multiple SRS resources for positioning can be used to determine the start of one subframe containing SRS.

In one or more embodiments, the UE and gNB time difference for the purpose of propagation delay calculation and compensation may be re-defined so that the receive and transmit times of subframe boundary is replaced by the receive and transmit times of slot boundary. When the two components are summed, a total RTT may be determined based on

Equation 1. The propagation delay may be multiplied by two because the RTT may involve a time a signal takes to travel from a source to a destination and back to the source.

$$RTT = 2 * PD = T_{UE\text{-}RX} - T_{UE\text{-}TX} + T_{gNB\text{-}RX} - T_{gNB\text{-}TX} = (T_{UE\text{-}RX} - T_{gNB\text{-}TX}) + (T_{gNB\text{-}RX} - T_{UE\text{-}TX}) \quad \text{(Equation 1)}$$

Although the UE time difference may already be provided for positioning purposes in NR, it may not be desirable to directly re-use this existing information for the purpose of propagation delay compensation. This may be because DL PRS signals are typically provided to UE(s) from a positioning server, not from the gNB. To obtain this measurement, the positioning server may need to be involved in the communications, and the UE may need to be capable of positioning features.

In one or more embodiments, to avoid requiring communications with the positioning server for purposes of propagation delay calculations, DL PRS reference signals may instead be provided to a UE in an NR system information block (SIB) or as part of UE-specific dedicated radio resource control (RRC) message, re-using signaling format from NR LTE positioning protocol (LPP). In particular, all or a subset of information provided by *NR-DL-PRS-AssistanceData* defined in the TS 37.355 standard may be conveyed using the regular SIB or dedicated RRC message. For example, this information may include PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list. These terms may be defined in the standard. Additionally, since the DL PRS for propagation delay compensation is assumed to be provided as part of regular UE operation without positioning support, the DL PRS may need to be mapped to an active DL bandwidth part of the UE. That is, the separate bandwidth part used for positioning may not need to be used. Alternatively, a new UE time difference measurement may be defined on reference signals different from the DL PRS. In particular, the UE time difference measured in SSB or CSI-RS may be defined.

More particularly, in one or more embodiments, any of this propagation delay information may be transmitted using a number of different methods. A first method may include signaling at a UE-specific higher layer. For example, a gNB time difference measured by the gNB based on UL signals from a UE may be encoded into a higher layer message and sent to a UE as a MAC Control Element or as a dedicated RRC information element. The UE in this case may monitor physical downlink control channel (PDCCH) with UE-specific C-RNTI (or MCS-C-RNTI or CS-RNTI), e.g. dedicated to this UE only.

In one or more embodiments, a second example method may include signaling at a UE group-specific higher layer. For example, a gNB time difference measured by gNB based on

UL signals from a UE may be encoded into a higher layer message and sent to a group of UEs as a MAC Control Element or as an RRC information element. The UE in this case may monitor PDCCH with group-specific or broadcast radio network temporary identifier (RNTI).

In one or more embodiments, a third example method may include signaling at a UE-specific physical layer. In one embodiment, a gNB time difference measured by gNB based on UL signals from a UE may be encoded into a Downlink Control Indication (DCI) format as a payload. A UE may monitor this new DCI format either with one of the existing UE-specific RNTIs, e.g. C-RNTI, MCS-C-RNTI, CS-RNTI, or a newly formed RNTI.

In one or more embodiments, a fourth example method may include signaling at a UE group-specific physical layer. For example, a gNB time difference measured by gNB based on UL signals from a UE may be encoded into a group common DCI monitored with a new group common RNTI. The DCI format may follow the design of 2_x family of DCI formats. A total payload of the new DCI format may comprise N groups of M bits, as illustrated in FIG. 4. Each M bit may encode a single value of gNB time difference or propagation delay. Each connected UE may be provided with a new RNTI to monitor the new DCI, e.g. TIME-RNTI. Each connected UE may be provided with an index 'n' from 0 to N-1 denoting which of the N groups of bits in DCI are dedicated for the current UE. Once CRC scrambled with the new RNTI pass for a PDCCH candidate, a UE may take n-th group of M bits and may interpret as the gNB time difference or propagation delay. The new DCI format 2_x may be provided together with a separate PDCCH CORESET, blind decoding candidates, etc. configuration.

In one or more embodiments, the granularity of gNB time difference signaling to a UE may be configurable through UE-specific, or group-specific or broadcast RRC message in a form of 2^k * Tc seconds, where Tc may be the basic NR time unit, and k may be configurable as a numerical value (for example, 0, 1, 2, 3, 4, 5, etc.) as currently possible for LPP-based time difference reporting. This may result in i21-bit bit indication for k = 0 and a 16-bit indication for k = 5 assuming the time difference has a minimum of 0 ms and a maximum of Tmax = 1 ms. Furthermore, larger values of k can be introduced, e.g. one or a sub-set from 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, etc. Additionally, the maximum time difference Tmax may be configurable between a set of values for example {1 ms, 0.5 ms, 0.1 ms} or other values.

In one or more embodiments, the signaling of a calculated UE time difference or final propagation delay determination may also be performed using a number of different methods. A first example method may include signaling at a UE time difference is defined as a regular UE measurement report and may be signaled in RRC following the procedures of UE measurement reports as defined in section 5.5.5 of TS 38.331 *MeasurementReport* information

element and *MeasResults* information element can include a new measurement of UE time difference.

In one or more embodiments, a second example method may include signaling at a UE time difference is defined as a measurement and is reported in MAC CE. A new MAC CE can be defined to carry the UE time difference. Resources for reporting the MAC CE, in this case, may be assumed to be scheduled by gNB dynamically or semi-persistently (e.g. using configured grants).

In one or more embodiments, a third example method may include signaling at a UE time difference is defined as a measurement and is reported as a new UCI type on PUCCH or on PUSCH. This report may be aperiodic, or periodic, or semi-persistent. Due to the o medium size of 16-bits depending on granularity, this indication could only be handled by PUCCH formats supporting payload greater than 11 bit. CSI on PUCCH or PUSCH design can be reused for the new UCI type.

In one or more embodiments, the granularity of UE time difference signaling to a gNB may be configurable through UE-specific, or group-specific or broadcast RRC message in a form of: $2^k * Tc$ seconds, where Tc – is the basic NR time unit, and k may be configurable as a number (for example, 0, 1, 2, 3, 4, 5) as currently possible for LPP-based time difference reporting resulting 21-bit indication for k = 0 and 16-bit indication for k = 5 assuming the time difference has a minimum of 0 ms and a maximum of 1 ms. Furthermore, larger values of k can be introduced, e.g. one or a sub-set from 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16. Additionally, the maximum time difference Tmax may be configurable between a set of values for example {1 ms, 0.5 ms, 0.1 ms} or any other values.

Turning to the figures, FIG. 1 illustrates an example flow diagram 100, in accordance with one or more embodiments of the disclosure.

Particularly, the flow diagram 100 may illustrate the first example method for performing RTT-based propagation delay compensation. The first example method may involve the compensation being performed on the UE side (for example, UE 104, UE 106, UE 108, and/or any other number of UEs). Not all of the UEs may necessarily be in communication with the gNB at one time. Rather, the figure is merely intended to illustrate that it is possible for multiple UEs to be in communication with the gNB. In this first example method, a UE may generally perform this compensation based on a UE time difference calculated by the UE and an indication of an associated gNB time difference received from an associated gNB (for example, gNB 102 or any other number of gNBs).

In one or more embodiments, the flow diagram 100 begins with the gNB 102 sending a first message to the one or more UEs (for example, message 110 may be sent to the first UE 104, message 112 may be sent to the second UE 106, and/or message 114 may be sent to the third UE 108). In some cases, the messages 110, 112, and 114 may be sent from the gNB 102 as a single broadcast. In one or more embodiments, the first message may more specifically include a DL PRS. The DL PRS (as well as the UL PRS described below) may be a reference signal that may provide information that may be used to perform timing and/or ranging determinations. This DL PRS (as well as the UL PRS described below) may be defined in any of the 3GPP specifications mentioned herein or otherwise.

Although the UE time difference may already be obtained for positioning purposes in NR, it may not be desirable to directly re-use this existing information for the purpose of propagation delay compensation. This may be because DL PRS signals are typically provided to UE(s) from a positioning server, not from the gNB 102. To obtain this measurement, the positioning server may need to be involved in the communications, and the UE may need to be capable of positioning features.

In one or more embodiments, to avoid requiring communications with the positioning server for purposes of propagation delay calculations, DL PRS reference signals may instead be provided to a UE in an NR system information block (SIB) or as part of UE-specific dedicated RRC message, re-using signaling format from NR LTE positioning protocol (LPP). In particular, all or a sub-set of subsection provided by *NR-DL-PRS-AssistanceData* defined in the TS 37.355 standard may be conveyed using the regular SIB or dedicated RRC message. For example, this information may include PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list. Additionally, since the DL PRS for propagation delay compensation may be assumed to be provided as part of regular UE operation without positioning support, the DL PRS may need to be mapped to an active DL bandwidth part of the UE. That is, the separate bandwidth part used for positioning may not need to be used. Alternatively, a new UE time difference measurement may be defined on reference signals different from the DL PRS. In particular, the UE time difference measured in SSB or CSI-RS may be defined.

In one or more embodiments, after receiving the first message from the gNB 102, a respective UE may calculate a difference between a time at which the first message was received by the particular UE and a time at which the message was transmitted by the gNB 102. Each individual Urm its own time difference calculation as well (for example, the first UE

104 may perform a first time difference calculation based on the message 110, the second UE 106 may perform a second time difference calculation based on the message 112, and the third UE 108 may perform a third time difference calculation based on the message 114). Following this calculation, the UE may then send a second message back to the gNB 102 (for example, message 116 may be sent by the first UE 104, message 118 may be sent by the second UE 106, and/or message 120 may be sent by the third UE 108). The second message may include, for example, an uplink positioning reference signal (UL PRS). This second message may also be sent back to the gNB 102 at any other time as well.

In one or more embodiments, once the gNB 102 receives the second message, the gNB 102 may calculate measure a difference between a time at which the first message was received by the gNB 102 and a time at which the message was transmitted by the particular UE that transmitted the second message. In some cases, the gNB 102 may perform multiple calculations depending on the number of UEs that are in communication with the gNB 102 (for example, the gNB 102 may perform a first time difference calculation based on the message 116, a second time difference calculation based on the message 118, and a third time difference calculation based on the message 120). Once any time differences are calculated by the gNB 102, the gNB 102 may provide an indication of a time difference back to an associated UE as a third message (for example, message 112, message 124, and/or message 126).

In one or more embodiments, once a UE receives any time difference indications provided by the gNB 102, that UE may perform a propagation delay calculation based on the difference between the time at which the first message was received by the particular UE and the time at which the message was transmitted by the gNB 102, and the difference between the time at which the first message was received by the gNB 102 and the time at which the message was transmitted by the particular UE. In some cases, the propagation delay may be calculated using Equation 1 presented above.

FIG. 2 illustrates an example flow diagram 200, in accordance with one or more embodiments of the disclosure.

Particularly, the flow diagram 200 may illustrate the second example method for performing RTT-based propagation delay compensation. The second example method may involve the gNB 202 performing pre-compensation for propagation delay rather than the compensation being performed by a UE. In the figure, gNB 202 may be the same as gNB 102, first UE 204 may be the same as first UE 204, second UE 206 may be the same as second UE 106, and/or third UE 208 may be the same as third UE 108.

In one or more embodiments, the flow diagram 200 begins with the gNB 202 sending a first message to the one or more UEs (for example, message 220 may be sent to the first UE 204, message 212 may be sent to the second UE 206, and/or message 214 may be sent to the third UE 208). In some cases, the messages 210, 212, and 214 may be sent from the gNB 202 as a single broadcast. In one or more embodiments, the first message may include a downlink positioning reference signal (DL PRS).

In one or more embodiments, after receiving the first message from the gNB 202, a respective UE may calculate a difference between a time at which the first message was received by the particular UE and a time at which the message was transmitted by the gNB 202. Each individual UE may perform its own time difference calculation as well (for example, the first UE 204 may perform a first time difference calculation based on the message 210, the second UE 206 may perform a second time difference calculation based on the message 212, and the third UE 208 may perform a third time difference calculation based on the message 214). Following this calculation (or at any other time), the UE may then send a second message back to the gNB 202 (for example, message 216 may be sent by the first UE 204, message 218 may be sent by the second UE 206, and/or message 220 may be sent by the third UE 208). The second message may include, for example, an uplink positioning reference signal (UL PRS). In contrast with the first example method illustrated in FIG. 1, in this second example method, the UE may also send a third message back to the gNB 202 as well (for example, message 222 from the first UE 204, message 224 from the second UE 206, and/or message 226 from the third UE 208). This third message may include the calculated difference between the time at which the first message was received by the particular UE and the time at which the message was transmitted by the gNB 102. In some cases, this information may be transmitted back to the gNB 202 in the second message as well (instead of sending the information as a separate, third message).

In one or more embodiments, once the gNB 202 receives the second message and/or the third message, the gNB 202 may calculate a difference between a time at which the first message was received by the gNB 202 and a time at which the message was transmitted by the particular UE that transmitted the second message. In some cases, the gNB 202 may perform multiple calculations depending on the number of UEs that are in communication with the gNB (for example, the gNB 202 may perform a first time difference calculation based on the message 116, a second time difference calculation based on the message 218, and a third time difference calculation based on the message 220). Once any time differences are calculated by the gNB 202, the gNB 202 may then determine the propagation delay based on the difference

between the time at which the first message was received by the particular UE and the time at which the message was transmitted by the gNB 202, and the difference between the time at which the first message was received by the gNB 202 and the time at which the message was transmitted by the particular UE. For example, the propagation delay may be determined using Equation 1 presented above.

FIG. 3 illustrates an example flow diagram 300, in accordance with one or more embodiments of the disclosure.

Particularly, the flow diagram 300 may illustrate the third example method for performing RTT-based propagation delay compensation. The third example method may involve the UE compensating for propagation delay after measuring UE time difference, sending it to gNB 302, and receiving final propagation delay from gNB 302. That is, the third example method may include elements of the first example method illustrated in FIG. 1 and the second example method illustrated in FIG. 2.

In one or more embodiments, the flow diagram 300 begins with the gNB 302 sending a first message to the one or more UEs (for example, message 310 may be sent to the first UE 304, message 312 may be sent to the second UE 306, and/or message 314 may be sent to the third UE 308). In some cases, the messages 310, 312, and 314 may be sent from the gNB 302 as a single broadcast. In one or more embodiments, the first message may include a downlink positioning reference signal (DL PRS). In the figure, gNB 302 may be the same as gNB 302 and/or gNB 202, first UE 204 may be the same as first UE 304 and/or first UE 204, second UE 206 may be the same as second UE 306 and/or second UE 206, and/or third UE 208 may be the same as third UE 308 and/or third UE 208.

In one or more embodiments, after receiving the first message from the gNB 302, a respective UE may calculate a difference between a time at which the first message was received by the particular UE and a time at which the message was transmitted by the gNB 302. Each individual UE may perform its own time difference calculation as well (for example, the first UE 304 may perform a first time difference calculation based on the message 310, the second UE 306 may perform a second time difference calculation based on the message 312, and the third UE 308 may perform a third time difference calculation based on the message 314). Following this calculation (or at any other time), the UE may then send a second message back to the gNB 302 (for example, message 316 may be sent by the first UE 304, message 318 may be sent by the second UE 306, and/or message 320 may be sent by the third UE 308). The second message may include, for example, an uplink positioning reference signal (UL PRS). In contrast with the first example method illustrated in FIG. 1, in this third example method the

UE may also send a third message back to the gNB 302 as well (for example, message 322 from the first UE 304, message 324 from the second UE 306, and/or message 326 from the third UE 308). This third message may include the calculated difference between the time at which the first message was received by the particular UE and the time at which the message was transmitted by the gNB 302. In some cases, this information may be transmitted back to the gNB 302 in the second message as well.

In one or more embodiments, once the gNB 302 receives the second message, the gNB 302 may calculate measure a difference between a time at which the first message was received by the gNB 302 and a time at which the message was transmitted by the particular UE that transmitted the second message. In some cases, the gNB may perform multiple calculations depending on the number of UEs that are in communication with the gNB (for example, the gNB 302 may perform a first time difference calculation based on the message 316, a second time difference calculation based on the message 318, and a third time difference calculation based on the message 320). Once any time differences are calculated by the gNB 302, the gNB 302 may provide an indication of a time difference back to an associated UE as a third message (for example, message 312, message 324, and/or message 326).

In one or more embodiments, once a UE receives any time difference indications provided by the gNB 302, that UE may perform a propagation delay calculation based on the difference between the time at which the first message was received by the particular UE and the time at which the message was transmitted by the gNB 302, and the difference between the time at which the first message was received by the gNB 302 and the time at which the message was transmitted by the particular UE.

FIG. 4 illustrates an example downlink control information (DCI) packet 400, in accordance with one or more embodiments of the disclosure.

In one or more embodiments, the example downlink control information (DCI) packet 400 may be associated with the aforementioned fourth example method for signaling at a UE group-specific physical layer. For example, a gNB time difference measured by gNB based on UL signals from a UE may be encoded into a group common DCI monitored with a new group common RNTI. The DCI format may follow the design of 2_x family of DCI formats. A total payload of the new DCI format may comprise N groups of M bits, as illustrated in FIG. 4. Each M bit may encode a single value of gNB time difference (for example, time difference 402, time difference 404, etc.) or propagation delay. Each connected UE may be provided with a new RNTI to monitor the new DCI, e.g. TIME-RNTI. Each connected UE may be provided with an index ‘n’ from 0 to N-1 denoting which of the N groups of bits in DCI are dedicated

for the current UE. Once CRC scrambled with the new RNTI pass for a PDCCH candidate, a UE may take n-th group of M bits and may interpret as the gNB time difference or propagation delay. The new DCI format 2_x may be provided together with a separate PDCCH CORESET, blind decoding candidates, etc. configuration.

FIG. 5 illustrates an example method 500, in accordance with one or more embodiments of this disclosure. At block 502, the method 500 may include generating, by a user equipment (UE) (for example, UEs 104, 106, and/or 108 of FIG. 1, UEs 204, 206, and/or 208 of FIG. 2, UEs 304, 306, and/or 308 of FIG. 3, UE 602 of FIG. 6, UE 702 of FIG. 7, and/or any other UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station. At block 504, the method 500 may include calculating a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE. At block 506, the method 500 may include determining a propagation delay based on the first time difference and the second time difference. At block 508, the method 500 may include performing a compensation for the propagation delay.

In one or more embodiments, wherein calculating the second time difference is performed by the base station, and wherein the method 500 further includes generating a first signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

In one or more embodiments, wherein calculating the second time difference is performed by the base station, and wherein the method 500 further includes processing a second signal received over a receive signal path, the signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station.

In one or more embodiments, wherein calculating the second time difference is performed by the base station, and wherein the method 500 further comprises processing a third signal received over a signal receive path, the third signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station. The method 500 may also include generating a fourth signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

In one or more embodiments, the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

In one or more embodiments, the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the base station.

In one or more embodiments, generating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

FIG. 6 illustrates a network 600 in accordance with various embodiments. The network 600 may operate in a manner consistent with 3GPP technical specifications for LTE or 5G/NR systems. However, the example embodiments are not limited in this regard and the described embodiments may apply to other networks that benefit from the principles described herein, such as future 3GPP systems, or the like.

The network 600 may include a UE 602, which may include any mobile or non-mobile computing device designed to communicate with a RAN 604 via an over-the-air connection. The UE 602 may be communicatively coupled with the RAN 604 by a Uu interface. The UE 602 may be, but is not limited to, a smartphone, tablet computer, wearable computer device, desktop computer, laptop computer, in-vehicle infotainment, in-car entertainment device, instrument cluster, head-up display device, onboard diagnostic device, dashtop mobile equipment, mobile data terminal, electronic engine management system, electronic/engine control unit, electronic/engine control module, embedded system, sensor, microcontroller, control module, engine management system, networked appliance, machine-type communication device, M2M or D2D device, IoT device, etc.

In some embodiments, the network 600 may include a plurality of UEs coupled directly with one another via a sidelink interface. The UEs may be M2M/D2D devices that communicate using physical sidelink channels such as, but not limited to, PSBCH, PSDCH, PSSCH, PSCCH, PSFCH, etc.

In some embodiments, the UE 602 may additionally communicate with an AP 606 via an over-the-air connection. The AP 606 may manage a WLAN connection, which may serve to offload some/all network traffic from the RAN 604. The connection between the UE 602 and the AP 606 may be consistent with any IEEE 802.11 protocol, wherein the AP 606 could be a wireless fidelity (Wi-Fi®) router. In some embodiments, the UE 602, RAN 604, and AP 606 may utilize cellular-WLAN aggregation (for example, LWA/LWIP). Cellular-WLAN

aggregation may involve the UE 602 being configured by the RAN 604 to utilize both cellular radio resources and WLAN resources.

The RAN 604 may include one or more access nodes, for example, AN 608. AN 608 may terminate air-interface protocols for the UE 602 by providing access stratum protocols including RRC, PDCP, RLC, MAC, and L1 protocols. In this manner, the AN 608 may enable data/voice connectivity between CN 620 and the UE 602. In some embodiments, the AN 608 may be implemented in a discrete device or as one or more software entities running on server computers as part of, for example, a virtual network, which may be referred to as a CRAN or virtual baseband unit pool. The AN 608 may be referred to as a BS, gNB, RAN node, eNB, ng-eNB, NodeB, RSU, TRxP, TRP, etc. The AN 608 may be a macrocell base station or a low power base station for providing femtocells, picocells or other like cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells.

In embodiments in which the RAN 604 includes a plurality of ANs, they may be coupled with one another via an X2 interface (if the RAN 604 is an LTE RAN) or an Xn interface (if the RAN 604 is a 5G RAN). The X2/Xn interfaces, which may be separated into control/user plane interfaces in some embodiments, may allow the ANs to communicate information related to handovers, data/context transfers, mobility, load management, interference coordination, etc.

The ANs of the RAN 604 may each manage one or more cells, cell groups, component carriers, etc. to provide the UE 602 with an air interface for network access. The UE 602 may be simultaneously connected with a plurality of cells provided by the same or different ANs of the RAN 604. For example, the UE 602 and RAN 604 may use carrier aggregation to allow the UE 602 to connect with a plurality of component carriers, each corresponding to a Pcell or Scell. In dual connectivity scenarios, a first AN may be a master node that provides an MCG and a second AN may be secondary node that provides an SCG. The first/second ANs may be any combination of eNB, gNB, ng-eNB, etc.

The RAN 604 may provide the air interface over a licensed spectrum or an unlicensed spectrum. To operate in the unlicensed spectrum, the nodes may use LAA, eLAA, and/or feLAA mechanisms based on CA technology with PCells/Scells. Prior to accessing the unlicensed spectrum, the nodes may perform medium/carrier-sensing operations based on, for example, a listen-before-talk (LBT) protocol.

In V2X scenarios the UE 602 or AN 608 may be or act as a RSU, which may refer to any transportation infrastructure entity used for V2X communications. An RSU may be implemented in or by a suitable AN or a stationary (or relatively stationary) UE. An RSU

implemented in or by: a UE may be referred to as a "UE-type RSU"; an eNB may be referred to as an "eNB-type RSU"; a gNB may be referred to as a "gNB-type RSU"; and the like. In one example, an RSU is a computing device coupled with radio frequency circuitry located on a roadside that provides connectivity support to passing vehicle UEs. The RSU may also include internal data storage circuitry to store intersection map geometry, traffic statistics, media, as well as applications/software to sense and control ongoing vehicular and pedestrian traffic. The RSU may provide very low latency communications required for high speed events, such as crash avoidance, traffic warnings, and the like. Additionally or alternatively, the RSU may provide other cellular/WLAN communications services. The components of the RSU may be packaged in a weatherproof enclosure suitable for outdoor installation, and may include a network interface controller to provide a wired connection (e.g., Ethernet) to a traffic signal controller or a backhaul network.

In some embodiments, the RAN 604 may be an LTE RAN 610 with eNBs, for example, eNB 612. The LTE RAN 610 may provide an LTE air interface with the following characteristics: SCS of 15 kHz; CP-OFDM waveform for DL and SC-FDMA waveform for UL; turbo codes for data and TBCC for control; etc. The LTE air interface may rely on CSI-RS for CSI acquisition and beam management; PDSCH/PDCCH DMRS for PDSCH/PDCCH demodulation; and CRS for cell search and initial acquisition, channel quality measurements, and channel estimation for coherent demodulation/detection at the UE. The LTE air interface may operating on sub-6 GHz bands.

In some embodiments, the RAN 604 may be an NG-RAN 614 with gNBs, for example, gNB 616, or ng-eNBs, for example, ng-eNB 618. The gNB 616 may connect with 5G-enabled UEs using a 5G NR interface. The gNB 616 may connect with a 5G core through an NG interface, which may include an N2 interface or an N3 interface. The ng-eNB 618 may also connect with the 5G core through an NG interface, but may connect with a UE via an LTE air interface. The gNB 616 and the ng-eNB 618 may connect with each other over an Xn interface.

In some embodiments, the NG interface may be split into two parts, an NG user plane (NG-U) interface, which carries traffic data between the nodes of the NG-RAN 614 and a UPF 648 (e.g., N3 interface), and an NG control plane (NG-C) interface, which is a signaling interface between the nodes of the NG-RAN614 and an AMF 644 (e.g., N2 interface).

The NG-RAN 614 may provide a 5G-NR air interface with the following characteristics: variable SCS; CP-OFDM for DL, CP-OFDM and DFT-s-OFDM for UL; polar, repetition, simplex, and Reed-Muller codes for control and LDPC for data. The 5G-NR air interface may rely on CSI-RS, PDSCH/PDCCH DMRS similar to the LTE air interface. The

5G-NR air interface may not use a CRS, but may use PBCH DMRS for PBCH demodulation; PTRS for phase tracking for PDSCH; and tracking reference signal for time tracking. The 5G-NR air interface may operating on FR1 bands that include sub-6 GHz bands or FR2 bands that include bands from 24.25 GHz to 52.6 GHz. The 5G-NR air interface may include an SSB that is an area of a downlink resource grid that includes PSS/SSS/PBCH.

In some embodiments, the 5G-NR air interface may utilize BWPs for various purposes. For example, BWP can be used for dynamic adaptation of the SCS. For example, the UE 602 can be configured with multiple BWPs where each BWP configuration has a different SCS. When a BWP change is indicated to the UE 602, the SCS of the transmission is changed as well. Another use case example of BWP is related to power saving. In particular, multiple BWPs can be configured for the UE 602 with different amount of frequency resources (for example, PRBs) to support data transmission under different traffic loading scenarios. A BWP containing a smaller number of PRBs can be used for data transmission with small traffic load while allowing power saving at the UE 602 and in some cases at the gNB 616. A BWP containing a larger number of PRBs can be used for scenarios with higher traffic load.

The RAN 604 is communicatively coupled to CN 620 that includes network elements to provide various functions to support data and telecommunications services to customers/subscribers (for example, users of UE 602). The components of the CN 620 may be implemented in one physical node or separate physical nodes. In some embodiments, NFV may be utilized to virtualize any or all of the functions provided by the network elements of the CN 620 onto physical compute/storage resources in servers, switches, etc. A logical instantiation of the CN 620 may be referred to as a network slice, and a logical instantiation of a portion of the CN 620 may be referred to as a network sub-slice.

In some embodiments, the CN 620 may be an LTE CN 622, which may also be referred to as an EPC. The LTE CN 622 may include MME 624, SGW 626, SGSN 628, HSS 630, PGW 632, and PCRF 634 coupled with one another over interfaces (or "reference points") as shown. Functions of the elements of the LTE CN 622 may be briefly introduced as follows.

The MME 624 may implement mobility management functions to track a current location of the UE 602 to facilitate paging, bearer activation/deactivation, handovers, gateway selection, authentication, etc.

The SGW 626 may terminate an S1 interface toward the RAN and route data packets between the RAN and the LTE CN 622. The SGW 626 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

The SGSN 628 may track a location of the UE 602 and perform security functions and access control. In addition, the SGSN 628 may perform inter-EPC node signaling for mobility between different RAT networks; PDN and S-GW selection as specified by MME 624; MME selection for handovers; etc. The S3 reference point between the MME 624 and the SGSN 628 may enable user and bearer information exchange for inter-3GPP access network mobility in idle/active states.

The HSS 630 may include a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The HSS 630 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 630 and the MME 624 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the LTE CN 620.

The PGW 632 may terminate an SGi interface toward a data network (DN) 636 that may include an application/content server 638. The PGW 632 may route data packets between the LTE CN 622 and the data network 636. The PGW 632 may be coupled with the SGW 626 by an S5 reference point to facilitate user plane tunneling and tunnel management. The PGW 632 may further include a node for policy enforcement and charging data collection (for example, PCEF). Additionally, the SGi reference point between the PGW 632 and the data network 6 36 may be an operator external public, a private PDN, or an intra-operator packet data network, for example, for provision of IMS services. The PGW 632 may be coupled with a PCRF 634 via a Gx reference point.

The PCRF 634 is the policy and charging control element of the LTE CN 622. The PCRF 634 may be communicatively coupled to the app/content server 638 to determine appropriate QoS and charging parameters for service flows. The PCRF 632 may provision associated rules into a PCEF (via Gx reference point) with appropriate TFT and QCI.

In some embodiments, the CN 620 may be a 5GC 640. The 5GC 640 may include an AUSF 642, AMF 644, SMF 646, UPF 648, NSSF 650, NEF 652, NRF 654, PCF 656, UDM 658, and AF 660 coupled with one another over interfaces (or "reference points") as shown. Functions of the elements of the 5GC 640 may be briefly introduced as follows.

The AUSF 642 may store data for authentication of UE 602 and handle authentication-related functionality. The AUSF 642 may facilitate a common authentication framework for various access types. In addition to communicating with other elements of the 5GC 640 over reference points as shown, the AUSF 642 may exhibit an Nausf service-based interface.

The AMF 644 may allow other functions of the 5GC 640 to communicate with the UE 602 and the RAN 604 and to subscribe to notifications about mobility events with respect to the UE 602. The AMF 644 may be responsible for registration management (for example, for registering UE 602), connection management, reachability management, mobility management, lawful interception of AMF-related events, and access authentication and authorization. The AMF 644 may provide transport for SM messages between the UE 602 and the SMF 646, and act as a transparent proxy for routing SM messages. AMF 644 may also provide transport for SMS messages between UE 602 and an SMSF. AMF 644 may interact with the AUSF 642 and the UE 602 to perform various security anchor and context management functions. Furthermore, AMF 644 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the RAN 604 and the AMF 644; and the AMF 644 may be a termination point of NAS (N1) signaling, and perform NAS ciphering and integrity protection. AMF 644 may also support NAS signaling with the UE 602 over an N3 IWF interface.

The SMF 646 may be responsible for SM (for example, session establishment, tunnel management between UPF 648 and AN 608); UE IP address allocation and management (including optional authorization); selection and control of UP function; configuring traffic steering at UPF 648 to route traffic to proper destination; termination of interfaces toward policy control functions; controlling part of policy enforcement, charging, and QoS; lawful intercept (for SM events and interface to LI system); termination of SM parts of NAS messages; downlink data notification; initiating AN specific SM information, sent via AMF 644 over N2 to AN 608; and determining SSC mode of a session. SM may refer to management of a PDU session, and a PDU session or "session" may refer to a PDU connectivity service that provides or enables the exchange of PDUs between the UE 602 and the data network 636.

The UPF 648 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to data network 636, and a branching point to support multi-homed PDU session. The UPF 648 may also perform packet routing and forwarding, perform packet inspection, enforce the user plane part of policy rules, lawfully intercept packets (UP collection), perform traffic usage reporting, perform QoS handling for a user plane (e.g., packet filtering, gating, UL/DL rate enforcement), perform uplink traffic verification (e.g., SDF-to-QoS flow mapping), transport level packet marking in the uplink and downlink, and perform downlink packet buffering and downlink data notification triggering. UPF 648 may include an uplink classifier to support routing traffic flows to a data network.

The NSSF 650 may select a set of network slice instances serving the UE 602. The NSSF 650 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 650 may also determine the AMF set to be used to serve the UE 602, or a list of candidate AMFs based on a suitable configuration and possibly by querying the NRF 654. The selection of a set of network slice instances for the UE 602 may be triggered by the AMF 644 with which the UE 602 is registered by interacting with the NSSF 650, which may lead to a change of AMF. The NSSF 650 may interact with the AMF 644 via an N22 reference point; and may communicate with another NSSF in a visited network via an N31 reference point (not shown). Additionally, the NSSF 650 may exhibit an Nnssf service-based interface.

The NEF 652 may securely expose services and capabilities provided by 3GPP network functions for third party, internal exposure/re-exposure, AFs (e.g., AF 660), edge computing or fog computing systems, etc. In such embodiments, the NEF 652 may authenticate, authorize, or throttle the AFs. NEF 652 may also translate information exchanged with the AF 660 and information exchanged with internal network functions. For example, the NEF 652 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 652 may also receive information from other NFs based on exposed capabilities of other NFs. This information may be stored at the NEF 652 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 652 to other NFs and AFs, or used for other purposes such as analytics. Additionally, the NEF 652 may exhibit an Nnef service-based interface.

The NRF 654 may support service discovery functions, receive NF discovery requests from NF instances, and provide the information of the discovered NF instances to the NF instances. NRF 654 also maintains information of available NF instances and their supported services. As used herein, the terms "instantiate," "instantiation," and the like may refer to the creation of an instance, and an "instance" may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. Additionally, the NRF 654 may exhibit the Nnrf service-based interface.

The PCF 656 may provide policy rules to control plane functions to enforce them, and may also support unified policy framework to govern network behavior. The PCF 656 may also implement a front end to access subscription information relevant for policy decisions in a UDR of the UDM 658. In addition to communicating with functions over reference points as shown, the PCF 656 exhibit an Npcf service-based interface.

The UDM 658 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 602. For

example, subscription data may be communicated via an N8 reference point between the UDM 658 and the AMF 644. The UDM 658 may include two parts, an application front end and a UDR. The UDR may store subscription data and policy data for the UDM 658 and the PCF 656, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 602) for the NEF 652. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 658, PCF 656, and NEF 652 to access a particular set of the stored data, as well as to read, update (e.g., add, modify), delete, and subscribe to notification of relevant data changes in the UDR. The UDM may include a UDM-FE, which is in charge of processing credentials, location management, subscription management and so on. Several different front ends may serve the same user in different transactions. The UDM-FE accesses subscription information stored in the UDR and performs authentication credential processing, user identification handling, access authorization, registration/mobility management, and subscription management. In addition to communicating with other NFs over reference points as shown, the UDM 658 may exhibit the Nudm service-based interface.

The AF 660 may provide application influence on traffic routing, provide access to NEF, and interact with the policy framework for policy control.

In some embodiments, the 5GC 640 may enable edge computing by selecting operator/3rd party services to be geographically close to a point that the UE 602 is attached to the network. This may reduce latency and load on the network. To provide edge-computing implementations, the 5GC 640 may select a UPF 648 close to the UE 602 and execute traffic steering from the UPF 648 to data network 636 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 660. In this way, the AF 660 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 660 is considered to be a trusted entity, the network operator may permit AF 660 to interact directly with relevant NFs. Additionally, the AF 660 may exhibit an Naf service-based interface.

The data network 636 may represent various network operator services, Internet access, or third party services that may be provided by one or more servers including, for example, application/content server 638.

Figure 7 schematically illustrates a wireless network 700 in accordance with various embodiments. The wireless network 700 may include a UE 702 in wireless communication with an AN 704. The UE 702 and AN 704 may be similar to, and substantially interchangeable with, like-named components described elsewhere herein.

The UE 702 may be communicatively coupled with the AN 704 via connection 706. The connection 706 is illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols such as an LTE protocol or a 5G NR protocol operating at mmWave or sub-6GHz frequencies.

The UE 702 may include a host platform 708 coupled with a modem platform 710. The host platform 708 may include application processing circuitry 712, which may be coupled with protocol processing circuitry 714 of the modem platform 710. The application processing circuitry 712 may run various applications for the UE 702 that source/sink application data. The application processing circuitry 712 may further implement one or more layer operations to transmit/receive application data to/from a data network. These layer operations may include transport (for example UDP) and Internet (for example, IP) operations

The protocol processing circuitry 714 may implement one or more of layer operations to facilitate transmission or reception of data over the connection 706. The layer operations implemented by the protocol processing circuitry 714 may include, for example, MAC, RLC, PDCP, RRC and NAS operations.

The modem platform 710 may further include digital baseband circuitry 716 that may implement one or more layer operations that are "below" layer operations performed by the protocol processing circuitry 714 in a network protocol stack. These operations may include, for example, PHY operations including one or more of HARQ-ACK functions, scrambling/descrambling, encoding/decoding, layer mapping/de-mapping, modulation symbol mapping, received symbol/bit metric determination, multi-antenna port precoding/decoding, which may include one or more of space-time, space-frequency or spatial coding, reference signal generation/detection, preamble sequence generation and/or decoding, synchronization sequence generation/detection, control channel signal blind decoding, and other related functions.

The modem platform 710 may further include transmit circuitry 718, receive circuitry 720, RF circuitry 722, and RF front end (RFFE) 724, which may include or connect to one or more antenna panels 726. Briefly, the transmit circuitry 718 may include a digital-to-analog converter, mixer, intermediate frequency (IF) components, etc.; the receive circuitry 720 may include an analog-to-digital converter, mixer, IF components, etc.; the RF circuitry 722 may include a low-noise amplifier, a power amplifier, power tracking components, etc.; RFFE 724 may include filters (for example, surface/bulk acoustic wave filters), switches, antenna tuners, beamforming components (for example, phase-array antenna components), etc. The selection and arrangement of the components of the transmit circuitry 718, receive circuitry 720, RF

circuitry 722, RFFE 724, and antenna panels 726 (referred generically as "transmit/receive components") may be specific to details of a specific implementation such as, for example, whether communication is TDM or FDM, in mmWave or sub-6 gHz frequencies, etc. In some embodiments, the transmit/receive components may be arranged in multiple parallel transmit/receive chains, may be disposed in the same or different chips/modules, etc.

In some embodiments, the protocol processing circuitry 714 may include one or more instances of control circuitry (not shown) to provide control functions for the transmit/receive components.

A UE reception may be established by and via the antenna panels 726, RFFE 724, RF circuitry 722, receive circuitry 720, digital baseband circuitry 716, and protocol processing circuitry 714. In some embodiments, the antenna panels 726 may receive a transmission from the AN 704 by receive-beamforming signals received by a plurality of antennas/antenna elements of the one or more antenna panels 726.

A UE transmission may be established by and via the protocol processing circuitry 714, digital baseband circuitry 716, transmit circuitry 718, RF circuitry 722, RFFE 724, and antenna panels 726. In some embodiments, the transmit components of the UE 704 may apply a spatial filter to the data to be transmitted to form a transmit beam emitted by the antenna elements of the antenna panels 726.

Similar to the UE 702, the AN 704 may include a host platform 728 coupled with a modem platform 730. The host platform 728 may include application processing circuitry 732 coupled with protocol processing circuitry 734 of the modem platform 730. The modem platform may further include digital baseband circuitry 736, transmit circuitry 738, receive circuitry 740, RF circuitry 742, RFFE circuitry 744, and antenna panels 746. The components of the AN 704 may be similar to and substantially interchangeable with like-named components of the UE 702. In addition to performing data transmission/reception as described above, the components of the AN 708 may perform various logical functions that include, for example, RNC functions such as radio bearer management, uplink and downlink dynamic radio resource management, and data packet scheduling.

Figure 8 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 8 shows a diagrammatic representation of hardware resources 800 including one or more processors (or processor cores) 810, one or more memory/storage devices 820, and one or more communication resources 830, each of

which may be communicatively coupled via a bus 840 or other interface circuitry. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 802 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 800.

The processors 810 may include, for example, a processor 812 and a processor 814. The processors 810 may be, for example, 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 DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.

The memory/storage devices 820 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 820 may include, but are not limited to, any type of volatile, non-volatile, or semi-volatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

The communication resources 830 may include interconnection or network interface controllers, components, or other suitable devices to communicate with one or more peripheral devices 804 or one or more databases 806 or other network elements via a network 808. For example, the communication resources 830 may include wired communication components (e.g., for coupling via USB, Ethernet, etc.), cellular communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components.

Instructions 850 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 810 to perform any one or more of the methodologies discussed herein. The instructions 850 may reside, completely or partially, within at least one of the processors 810 (e.g., within the processor's cache memory), the memory/storage devices 820, or any suitable combination thereof. Furthermore, any portion of the instructions 850 may be transferred to the hardware resources 800 from any combination of the peripheral devices 804 or the databases 806. Accordingly, the memory of processors 810, the memory/storage devices 820, the peripheral devices 804, and the databases 806 are examples of computer-readable and machine-readable media.

For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques,

processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section.

Example 1 may include an apparatus for a next generation evolved Node B (gNB), the apparatus. The apparatus may comprise a processor. The processor may be configured to encode a first signal for transmission to a user equipment (UE) at a first time using a transmit signal path. The processor may be configured to detect a second signal received over a receive signal path, the second signal including an indication of a first time difference between the first time and a second time at which the UE received the first signal. The processor may be configured to detect, at a third time, a third signal received over the receive signal path from the UE. The processor may be configured to calculate a second time difference between the third time and a fourth time at which the third signal was transmitted from the UE. The processor may be configured to determine a propagation delay based on the first time difference and the second time difference. The processor may be configured to perform a compensation for the propagation delay. The apparatus may also comprise a memory configured to store the propagation delay.

Example 2 may include the apparatus of example 1 or some other example herein, wherein the processor is further configured to encode a fourth signal for transmission to the UE using the transmit signal path, the fourth signal including the second time difference.

Example 3 may include the system of example 1 or some other example herein, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

Example 4 may include the apparatus of example 1 or some other example herein, wherein the first time difference is sent using a MAC control element.

Example 5 may include the apparatus of example 1 or some other example herein, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the gNB.

Example 6 may include the apparatus of example 1 or some other example herein, wherein calculating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at

least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

Example 7 may include the apparatus of example 1 or some other example herein, wherein the processor comprises a baseband processor.

Example 8 may include a computer-readable medium storing computer-executable instructions. The computer-executable instructions, when executed by a processor, cause the processor to perform operations of generating, by a user equipment (UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station. The computer-executable instructions cause the processor to perform operations of calculating a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE. The computer-executable instructions cause the processor to perform operations of determining a propagation delay based on the first time difference and the second time difference. The computer-executable instructions cause the processor to perform operations of performing a compensation for the propagation delay.

Example 9 may include the computer-readable medium of example 8 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the computer-executable instructions further cause the processor to perform operations of generating a first signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

Example 10 may include the computer-readable medium of example 8 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the computer-executable instructions further cause the processor to perform operations of processing a second signal received over a receive signal path, the signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station.

Example 11 may include the computer-readable medium of example 8 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the computer-executable instructions further cause the processor to perform operations of processing a third signal received over a signal receive path, the third signal including an indication of the first time difference at the base station, wherein calculating

the propagation delay is performed by the base station; and generating a fourth signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

Example 12 may include the computer-readable medium of example 8 or some other example herein, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

Example 13 may include the computer-readable medium of example 8 or some other example herein, wherein the first time difference is sent using a MAC control element.

Example 14 may include the computer-readable medium of example 8 or some other example herein, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the base station.

Example 15 may include the computer-readable medium of example 8 or some other example herein, wherein generating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

Example 16 may include the computer-readable medium of example 8 or some other example herein, wherein the processing circuitry comprises a baseband processor.

Example 17 may include a method. The method may include generating, by a user equipment (UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station. The method may also include calculating a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE. The method may also include determining a propagation delay based on the first time difference and the second time difference. The method may also include performing a compensation for the propagation delay.

Example 18 may include the method of example 17 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises generating a first signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

Example 19 may include the method of example 17 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises processing a second signal received over a receive signal path, the signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station.

Example 20 may include the method of example 17 or some other example herein, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises processing a third signal received over a signal receive path, the third signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station; and generating a fourth signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

Example 21 may include the method of example 17 or some other example herein, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

Example 22 may include the method of example 17 or some other example herein, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the base station.

Example 23 may include the method of example 17 or some other example herein, wherein generating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

Example 24 may include a computer-readable storage medium comprising instructions to perform any of the method of examples 17-23.

Example 25 may include an apparatus comprising means for performing any of the methods of examples 17-23.

Any of the above-described examples may be combined with any other example (or combination of examples), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications

and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein.

The term "circuitry" as used herein refers to, is part of, or includes hardware components such as an electronic circuit, a logic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group), an Application Specific Integrated Circuit (ASIC), a field-programmable device (FPD) (e.g., a field-programmable gate array (FPGA), a programmable logic device (PLD), a complex PLD (CPLD), a high-capacity PLD (HCPLD), a structured ASIC, or a programmable SoC), digital signal processors (DSPs), etc., that are configured to provide the described functionality. In some embodiments, the circuitry may execute one or more software or firmware programs to provide at least some of the described functionality. The term "circuitry" may also refer to a combination of one or more hardware elements (or a combination of circuits used in an electrical or electronic system) with the program code used to carry out the functionality of that program code. In these embodiments, the combination of hardware elements and program code may be referred to as a particular type of circuitry.

The term "processor circuitry" as used herein refers to, is part of, or includes circuitry capable of sequentially and automatically carrying out a sequence of arithmetic or logical operations, or recording, storing, and/or transferring digital data. Processing circuitry may include one or more processing cores to execute instructions and one or more memory structures to store program and data information. The term "processor circuitry" may refer to one or more application processors, one or more baseband processors, a physical central processing unit (CPU), a single-core processor, a dual-core processor, a triple-core processor, a quad-core processor, and/or any other device capable of executing or otherwise operating computer-executable instructions, such as program code, software modules, and/or functional processes. Processing circuitry may include more hardware accelerators, which may be microprocessors, programmable processing devices, or the like. The one or more hardware accelerators may include, for example, computer vision (CV) and/or deep learning (DL) accelerators. The terms "application circuitry" and/or "baseband circuitry" may be considered synonymous to, and may be referred to as, "processor circuitry."

The term "interface circuitry" as used herein refers to, is part of, or includes circuitry that enables the exchange of information between two or more components or devices. The

term "interface circuitry" may refer to one or more hardware interfaces, for example, buses, I/O interfaces, peripheral component interfaces, network interface cards, and/or the like.

The term "user equipment" or "UE" as used herein refers to a device with radio communication capabilities and may describe a remote user of network resources in a communications network. The term "user equipment" or "UE" may be considered synonymous to, and may be referred to as, client, mobile, mobile device, mobile terminal, user terminal, mobile unit, mobile station, mobile user, subscriber, user, remote station, access agent, user agent, receiver, radio equipment, reconfigurable radio equipment, reconfigurable mobile device, etc. Furthermore, the term "user equipment" or "UE" may include any type of wireless/wired device or any computing device including a wireless communications interface.

The term "network element" as used herein refers to physical or virtualized equipment and/or infrastructure used to provide wired or wireless communication network services. The term "network element" may be considered synonymous to and/or referred to as a networked computer, networking hardware, network equipment, network node, router, switch, hub, bridge, radio network controller, RAN device, RAN node, gateway, server, virtualized VNF, NFVI, and/or the like.

The term "computer system" as used herein refers to any type interconnected electronic devices, computer devices, or components thereof. Additionally, the term "computer system" and/or "system" may refer to various components of a computer that are communicatively coupled with one another. Furthermore, the term "computer system" and/or "system" may refer to multiple computer devices and/or multiple computing systems that are communicatively coupled with one another and configured to share computing and/or networking resources.

The term "appliance," "computer appliance," or the like, as used herein refers to a computer device or computer system with program code (e.g., software or firmware) that is specifically designed to provide a specific computing resource. A "virtual appliance" is a virtual machine image to be implemented by a hypervisor-equipped device that virtualizes or emulates a computer appliance or otherwise is dedicated to provide a specific computing resource.

The term "resource" as used herein refers to a physical or virtual device, a physical or virtual component within a computing environment, and/or a physical or virtual component within a particular device, such as computer devices, mechanical devices, memory space, processor/CPU time, processor/CPU usage, processor and accelerator loads, hardware time or usage, electrical power, input/output operations, ports or network sockets, channel/link allocation, throughput, memory usage, storage, network, database and applications, workload

units, and/or the like. A "hardware resource" may refer to compute, storage, and/or network resources provided by physical hardware element(s). A "virtualized resource" may refer to compute, storage, and/or network resources provided by virtualization infrastructure to an application, device, system, etc. The term "network resource" or "communication resource" may refer to resources that are accessible by computer devices/systems via a communications network. The term "system resources" may refer to any kind of shared entities to provide services, and may include computing and/or network resources. System resources may be considered as a set of coherent functions, network data objects or services, accessible through a server where such system resources reside on a single host or multiple hosts and are clearly identifiable.

The term "channel" as used herein refers to any transmission medium, either tangible or intangible, which is used to communicate data or a data stream. The term "channel" may be synonymous with and/or equivalent to "communications channel," "data communications channel," "transmission channel," "data transmission channel," "access channel," "data access channel," "link," "data link," "carrier," "radiofrequency carrier," and/or any other like term denoting a pathway or medium through which data is communicated. Additionally, the term "link" as used herein refers to a connection between two devices through a RAT for the purpose of transmitting and receiving information.

The terms "instantiate," "instantiation," and the like as used herein refers to the creation of an instance. An "instance" also refers to a concrete occurrence of an object, which may occur, for example, during execution of program code.

The terms "coupled," "communicatively coupled," along with derivatives thereof are used herein. The term "coupled" may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term "directly coupled" may mean that two or more elements are in direct contact with one another. The term "communicatively coupled" may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or link, and/or the like.

The term "information element" refers to a structural element containing one or more fields. The term "field" refers to individual contents of an information element, or a data element that contains content.

The term "SMTC" refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.

The term "SSB" refers to an SS/PBCH block.

The term "a "Primary Cell" refers to the MCG cell, operating on the primary frequency, in which the UE either performs the initial connection establishment procedure or initiates the connection re-establishment procedure.

The term "Primary SCG Cell" refers to the SCG cell in which the UE performs random access when performing the Reconfiguration with Sync procedure for DC operation.

The term "Secondary Cell" refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.

The term "Secondary Cell Group" refers to the subset of serving cells comprising the PSCell and zero or more secondary cells for a UE configured with DC.

The term "Serving Cell" refers to the primary cell for a UE in RRC_CONNECTED not configured with CA/DC there is only one serving cell comprising of the primary cell.

The term "serving cell" or "serving cells" refers to the set of cells comprising the Special Cell(s) and all secondary cells for a UE in RRC_CONNECTED configured with CA.

The term "Special Cell" refers to the PCell of the MCG or the PSCell of the SCG for DC operation; otherwise, the term "Special Cell" refers to the Pcell.

Unless used differently herein, terms, definitions, and abbreviations may be consistent with terms, definitions, and abbreviations defined in 3GPP TR 21.905 v16.0.0 (2019-06) and/or any other 3GPP standard. For the purposes of the present document, the following abbreviations (shown in Table 1) may apply to the examples and embodiments discussed herein.

Table 1: Abbreviations:

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5GC	5G Core network
AC	Application Client
ACK	Acknowledgement
ACID	Application Client Identification
AF	Application Function
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AN	Access Network
ANR	Automatic Neighbour Relation
AP	Application Protocol, Antenna Port, Access Point
API	Application Programming Interface
APN	Access Point Name
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat Request
AS	Access Stratum
ASP	Application Service Provider
ASN.1	Abstract Syntax Notation One
AUSF	Authentication Server Function
AWGN	Additive White Gaussian Noise
BAP	Backhaul Adaptation Protocol
BCH	Broadcast Channel
BER	Bit Error Ratio
BFD	Beam Failure Detection
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BRAS	Broadband Remote Access Server
BSS	Business Support System
BS	Base Station
BSR	Buffer Status Report
BW	Bandwidth
BWP	Bandwidth Part
C-RNTI	Cell Radio Network Temporary Identity
CA	Carrier Aggregation, Certification Authority
CAPEX	CAPital EXpenditure
CBRA	Contention Based Random Access
CC	Component Carrier, Country Code, Cryptographic Checksum
CCA	Clear Channel Assessment
CCE	Control Channel Element
CCCH	Common Control Channel
CE	Coverage Enhancement
CDM	Content Delivery Network
CDMA	Code-Division Multiple Access
CFRA	Contention Free Random Access
CG	Cell Group
CGF	Charging Gateway Function
CHF	Charging Function
CI	Cell Identity
CID	Cell-ID (e.g., positioning method)
CIM	Common Information Model
CIR	Carrier to Interference Ratio
CK	Cipher Key
CM	Connection Management, Conditional Mandatory
CMAS	Commercial Mobile Alert Service
CMD	Command
CMS	Cloud Management System
CO	Conditional Optional
CoMP	Coordinated Multi-Point
CORESET	Control Resource Set
COTS	Commercial Off-The-Shelf
CP	Control Plane, Cyclic Prefix, Connection Point
CPD	Connection Point Descriptor
CPE	Customer Premise Equipment
CPICH	Common Pilot Channel
CQI	Channel Quality Indicator
CPU	CSI processing unit, Central Processing Unit
C/R	Command/Response field bit
CRAN	Cloud Radio Access Network, Cloud RAN
CRB	Common Resource Block
CRC	Cyclic Redundancy Check
CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
C-RNTI	Cell RNTI
CS	Circuit Switched
CSAR	Cloud Service Archive
CSI	Channel-State Information
CSI-IM	CSI Interference Measurement
CSI-RS	CSI Reference Signal
CSI-RSRP	CSI reference signal received power
CSI-RSRQ	CSI reference signal received quality
CSI-SINR	CSI signal-to-noise and interference ratio
CSMA	Carrier Sense Multiple Access
CSMA/CA	CSMA with collision avoidance
CSS	Common Search Space, Cell-specific Search Space
CTF	Charging Trigger Function
CTS	Clear-to-Send
CW	Codeword
CWS	Contention Window Size
D2D	Device-to-Device
DC	Dual Connectivity, Direct Current
DCI	Downlink Control Information
DF	Deployment Flavour
DL	Downlink
DMTF	Distributed Management Task Force
DPDK	Data Plane Development Kit
DM-RS,	DMRS Demodulation Reference Signal
DN	Data network
DNN	Data Network Name
DNAI	Data Network Access Identifier
DRB	Data Radio Bearer
DRS	Discovery Reference Signal
DRX	Discontinuous Reception
DSL	Domain Specific Language. Digital Subscriber Line
DSLAM	DSL Access Multiplexer
DwPTS	Downlink Pilot Time Slot
E-LAN	Ethernet Local Area Network
E2E	End-to-End
ECCA	extended clear channel assessment, extended CCA
ECCE	Enhanced Control Channel Element, Enhanced CCE
ED	Energy Detection
EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
EAS	Edge Application Server
EASID	Edge Application Server Identification
ECS	Edge Configuration Server
ECSP	Edge Computing Service Provider
EDN	Edge Data Network
EEC	Edge Enabler Client
EECID	Edge Enabler Client Identification
EES	Edge Enabler Server
EESID	Edge Enabler Server Identification
EHE	Edge Hosting Environment
EGMF	Exposure Governance Management Function
EGPRS	Enhanced GPRS
EIR	Equipment Identity Register
eLAA	enhanced Licensed Assisted Access, enhanced LAA
EM	Element Manager
eMBB	Enhanced Mobile Broadband
EMS	Element Management System
eNB	evolved NodeB, E-UTRAN Node B
EN-DC	E-UTRA-NR Dual Connectivity
EPC	Evolved Packet Core
EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Cannel
EPRE	Energy per resource element
EPS	Evolved Packet System
EREG	enhanced REG, enhanced resource element groups
ETSI	European Telecommunications Standards Institute
ETWS	Earthquake and Tsunami Warning System
eUICC	embedded UICC, embedded Universal Integrated Circuit Card
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
EV2X	Enhanced V2X
F1AP	F1 Application Protocol
F1-C	F1 Control plane interface
F1-U	F1 User plane interface
FACCH	Fast Associated Control CHannel
FACCH/F	Fast Associated Control Channel/Full rate
FACCH/H	Fast Associated Control Channel/Half rate
FACH	Forward Access Channel
FAUSCH	Fast Uplink Signalling Channel
FB	Functional Block
FBI	Feedback Information

FCC	Federal Communications Commission
FCCH	Frequency Correction CHannel
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FE	Front End
FEC	Forward Error Correction
FFS	For Further Study
FFT	Fast Fourier Transformation
feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
FN	Frame Number
FPGA	Field-Programmable Gate Array
FR	Frequency Range
FQDN	Fully Qualified Domain Name
G-RNTI	GERAN Radio Network Temporary Identity
GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
gNB	Next Generation NodeB
gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPSI	Generic Public Subscription Identifier
GSM	Global System for Mobile Communications, Groupe Spécial Mobile
GTP	GPRS Tunneling Protocol
GTP-U	GPRS Tunnelling Protocol for User Plane
GTS	Go To Sleep Signal (related to WUS)
GUMMEI	Globally Unique MME Identifier
GUTI	Globally Unique Temporary UE Identity
HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
HANDO	Handover
HFN	HyperFrame Number
HHO	Hard Handover
HLR	Home Location Register
HN	Home Network
HO	Handover
HPLMN	Home Public Land Mobile Network
HSDPA	High Speed Downlink Packet Access
HSN	Hopping Sequence Number
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
I-Block	Information Block
ICCID	Integrated Circuit Card Identification
IAB	Integrated Access and Backhaul
ICIC	Inter-Cell Interference Coordination
ID	Identity, identifier
IDFT	Inverse Discrete Fourier Transform
IE	Information element
IBE	In-Band Emission
IEEE	Institute of Electrical and Electronics Engineers
IEI	Information Element Identifier
IEIDL	Information Element Identifier Data Length
IETF	Internet Engineering Task Force
IF	Infrastructure
IM	Interference Measurement, Intermodulation, IP Multimedia
IMC	IMS Credentials
IMEI	International Mobile Equipment Identity
IMGI	International mobile group identity
IMPI	IP Multimedia Private Identity
IMPU	IP Multimedia PUblic identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
Ipsec	IP Security, Internet Protocol Security
IP-CAN	IP-Connectivity Access Network
IP-M	IP Multicast
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
IR	Infrared
IS	In Sync
IRP	Integration Reference Point
ISDN	Integrated Services Digital Network
ISIM	IM Services Identity Module
ISO	International Organisation for Standardisation
ISP	Internet Service Provider
IWF	Interworking-Function
I-WLAN	Interworking WLAN
Constraint length of the convolutional code, USIM Individual key	
kB	Kilobyte (1000 bytes)
kbps	kilo-bits per second
Kc	Ciphering key
Ki	Individual subscriber authentication key
KPI	Key Performance Indicator
KQI	Key Quality Indicator
KSI	Key Set Identifier
ksps	kilo-symbols per second
KVM	Kernel Virtual Machine
L1	Layer 1 (physical layer)
L1-RSRP	Layer 1 reference signal received power
L2	Layer 2 (data link layer)
L3	Layer 3 (network layer)
LAA	Licensed Assisted Access
LAN	Local Area Network
LADN	Local Area Data Network
LBT	Listen Before Talk
LCM	LifeCycle Management
LCR	Low Chip Rate
LCS	Location Services
LCID	Logical Channel ID
LI	Layer Indicator
LLC	Logical Link Control, Low Layer Compatibility
LPLMN	Local PLMN
LPP	LTE Positioning Protocol
LSB	Least Significant Bit
LTE	Long Term Evolution
LWA	LTE-WLAN aggregation
LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
LTE	Long Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control (protocol layering context)
MAC	Message authentication code (security/encryption context)
MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
MANO	Management and Orchestration
MBMS	Multimedia Broadcast and Multicast Service
MBSFN	Multimedia Broadcast multicast service Single Frequency Network
MCC	Mobile Country Code
MCG	Master Cell Group
MCOT	Maximum Channel Occupancy Time
MCS	Modulation and coding scheme
MDAF	Management Data Analytics Function
MDAS	Management Data Analytics Service
MDT	Minimization of Drive Tests
ME	Mobile Equipment
MeNB	master eNB
MER	Message Error Ratio
MGL	Measurement Gap Length
MGRP	Measurement Gap Repetition Period
MIB	Master Information Block, Management Information Base
MIMO	Multiple Input Multiple Output
MLC	Mobile Location Centre
MM	Mobility Management
MME	Mobility Management Entity
MN	Master Node
MNO	Mobile Network Operator
MO	Measurement Object, Mobile Originated
MPBCH	MTC Physical Broadcast CHannel
MPDCCH	MTC Physical Downlink Control CHannel
MPDSCH	MTC Physical Downlink Shared CHannel
MPRACH	MTC Physical Random Access CHannel
MPUSCH	MTC Physical Uplink Shared Channel
MPLS	MultiProtocol Label Switching
MS	Mobile Station
MSB	Most Significant Bit
MSC	Mobile Switching Centre

MSI	Minimum System Information, MCH Scheduling Information
MSID	Mobile Station Identifier
MSIN	Mobile Station Identification Number
MSISDN	Mobile Subscriber ISDN Number
MT	Mobile Terminated, Mobile Termination
MTC	Machine-Type Communications
mMTC	massive MTC, massive Machine-Type Communications
MU-MIMO	Multi User MIMO
MWUS	MTC wake-up signal, MTC WUS
NACK	Negative Acknowledgement
NAI	Network Access Identifier
NAS	Non-Access Stratum, Non-Access Stratum layer
NCT	Network Connectivity Topology
NC-JT	Non-Coherent Joint Transmission
NEC	Network Capability Exposure
NE-DC	NR-E-UTRA Dual Connectivity
NEF	Network Exposure Function
NF	Network Function
NFP	Network Forwarding Path
NFPD	Network Forwarding Path Descriptor
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NG	Next Generation, Next Gen
NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
NM	Network Manager
NMS	Network Management System
N-PoP	Network Point of Presence
NMIB, N-MIB	Narrowband MIB
NPBCH	Narrowband Physical Broadcast CHannel
NPDCCH	Narrowband Physical Downlink Control CHannel
NPDSCH	Narrowband Physical Downlink Shared CHannel
NPRACH	Narrowband Physical Random Access CHannel
NPUSCH	Narrowband Physical Uplink Shared CHannel
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
NR	New Radio, Neighbour Relation
NRF	NF Repository Function
NRS	Narrowband Reference Signal
NS	Network Service
NSA	Non-Standalone operation mode
NSD	Network Service Descriptor
NSR	Network Service Record
NSSAI	Network Slice Selection Assistance Information
S-NNSAI	Single-NSSAI
NSSF	Network Slice Selection Function
NW	Network
NWUS	Narrowband wake-up signal, Narrowband WUS
NZP	Non-Zero Power
O&M	Operation and Maintenance
ODU2	Optical channel Data Unit - type 2
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-of-band
OOS	Out of Sync
OPEX	OPerating EXpense
OSI	Other System Information
OSS	Operations Support System
OTA	over-the-air
PAPR	Peak-to-Average Power Ratio
PAR	Peak to Average Ratio
PBCH	Physical Broadcast Channel
PC	Power Control, Personal Computer
PCC	Primary Component Carrier, Primary CC
PCell	Primary Cell
PCI	Physical Cell ID, Physical Cell Identity
PCEF	Policy and Charging Enforcement Function
PCF	Policy Control Function
	PCRFPolicy Control and Charging Rules Function
PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network, Public Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PEI	Permanent Equipment Identifiers
PFD	Packet Flow Description
P-GW	PDN Gateway
PHICH	Physical hybrid-ARQ indicator channel
PHY	Physical layer
PLMN	Public Land Mobile Network
PIN	Personal Identification Number
PM	Performance Measurement
PMI	Precoding Matrix Indicator
PNF	Physical Network Function
PNFD	Physical Network Function Descriptor
PNFR	Physical Network Function Record
POC	PTT over Cellular
PP, PTP	Point-to-Point
PPP	Point-to-Point Protocol
PRACH	Physical RACH
PRB	Physical resource block
PRG	Physical resource block group
ProSe	Proximity Services, Proximity-Based Service
PRS	Positioning Reference Signal
PRR	Packet Reception Radio
PS	Packet Services
PSBCH	Physical Sidelink Broadcast Channel
PSDCH	Physical Sidelink Downlink Channel
PSCCH	Physical Sidelink Control Channel
PSSCH	Physical Sidelink Shared Channel
PSCell	Primary SCell
PSS	Primary Synchronization Signal
PSTN	Public Switched Telephone Network
PT-RS	Phase-tracking reference signal
PTT	Push-to-Talk
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS class of identifier
QCL	Quasi co-location
QFI	QoS Flow ID, QoS Flow Identifier
QoS	Quality of Service
QPSK	Quadrature (Quaternary) Phase Shift Keying
QZSS	Quasi-Zenith Satellite System
RA-RNTI	Random Access RNTI
RAB	Radio Access Bearer, Random Access Burst
RACH	Random Access Channel
RADIUS	Remote Authentication Dial In User Service
RAN	Radio Access Network
RAND	RANDom number (used for authentication)
RAR	Random Access Response
RAT	Radio Access Technology
RAU	Routing Area Update
RB	Resource block, Radio Bearer
RBG	Resource block group
REG	Resource Element Group
Rel	Release
REQ	REQuest
RF	Radio Frequency
RI	Rank Indicator
RIV	Resource indicator value
RL	Radio Link
RLC	Radio Link Control, Radio Link Control layer
RLC AM	RLC Acknowledged Mode
RLC UM	RLC Unacknowledged Mode
RLF	Radio Link Failure
RLM	Radio Link Monitoring
RLM-RS	Reference Signal for RLM
RM	Registration Management
RMC	Reference Measurement Channel
RMSI	Remaining MSI, Remaining Minimum System Information
RN	Relay Node
RNC	Radio Network Controller
RNL	Radio Network Layer
RNTI	Radio Network Temporary Identifier
ROHC	RObust Header Compression
RRC	Radio Resource Control, Radio Resource Control layer
RRM	Radio Resource Management
RS	Reference Signal
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
RSTD	Reference Signal Time difference
RTP	Real Time Protocol
RTS	Ready-To-Send

RTT	Round Trip Time
Rx	Reception, Receiving, Receiver
S1AP	S1 Application Protocol
S1-MME	S1 for the control plane
S1-U	S1 for the user plane
S-GW	Serving Gateway
S-RNTI	SRNC Radio Network Temporary Identity
S-TMSI	SAE Temporary Mobile Station Identifier
SA	Standalone operation mode
SAE	System Architecture Evolution
SAP	Service Access Point
SAPD	Service Access Point Descriptor
SAPI	Service Access Point Identifier
SCC	Secondary Component Carrier, Secondary CC
SCell	Secondary Cell
SCEF	Service Capability Exposure Function
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCG	Secondary Cell Group
SCM	Security Context Management
SCS	Subcarrier Spacing
SCTP	Stream Control Transmission Protocol
SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
SDL	Supplementary Downlink
SDNF	Structured Data Storage Network Function
SDP	Session Description Protocol
SDSF	Structured Data Storage Function
SDU	Service Data Unit
SEAF	Security Anchor Function
SeNB	secondary eNB
SEPP	Security Edge Protection Proxy
SFI	Slot format indication
SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
SFN	System Frame Number
SgNB	Secondary gNB
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SI	System Information
SI-RNTI	System Information RNTI
SIB	System Information Block
SIM	Subscriber Identity Module
SIP	Session Initiated Protocol
SiP	System in Package
SL	Sidelink
SLA	Service Level Agreement
SM	Session Management
SMF	Session Management Function
SMS	Short Message Service
SMSF	SMS Function
SMTC	SSB-based Measurement Timing Configuration
SN	Secondary Node, Sequence Number
SoC	System on Chip
SON	Self-Organizing Network
SpCell	Special Cell
SP-CSI-RNTI	Semi-Persistent CSI RNTI
SPS	Semi-Persistent Scheduling
SQN	Sequence number
SR	Scheduling Request
SRB	Signalling Radio Bearer
SRS	Sounding Reference Signal
SS	Synchronization Signal
SSB	Synchronization Signal Block
SSID	Service Set Identifier
SS/PBCH	Block
SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
SSC	Session and Service Continuity
SS-RSRP	Synchronization Signal based Reference Signal Received Power
SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
SSS	Secondary Synchronization Signal
SSSG	Search Space Set Group
SSSIF	Search Space Set Indicator
SST	Slice/Service Types
SU-MIMO	Single User MIMO
SUL	Supplementary Uplink
TA	Timing Advance, Tracking Area
TAC	Tracking Area Code
TAG	Timing Advance Group
TAI	Tracking Area Identity
TAU	Tracking Area Update
TB	Transport Block
TBS	Transport Block Size
TBD	To Be Defined
TCI	Transmission Configuration Indicator
TCP	Transmission Communication Protocol
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TEID	Tunnel End Point Identifier
TFT	Traffic Flow Template
TMSI	Temporary Mobile Subscriber Identity
TNL	Transport Network Layer
TPC	Transmit Power Control
TPMI	Transmitted Precoding Matrix Indicator
TR	Technical Report
TRP, TRxP	Transmission Reception Point
TRS	Tracking Reference Signal
TRx	Transceiver
TS	Technical Specifications, Technical Standard
TTI	Transmission Time Interval
Tx	Transmission, Transmitting, Transmitter
U-RNTI	UTRAN Radio Network Temporary Identity
UART	Universal Asynchronous Receiver and Transmitter
UCI	Uplink Control Information
UE	User Equipment
UDM	Unified Data Management
UDP	User Datagram Protocol
UDSF	Unstructured Data Storage Network Function
UICC	Universal Integrated Circuit Card
UL	Uplink
UM	Unacknowledged Mode
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
URLLC	Ultra-Reliable and Low Latency
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
USS	UE-specific search space
UTRA	UMTS Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
UwPTS	Uplink Pilot Time Slot
V2I	Vehicle-to-Infrastruction
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VIM	Virtualized Infrastructure Manager
VL	Virtual Link,
VLAN	Virtual LAN, Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualized Network Function
VNFFG	VNF Forwarding Graph
VNFFGD	VNF Forwarding Graph Descriptor
VNFM	VNF Manager
VoIP	Voice-over-IP, Voice-over-Internet Protocol
VPLMN	Visited Public Land Mobile Network
VPN	Virtual Private Network
VRB	Virtual Resource Block
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
X2-C	X2-Control plane
X2-U	X2-User plane
XML	eXtensible Markup Language
XRES	EXpected user RESponse
XOR	eXclusive OR
ZC	Zadoff-Chu
ZP	Zero Po

CLAIMS

What is claimed is:

1. An apparatus for a next generation evolved Node B (gNB), the apparatus comprising:

a processor configured to:

encode a first signal for transmission to a user equipment (UE) at a first time using a transmit signal path;

detect a second signal received over a receive signal path, the second signal including an indication of a first time difference between the first time and a second time at which the UE received the first signal;

detect, at a third time, a third signal received over the receive signal path from the UE;

calculate a second time difference between the third time and a fourth time at which the third signal was transmitted from the UE;

determine a propagation delay based on the first time difference and the second time difference; and

perform a compensation for the propagation delay; and

a memory to store the propagation delay.

2. The apparatus of claim 1, wherein the processor is further configured to:

encode a fourth signal for transmission to the UE using the transmit signal path, the fourth signal including the second time difference.

3. The apparatus claim 1, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

4. The apparatus of claim 1, wherein the first time difference is sent using a MAC control element.

5. The apparatus of claim 1, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the gNB.

6. The apparatus of claim 1, wherein calculating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

7. The apparatus of claim 1, wherein the processor comprises a baseband processor.

8. A computer-readable storage medium comprising instructions to cause processing circuitry, upon execution of the instructions by the processing circuitry, to:

calculate, by a user equipment (UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station;

calculate a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE;

determine a propagation delay based on the first time difference and the second time difference; and

perform a compensation for the propagation delay.

9. The computer-readable storage medium of claim 8, wherein calculating the second time difference is performed by the base station, and wherein the instructions further cause the processing circuitry to:

encode a first signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

10. The computer-readable storage medium of claim 8, wherein calculating the second time difference is performed by the base station, and wherein the instructions further cause the processing circuitry to:

detect a second signal received over a receive signal path, the second signal including an indication of the first time difference at the base station, wherein determining the propagation delay is performed by the base station.

11. The computer-readable storage medium of claim 8, wherein calculating the second time difference is performed by the base station, and wherein the instructions further cause the processing circuitry to:

detect a third signal received over a signal receive path, the third signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station; and

encode a fourth signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

12. The computer-readable storage medium of claim 8, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

13. The computer-readable storage medium of claim 8, wherein the first time difference is sent using a MAC control element.

14. The computer-readable storage medium of claim 8, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the base station.

15. The computer-readable storage medium of any one of claims 8-14, wherein calculating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

16. The computer-readable storage medium of any one of claims 8-14, wherein the processing circuitry comprises a baseband processor.

17. A method comprising:

calculating, by a user equipment (UE), a first time difference between a first time at which a first message was received from a base station and a second time at which the first message was transmitted from the base station;

calculating a second time difference between a third time at which a second message was received from the UE and a fourth time at which the second message was transmitted from the UE;

determining a propagation delay based on the first time difference and the second time difference; and

performing a compensation for the propagation delay.

18. The method of claim 17, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises:

encoding a first signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

19. The method of claim 17, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises:

detecting a second signal received over a receive signal path, the second signal including an indication of the first time difference at the base station, wherein determining the propagation delay is performed by the base station.

20. The method of claim 17, wherein calculating the second time difference is performed by the base station, and wherein the method further comprises:

detecting a third signal received over a signal receive path, the third signal including an indication of the first time difference at the base station, wherein calculating the propagation delay is performed by the base station; and

encoding a fourth signal for transmission using a transmit signal path including an indication of the second time difference to the UE, wherein calculating the propagation delay is performed by the UE.

21. The method of claim 17, wherein the first time difference is sent using a system information block (SIB) or using a dedicated radio resource control (RRC) message.

22. The method of claim 17, wherein the first time difference is sent using an active downlink portion of a bandwidth that is separate from a positioning portion of the bandwidth used by a positioning server that is separate from the base station.

23. The method of claim 17, wherein calculating the first time difference is based on information included within a downlink positioning reference signal (PRS) configuration message, wherein the information includes at least one of the following: PRS periodicity and resource slot offset, PRS resource repetition factor, PRS resource time gap, PRS number of symbols, PRS muting, PRS resource power, and/or PRS resource list.

24. An apparatus comprising means for performing any of the methods of claims 17-23.

25. A network node comprising a communication interface and processing circuitry connected thereto and configured to perform the method of claims 17-23.

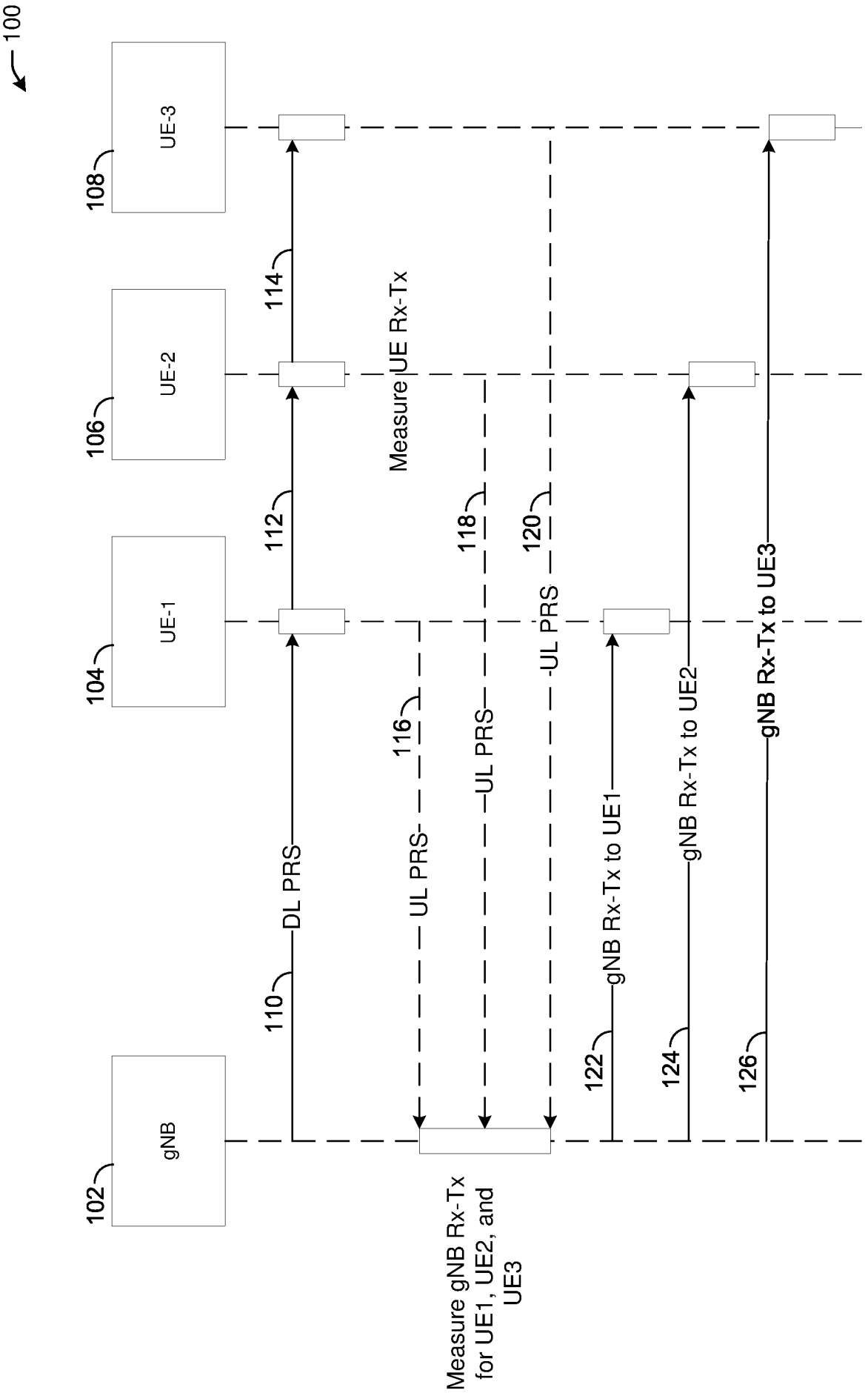

100
gNB
UE-1
UE-2
UE-3
102
104
106
108
110
112
114
116
118
120
122
124
126
DL PRS
UL PRS
UL PRS
UL PRS
Measure UE Rx-Tx
gNB Rx-Tx to UE1
gNB Rx-Tx to UE2
gNB Rx-Tx to UE3
Measure gNB Rx-Tx for UE1, UE2, and UE3

FIG. 1

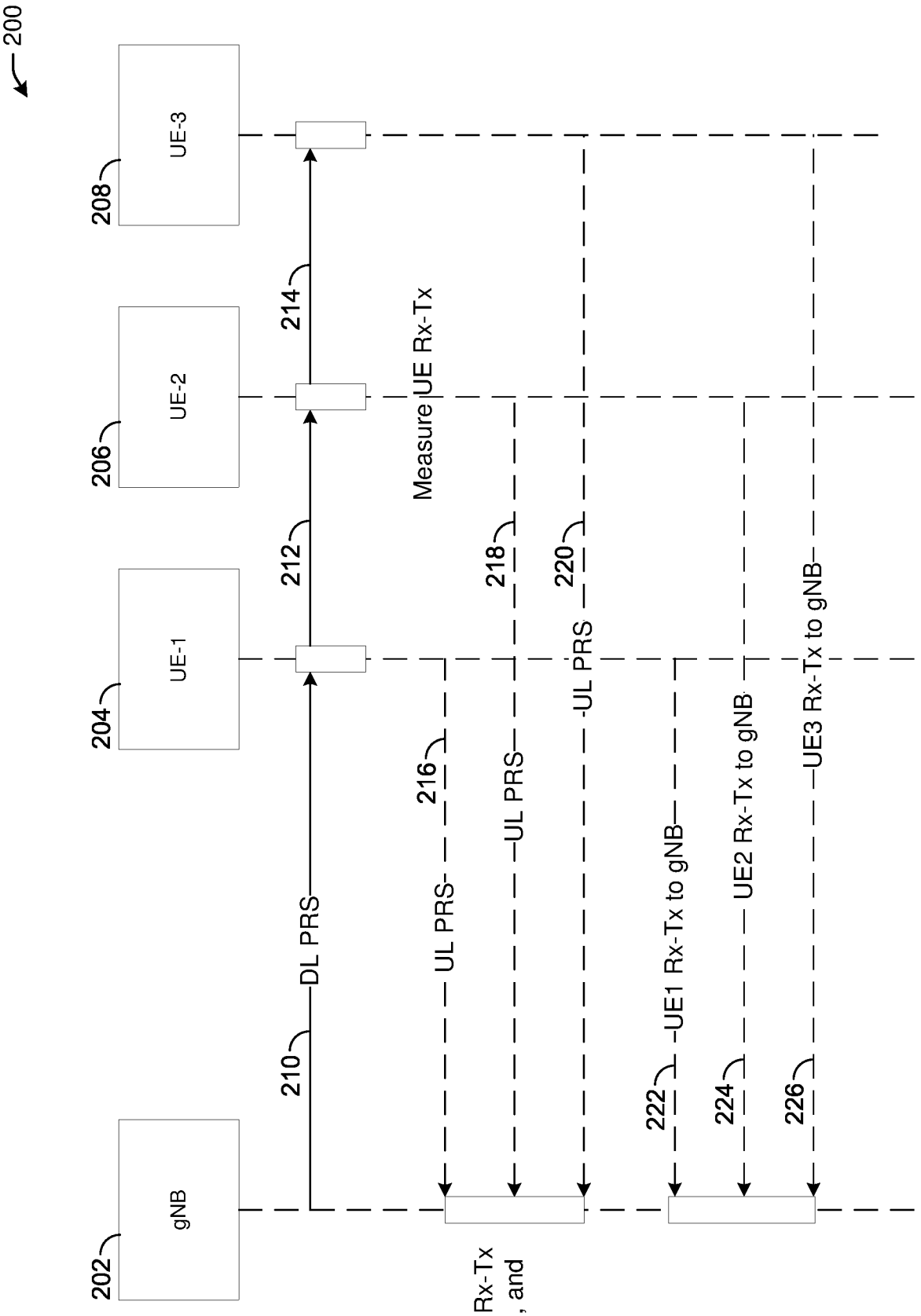

200
gNB
UE-1
UE-2
UE-3
202
204
206
208
210
212
214
216
218
220
222
224
226
DL PRS
UL PRS
UL PRS
UL PRS
Measure UE Rx-Tx
UE1 Rx-Tx to gNB
UE2 Rx-Tx to gNB
UE3 Rx-Tx to gNB
Measure gNB Rx-Tx for UE1, UE2, and UE3

FIG. 2

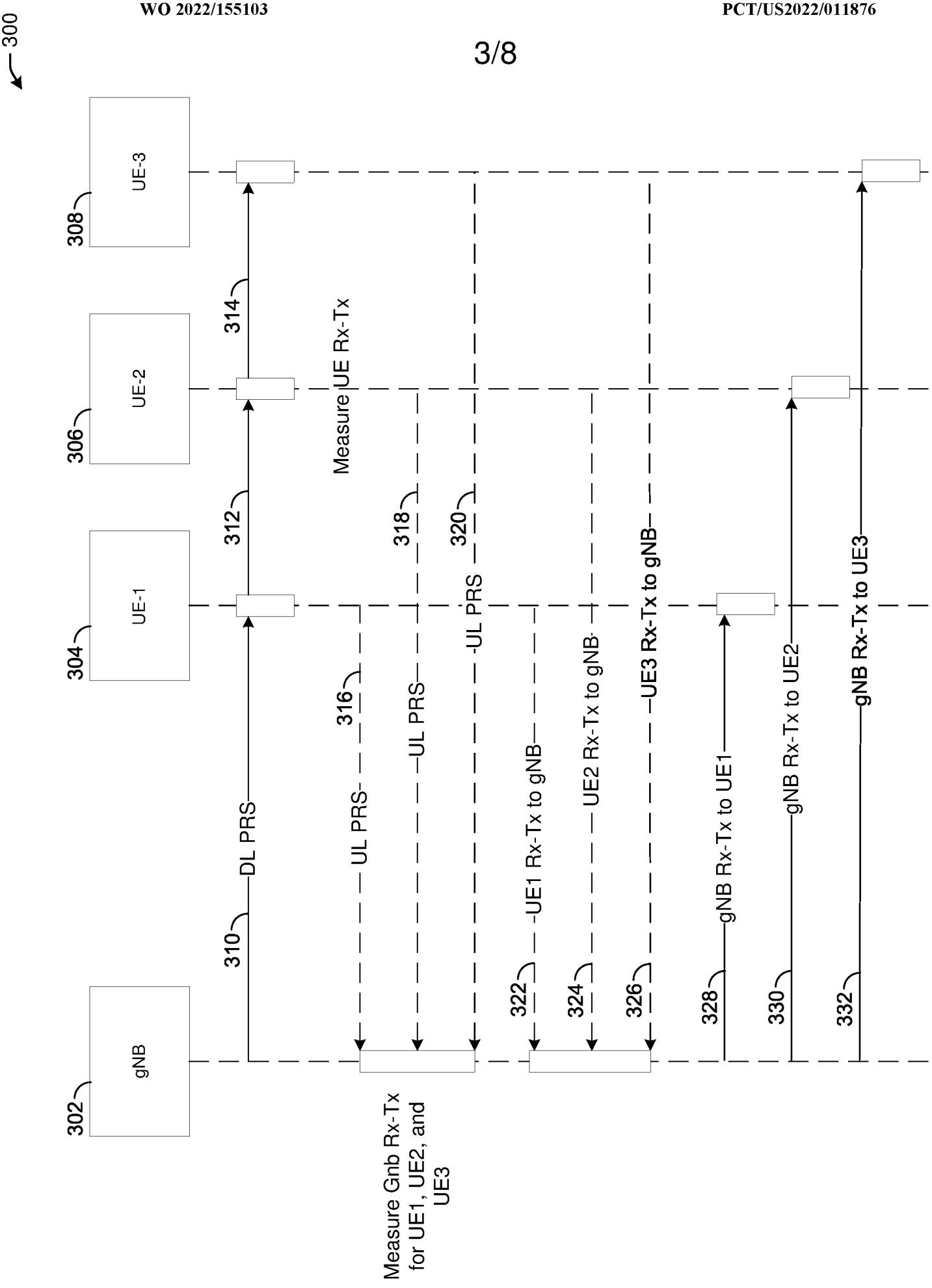

300
gNB
UE-1
UE-2
UE-3
302
304
306
308
310
312
314
316
318
320
322
324
326
328
330
332
DL PRS
Measure UE Rx-Tx
UL PRS
UL PRS
UL PRS
UE1 Rx-Tx to gNB
UE2 Rx-Tx to gNB
UE3 Rx-Tx to gNB
gNB Rx-Tx to UE1
gNB Rx-Tx to UE2
gNB Rx-Tx to UE3
Measure Gnb Rx-Tx for UE1, UE2, and UE3

FIG. 3

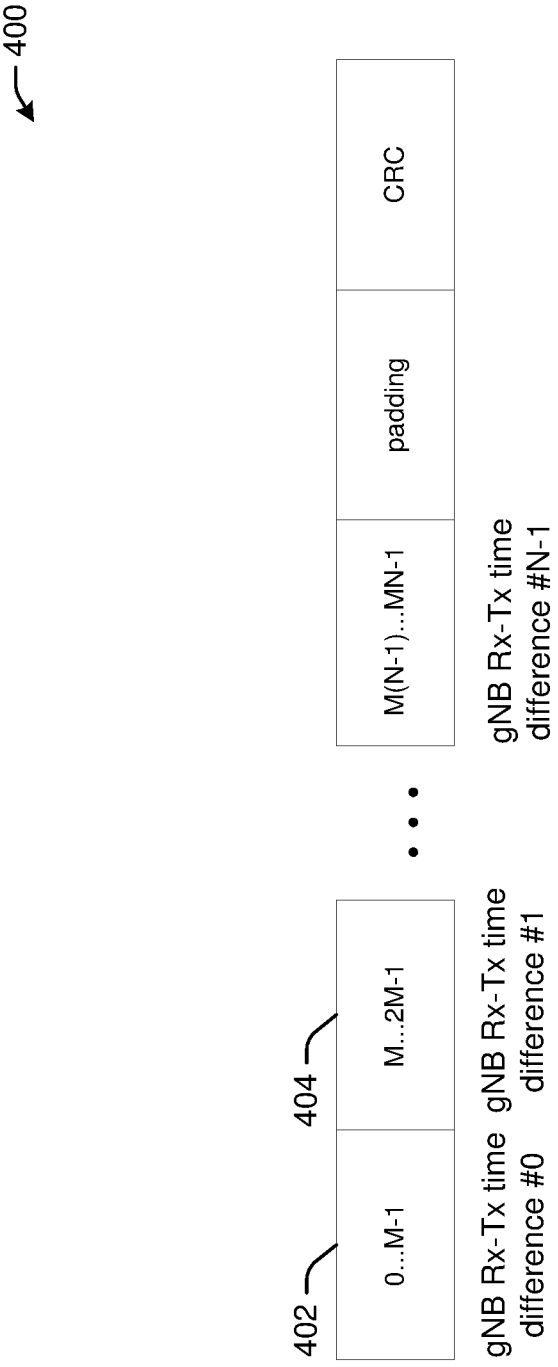

400
402
404
0...M-1
M...2M-1
M(N-1)...MN-1
padding
CRC
gNB Rx-Tx time difference #0
gNB Rx-Tx time difference #1
gNB Rx-Tx time difference #N-1

FIG. 4

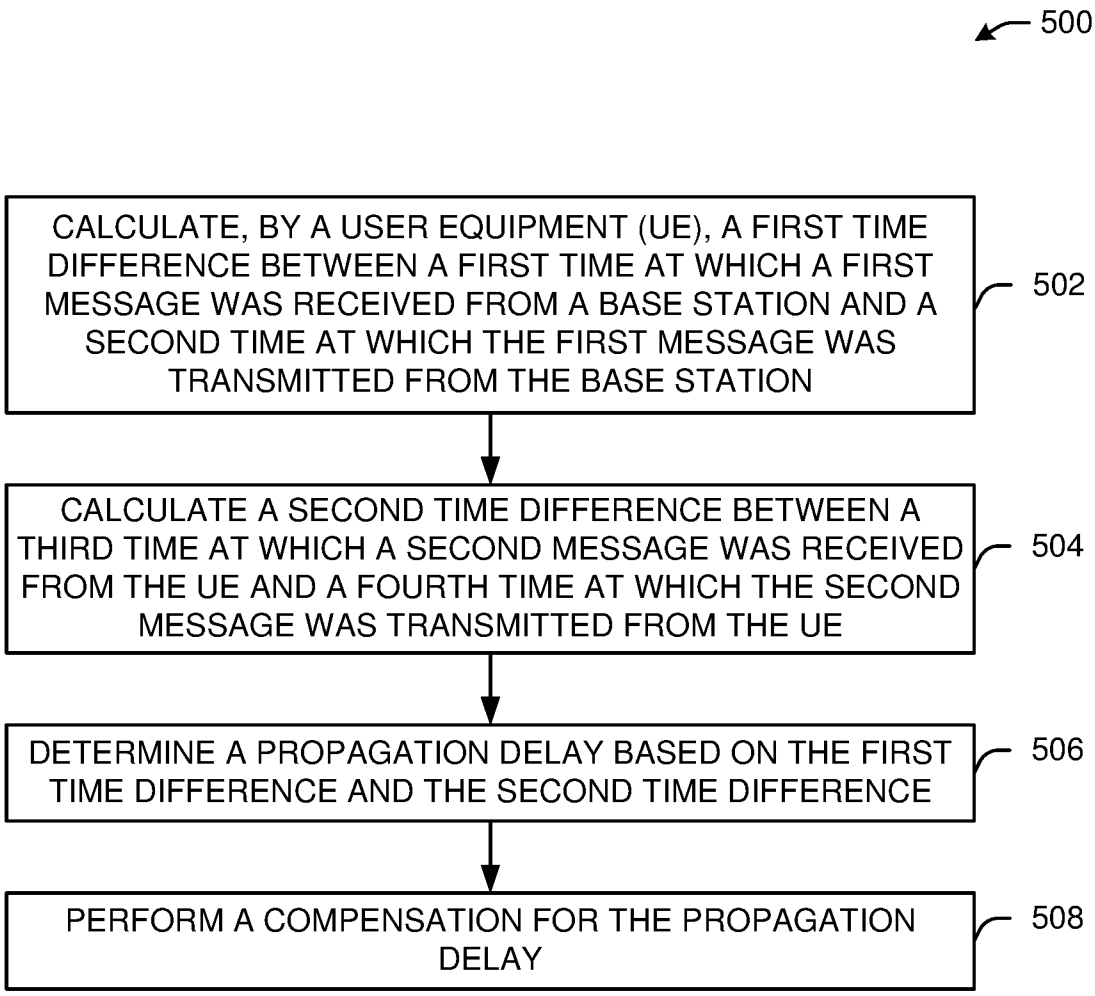

500
CALCULATE, BY A USER EQUIPMENT (UE), A FIRST TIME DIFFERENCE BETWEEN A FIRST TIME AT WHICH A FIRST MESSAGE WAS RECEIVED FROM A BASE STATION AND A SECOND TIME AT WHICH THE FIRST MESSAGE WAS TRANSMITTED FROM THE BASE STATION
502
CALCULATE A SECOND TIME DIFFERENCE BETWEEN A THIRD TIME AT WHICH A SECOND MESSAGE WAS RECEIVED FROM THE UE AND A FOURTH TIME AT WHICH THE SECOND MESSAGE WAS TRANSMITTED FROM THE UE
504
DETERMINE A PROPAGATION DELAY BASED ON THE FIRST TIME DIFFERENCE AND THE SECOND TIME DIFFERENCE
506
PERFORM A COMPENSATION FOR THE PROPAGATION DELAY
508

FIG. 5

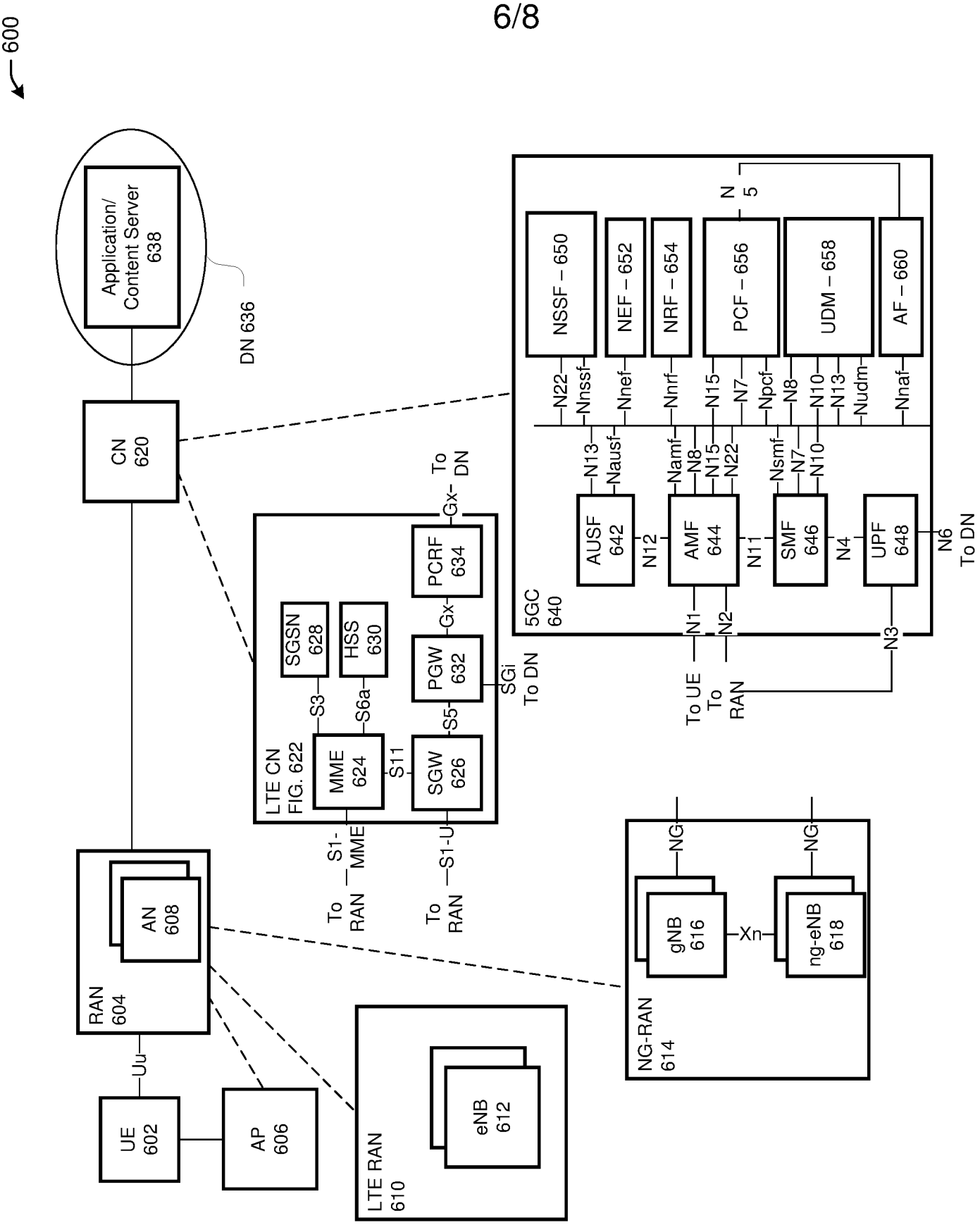

600
Application/ Content Server 638
DN 636
CN 620
5GC 640
NSSF – 650
NEF – 652
NRF – 654
PCF – 656
UDM – 658
AF – 660
N5
N22
Nnssf
Nnef
Nnrf
N15
N7
Npcf
N8
N10
N13
Nudm
Nnaf
N13
Nausf
Namf
N8
N15
N22
Nsmf
N7
N10
AUSF 642
N12
AMF 644
N11
SMF 646
N4
UPF 648
N6
To DN
N1
N2
N3
To UE
To RAN
To DN
Gx
PCRF 634
Gx
PGW 632
SGi
To DN
SGSN 628
HSS 630
S3
S6a
S5
LTE CN FIG. 622
MME 624
S11
SGW 626
S1-MME
S1-U
To RAN
To RAN
RAN 604
AN 608
Uu
UE 602
AP 606
LTE RAN 610
eNB 612
NG-RAN 614
NG
NG
gNB 616
Xn
ng-eNB 618

FIG. 6

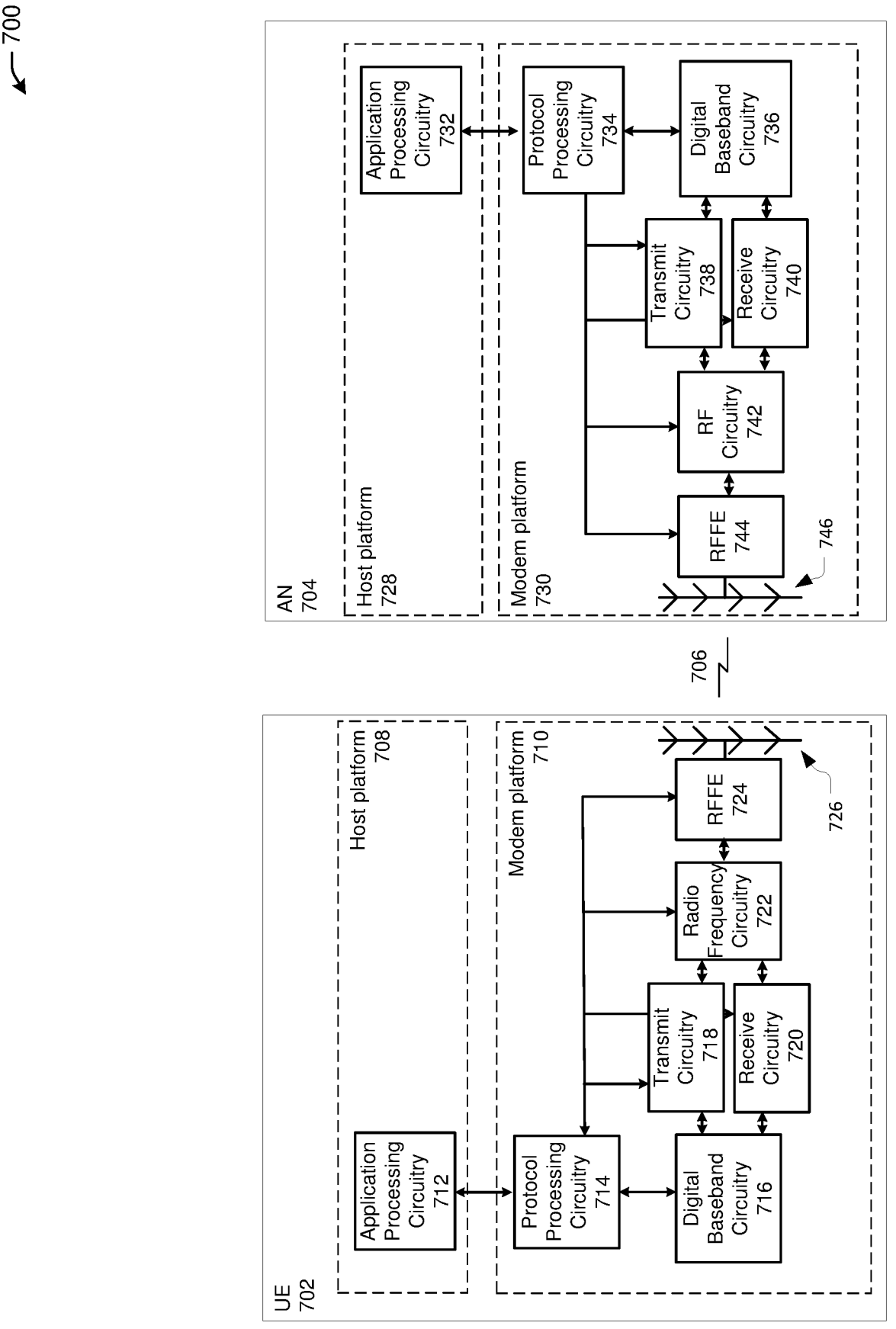

700
AN
704
Host platform
728
Application Processing Circuitry
732
Modem platform
730
Protocol Processing Circuitry
734
Digital Baseband Circuitry
736
Transmit Circuitry
738
Receive Circuitry
740
RF Circuitry
742
RFFE
744
746
706
UE
702
Host platform
708
Application Processing Circuitry
712
Modem platform
710
Protocol Processing Circuitry
714
Digital Baseband Circuitry
716
Transmit Circuitry
718
Receive Circuitry
720
Radio Frequency Circuitry
722
RFFE
724
726

FIG. 7

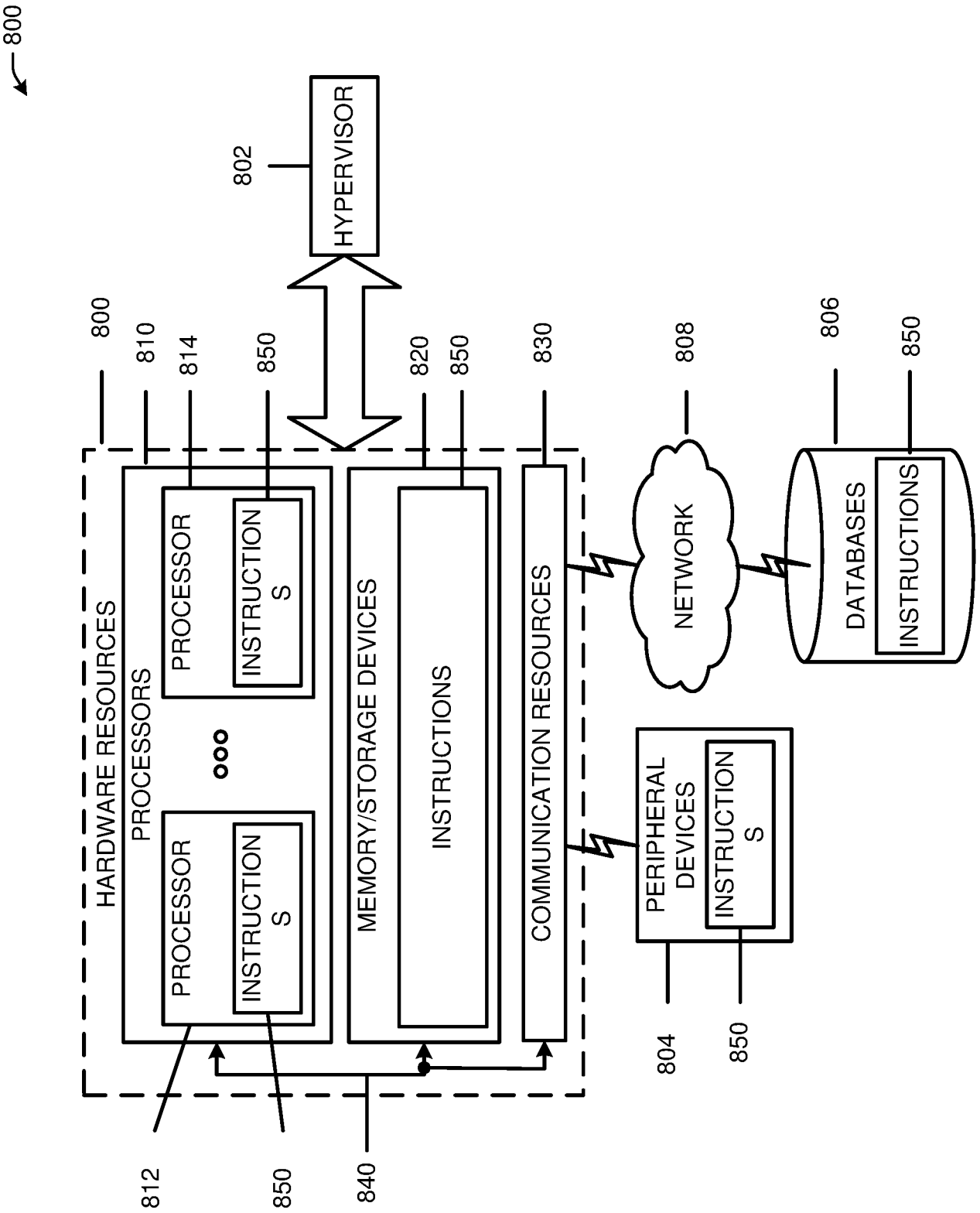

800
HYPERVISOR
802
800
810
814
850
820
850
830
808
806
850
HARDWARE RESOURCES
PROCESSORS
PROCESSOR
INSTRUCTIONS
PROCESSOR
INSTRUCTIONS
MEMORY/STORAGE DEVICES
INSTRUCTIONS
COMMUNICATION RESOURCES
NETWORK
DATABASES
INSTRUCTIONS
PERIPHERAL DEVICES
INSTRUCTIONS
804
850
812
850
840

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/011876

A. CLASSIFICATION OF SUBJECT MATTER

H04W 56/00(2009.01)i; **H04W 72/04**(2009.01)i; **H04W 88/08**(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 56/00(2009.01); H04L 7/00(2006.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: time difference, propagation delay, compensation, SIB, RRC, MAC control element, PRS (positioning reference signal)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	ERICSSON, 'Enhanced RTT Based Propagation Delay Determination', R1-2007711, 3GPP TSG-RAN WG1#103e, Electronic meeting, 01 November 2020	
X	sections 2-2.2; and figure 3	8,12-13,15-17,21,23-25
Y		14,22
A		1-7,9-11,18-20
	VIVO, 'Discussion on propagation delay compensation enhancements', R1-2007659, 3GPP TSG RAN WG 1 #103-e, e-Meeting, 01 November 2020	
Y	sections 1, 2.2, 3, 4.1; and figure 2	14,22
	SAMSUNG, 'Discussion for propagation delay compensation enhancements', R1-2008163, 3GPP TSG RAN WG1 #103-e, e-meeting, 01 November 2020	
A	sections 2.2-2.3	1-25
	'3GPP; TSG RAN; NR; Physical layer measurements (Release 16)', 3GPP TS 38.215 V16.4.0, 08 January 2021	
DA	sections 5.1.30, 5.2.3	1-25

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 April 2022	**22 April 2022**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea**	**YANG, Jeong Rok**
Facsimile No. **+82-42-481-8578**	Telephone No. **+82-42-481-5709**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2019-0191403 A1 (QUALCOMM INCORPORATED) 20 June 2019 (2019-06-20) claims 1-12	1-25

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2022/011876

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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