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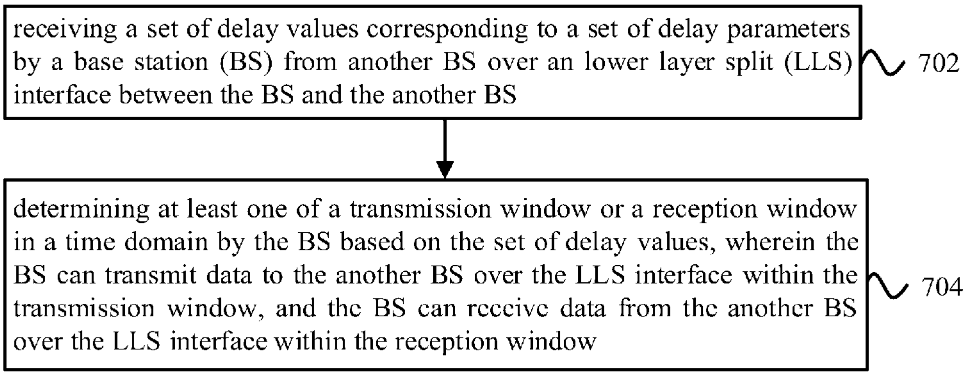


Figure 7

**(57) Abstract:** Various aspects of the present disclosure relate to methods and apparatuses for an optimization or adjustment of a time window in a lower layer split (LLS) radio access network (RAN) architecture. According to an embodiment of the present disclosure, a base station (BS) includes at least one memory and at least one processor coupled to the at least one memory and configured to cause the BS to: receive a set of delay values corresponding to a set of delay parameters from another BS over an lower layer split (LLS) interface between the BS and the another BS; and determine at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the BS can transmit data to the another BS over the LLS interface within the transmission window, and the BS can receive data from the another BS over the LLS interface within the reception window.

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# METHODS AND APPARATUSES FOR AN OPTIMIZATION OF A TIME WINDOW IN A LOWER LAYER SPLIT (LLS) RADIO ACCESS NETWORK (RAN) ARCHITECTURE

## TECHNICAL FIELD

**[0001]** The present disclosure relates to wireless communications, and more specifically to methods and apparatuses for an optimization or adjustment of a time window in a lower layer split (LLS) radio access network (RAN) architecture.

## BACKGROUND

**[0002]** A wireless communications system may include one or multiple network communication devices, such as a base station (BS), which may support wireless communications for one or multiple user communication devices, which may be otherwise known as user equipment (UE), or other suitable terminology. The wireless communications system may support wireless communications with one or multiple user communication devices by utilizing resources of the wireless communication system (e.g. time-domain resources (e.g. symbols, slots, subframes, frames, or the like) or frequency-domain resources (e.g. subcarriers, carriers, or the like). Additionally, the wireless communications system may support wireless communications across various radio access technologies including third generation (3G) radio access technology, fourth generation (4G) radio access technology, fifth generation (5G) radio access technology, among other suitable radio access technologies beyond 5G (e.g. sixth generation (6G)).

## SUMMARY

**[0003]** An article "a" before an element is unrestricted and understood to refer to "at least one" of those elements or "one or more" of those elements. The terms "a," "at least one," "one or more," and "at least one of one or more" may be interchangeable. As used herein, including in the claims, "or" as used in a list of items (e.g. a list of items prefaced by a phrase such as "at least one of" or "one or more of" or "one or both of") indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e. A and B and C). Also, as used herein, the phrase "based on" shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as "based on condition A" may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase "based on" shall be construed in the same manner as the phrase "based at least in part on. Further, as used herein, including in the claims, a "set" may include one or more elements.

**[0004]** Some implementations of the present disclosure provide a first base station (BS). The first BS includes at least one memory; and at least one processor coupled to the at least one memory and configured to cause the first BS to: receive a set of delay values corresponding to a set of delay parameters from a second BS over an lower layer split (LLS) interface between the first BS and the second BS; and determine at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the first BS can transmit data to the second BS over the LLS interface within the transmission window, and the first BS can receive data from the second BS over the LLS interface within the reception window.

**[0005]** In some implementations of the first BS described herein, the at least one processor is configured to cause the first BS to transmit, to the second BS over the LLS interface, a first message for requesting the second BS to report the set of delay values corresponding to the set of delay parameters.

**[0006]** In some implementations of the first BS described herein, the first message includes a bitmap of one or more positions, and each position in the bitmap indicates one delay parameter within the set of delay parameters that the second BS is requested to report a delay value corresponding to the one delay parameter.

**[0007]** In some implementations of the first BS described herein, the first message includes information indicating: a periodic reporting manner and a periodicity for delay value reporting; or an event-triggered reporting manner and one or more events for delay value reporting.

**[0008]** In some implementations of the first BS described herein, the one or more events for delay value reporting include a set of reporting levels, and the second BS is configured to divide the set of delay values into at least one reporting level within the set of reporting levels.

**[0009]** In some implementations of the first BS described herein, the at least one processor is configured to cause the first BS to receive first information from the second BS or transmit the first information to the second BS, wherein the first information indicates at least one of the following: the second BS is capable to provide one or more delay values corresponding to delay parameters requested by the first BS; or at least one delay value corresponding to the delay parameters requested by the first BS cannot be provided.

**[0010]** In some implementations of the first BS described herein, to determine the reception window, the at least one processor is configured to cause the first BS to use one or more delay values corresponding to transmission window related parameters at the second BS as a minimum delay associated with the reception window at the first BS.

**[0011]** In some implementations of the first BS described herein, the first BS is a distributed unit (DU) hosting high physical layers, and the second BS is a radio unit (RU) hosting low physical layers, the set of delay parameters includes at least one of the following: first timing difference between receiving a data packet over the LLS interface and transmitting an in-phase quadrature (IQ) sample corresponding to the data packet at an antenna of the RU; second timing difference between receiving a downlink (DL) LLS control plane (LLS-C) message over the LLS interface and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU; third timing difference between an output of a DL signal at an antenna connector of the RU and a transmission of the DL signal over an air interface; fourth timing difference between receiving an IQ sample corresponding to a data packet at the antenna of the RU and transmitting the data packet over the LLS interface; fifth timing difference between receiving a LLS-C message from the DU over the LLS interface and receiving an IQ sample from a user equipment (UE) at the antenna of the RU; or sixth timing difference between a reception of a uplink (UL) signal over the air interface and an input of the UL signal at the antenna connector of the RU.

**[0012]** In some implementations of the first BS described herein, to determine the transmission window, the at least one processor is configured to cause the DU to: use a delay value corresponding to the first timing difference as a minimum delay of a start time point of the transmission window for the data packet.

**[0013]** In some implementations of the first BS described herein, to determine the transmission window, the at least one processor is configured to cause the DU to: use a difference between a preconfigured time value and a delay value corresponding to the first timing difference as a maximum size of the transmission window for the DL LLS-U message; and use a difference between the preconfigured time value and a delay value corresponding to the second timing difference as a maximum size of the transmission window for the DL LLS-C message.

**[0014]** In some implementations of the first BS described herein, to determine the transmission window, the at least one processor is configured to cause the DU to shift a position of the transmission window for a downlink (DL) LLS user plane (LLS-U) message later in the time domain, by a delay value corresponding to the third timing difference.

**[0015]** In some implementations of the first BS described herein, to determine the reception window, the at least one processor is configured to cause the DU to: use a delay value corresponding to the fourth timing difference as a minimum delay of a start time point of the reception window for the data packet.

**[0016]** In some implementations of the first BS described herein, to determine the reception window, the at least one processor is configured to cause the DU to: use a difference between the preconfigured time value and a delay value corresponding to the fifth timing difference as a maximum size of the reception window for the UL LLS-U message.

**[0017]** In some implementations of the first BS described herein, to determine the reception window, the at least one processor is configured to cause the DU to shift a position of the reception window for a UL LLS-U message earlier in the time domain, by a delay value corresponding to the sixth timing difference.

**[0018]** In some implementations of the first BS described herein, the first BS is a radio unit (RU) hosting low physical layers, and the second BS is a distributed unit (DU) hosting high physical layers, and the set of delay values includes at least one of the following: a first delay value corresponding to timing difference between transmitting a DL LLS-U data message and transmitting an IQ sample corresponding to the DL LLS-U data message; an amount of time which the DU requires to transmit all DL LLS-U messages for a symbol; a second delay value corresponding to timing difference between receiving an initial UL LLS-

U message for a first symbol and receiving a last UL LLS-U message for the first symbol; or a third delay value corresponding to timing difference between transmitting a DL LLS-C data message and transmitting an IQ sample corresponding to the DL LLS-C data message.

**[0019]** In some implementations of the first BS described herein, to determine the reception window, the at least one processor is configured to cause the RU to: increase a size of the reception window if at least one of the first delay value, the amount of time, or the third delay value is greater than a threshold; or decrease the size of the reception window if at least one of the first delay value, the amount of time, or the third delay value is less than the threshold.

**[0020]** In some implementations of the first BS described herein, to determine the transmission window, the at least one processor is configured to cause the RU to: increase a size of the transmission window if the second delay value is greater than a threshold; or decrease the size of the transmission window if the second delay value is less than the threshold.

**[0021]** In some implementations of the first BS described herein, the set of delay values is a first set of delay values, and the at least one processor is configured to cause the RU to transmit a second set of delay values to the DU over the LLS interface, and the second set of delay values includes one or more delay values corresponding to at least one of the following: first timing difference between receiving a data packet over the LLS interface and transmitting an IQ sample corresponding to the data packet at an antenna of the RU; second timing difference between receiving a downlink (DL) LLS control plane (LLS-C) message over the LLS interface and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU; third timing difference between an output of a DL signal at an antenna connector of the RU and a transmission of the DL signal over an air interface; fourth timing difference between receiving an IQ sample corresponding to a data packet at the antenna of the RU and transmitting the data packet over the LLS interface; fifth timing difference between receiving a LLS-C message from the DU over the LLS interface and receiving an IQ sample from a user equipment (UE) at the antenna of the RU; or sixth timing difference between a reception of a UL signal over the air interface and an input of the UL signal at the antenna connector of the RU.

**[0022]** In some implementations of the first BS described herein, at least one delay value within the set of delay values or at least one delay parameter within the set of delay parameters is associated with at least one of the following: one or more beamforming methods; or one or more combinations of sub carrier spacing (SCS) and bandwidth.

**[0023]** In some implementations of the first BS described herein, the one or more beamforming methods include at least one of the following: predefined-beam beamforming; weight-based dynamic beamforming; attribute-based dynamic beamforming; channel-information-based beamforming; or demodulation reference signal (DMRS) based beamforming.

**[0024]** In some implementations of the first BS described herein, at least one delay value within the set of delay values is a delta value related to a default delay value, and the default delay value is common for multiple beamforming methods or common for multiple combinations of sub carrier spacing (SCS) and bandwidth.

**[0025]** Some implementations of the present disclosure provide a processor for wireless communication, comprising at least one controller coupled with at least one memory and configured to cause the processor to: receive a set of delay values corresponding to a set of delay parameters from a base station (BS) over an lower layer split (LLS) interface between the processor and the BS; and determine at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the processor can transmit data to the BS over the LLS interface within the transmission window, and the processor can receive data from the BS over the LLS interface within the reception window.

**[0026]** Some implementations of the present disclosure provide a method performed by a first base station (BS). The method includes: receiving a set of delay values corresponding to a set of delay parameters from a second BS over an lower layer split (LLS) interface between the first BS and the second BS; and determining at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the first BS can transmit data to the second BS over the LLS interface within the transmission window, and the first BS can receive data from the second BS over the LLS interface within the reception window.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0027]** Figure 1 illustrates an example of a wireless communications system in accordance with some aspects of the present disclosure.

**[0028]** Figure 2 illustrates an example of a processor 200 in accordance with some aspects of the present disclosure.

**[0029]** Figure 3 illustrates an example of a network equipment (NE) 300 in accordance with some aspects of the present disclosure.

**[0030]** Figure 4 illustrates a diagram of a logical architecture of an LLS RAN in accordance with some aspects of the present disclosure.

**[0031]** Figure 5 illustrates a diagram of reference points for delay management in accordance with some aspects of the present disclosure.

**[0032]** Figure 6 illustrates a diagram of reference points for delay management including external antenna delay in accordance with some aspects of the present disclosure.

**[0033]** Figure 7 illustrates a flowchart of a method for an optimization of a time window in an LLS RAN architecture in accordance with some aspects of the present disclosure.

**[0034]** Figures 8 and 9 illustrate schematic diagrams of an optimization of a time window in an LLS RAN architecture in accordance with some aspects of the present disclosure.

## DETAILED DESCRIPTION

**[0035]** In general, split RAN, in which a RAN architecture is split into centralized baseband units and distributed radio units, has gained traction and has proven to be effective in commercial RAN deployments over the past years. Such centralized architecture has both performance benefits (due to improved inter-cell/frequency coordination at the centralized baseband) and cost benefits (e.g. due to increased hardware/software pooling, reduced site rental and management costs). Therefore, with the challenging and diverse requirements for the radio systems, the need for such split RAN architecture is becoming ever more important.

**[0036]** A typical lower layer split RAN architecture is shown in Figure 4, as defined by open radio access network (O-RAN). **Figure 4** illustrates a diagram of a logical architecture of an LLS RAN in accordance with some aspects of the present disclosure.

- **O-RAN distributed unit (O-DU):** a logical node hosting PDCP (packet data convergence protocol), RRC (radio resource control), SDAP (service data adaption protocol), RLC (radio link control), MAC (medium access protocol), High-PHY (physical) layers based on a lower layer functional split. The O-DU controls the operation of O-RUs. For example, the High-PHY layer includes the functionalities of scrambling, modulation, layer mapping, resource element mapping, IQ (in-phase quadrature) compression, etc.

- **O-RAN radio unit (O-RU):** a logical node hosting Low-PHY layer and RF (radio frequency) processing based on a lower layer functional split. The real-time aspects of control & user plane communication with the O-RU are controlled by the O-DU. For example, the Low-PHY layer includes the functionalities of IQ decompression, digital beamforming, IFFT (inverse fast fourier transform) and CP (cyclic prefix) addition, digital to analog, analog beamforming, etc.

- **LLS (lower layer split)**: a logic interface between O-DU and O-RU when using a lower layer functional split. LLS control plane (LLS-C) is the lower layer split control plane, while LLS user plane (LLS-U) is the lower layer split user plane.

**[0037]** An LLS RAN has characteristics of a stringent bandwidth and tight latency requirement. For example, O-DU shall send LLS-C or LLS-U messages to O-RU within appropriate transmission window, where the transmission window defines the boundaries that the LLS-C or LLS-U O-DU transmission shall operate within. O-DU shall receive LLS-C or LLS-U messages from O-RU within appropriate reception window, where the reception window defines the boundaries that the LLS-C or LLS-U O-DU reception shall operate within. O-RU shall send LLS-C or LLS-U messages to O-DU within appropriate transmission window, where the transmission window defines the boundaries that the LLS-C or LLS-U O-RU transmission shall operate within. O-RU shall receive LLS-C or LLS-U messages from O-DU within appropriate reception window, where the reception window defines the boundaries that the LLS-C or LLS-U O-RU reception shall operate within.

**[0038]** However, it is not easy to decide a transmission or reception window of O-DU or a transmission or reception window of O-RU. For example, on one hand, to support coordination of LLS-C and LLS-U timing, the LLS-C messages shall arrive at O-RU some amount of time in advance of the latest possible time the initial corresponding LLS-U messages may arrive. On the other hand, if the LLS-C messages arrives at O-RU too early, O-RU shall buffer the received LLS-C messages, which makes buffering in O-RU more complex.

**[0039]** Currently, O-RAN defines a latency model for delay management definitions, as shown in Figure 5. O-DU may also be named as DU. O-RU may also be named as RU.

**[0040]** **Figure 5** illustrates a diagram of reference points for delay management in accordance with some aspects of the present disclosure. A DU obtains the delay parameters value (e.g., T2a, Ta3) related to the operation of a RU from the management system, i.e. pre-configured by the management system.

**[0041]** As shown in Figure 5, R1 is a transmit interface at a DU, and R4 is a receive interface at the DU. R2 is a receive interface at a RU, and R3 is a transmit interface at the RU. Ra is an antenna interface at the RU. When an external antenna is used with a cable imposing a negligible delay, the RU connector to the external antenna can be assumed as Ra. Ra is used as a reference point for delay management and transmission and reception at the reference points shall be measured relative to Ra.

**[0042]** Transmission delay between the DU and the RU are specified as T12 (downlink) and T34 (uplink). The transmission delay encompasses only the time from when a bit leaves the sender (R1 or R3) until it is received at the receiver (R2 or R4). T1a is measured from output at the DU (R1) to transmission over the air. T2a is measured from reception at the RU (R2) to transmission over the air. Ta4 is measured from reception at the RU antenna to reception at the DU port (R4). Ta3 is measured from reception at the RU antenna to an output at the RU port (R3). As shown in Figure 5, T1a = T12 + T2a. Ta4 =Ta3 + T34.

**[0043]** The latency model of Figure 5 assumes that the antenna delay is negligible compared to the O-RU's internal delay or is known by the O-RU. Figure 5 defines T2a and Ta3 values as the total processing time between front-haul interface input or output ports (R2 and R3) and the antenna interface point (Ra).

**[0044]** **Figure 6** illustrates a diagram of reference points for delay management including external antenna delay in accordance with some aspects of the present disclosure. Figure 6 further defines the RU external antenna delay parameters. T2a and Ta3 will have a new definition when external antenna delays are introduced. In particular, T2a is the RU internal delay between R2 and Rd. Ta3 is the RU internal delay between Ru and R3. In downlink (DL), Tda is timing difference between the output of DL signal at the antenna connector (Rd) of the RU and the transmission over the air (Ra). In uplink (UL), Tau is timing difference between the reception over the air (Ra) and the input of UL signal at the antenna connector (Ru) of the RU. As shown in Figure 6, T1a = T12 + T2a + Tda. Ta4 = Tau +Ta3 + T34. Other reference points for delay management in Figure 6 are the same as those of Figure 5.

**[0045]** However, due to the very high bitrates, the delay parameters value may differ largely depending on the operation environment, topology and target use cases. Therefore, the approach of pre-configured delay parameters value by the management system is not well. For example, a DU shall always consider the maximum T2a delay for all operation environment (e.g., high bitrate, low bitrate), where the maximum T2a delay is a fixed value. Therefore, the following issues need to be solved:

- Issue 1: How to support the optimization of a DU transmission window with dynamic timing advance to reduce the RU buffering load, or a DU reception window to reduce the DU buffering load?
- Issue 2: How to support the multiple beamforming methods, where each beamforming method can have different delay parameters value from others?
- Issue 3: The current latency model assumes that the antenna delay is negligible compared to the RU's internal delay or is known by the DU. How to support the RU external antenna delay, where the processing time between input or output ports of the RU and antenna interface point is non-negligible?

**[0046]** Currently, details regarding issues 1, 2 and 3 have not been discussed yet. Embodiments of the present disclosure aim to resolve the abovementioned issues. For example, some embodiments of the present disclosure define a new LLS-C procedure for the provision of RU delay parameters value from a RU to a DU. Some embodiments of the present disclosure introduce a new LLS-C message sent by the DU to request the RU to provide values of one or more delay parameters (for simplicity, the message is called as a delay request). For example, the delay parameters may include RU reception window range related parameters for a DL, and/or RU transmission window range related parameters for a UL. The delay request may include DU reception window range related parameters for the UL and/or DU transmission window range related parameters for the DL, to be used by the RU for the optimization of a RU reception window or a RU transmission window. The delay request may include an indicator indicating a reporting method or manner. In an example, the reporting method may be a periodic reporting, indicating the periodicity that can be used for reporting of RU delay parameters value. In another example, the reporting method may be an event-triggered reporting, indicating one or more events for RU delay parameters value reporting.

**[0047]** Some embodiments of the present disclosure introduce a new LLS-C message sent by a RU to provide values of one or more delay parameters to a DU (for simplicity, the message is called as delay report).

**[0048]** Some embodiments of the present disclosure introduce an indicator indicating the beamforming method or manner associated with the delay parameters value. The beamforming method may include the predefined-beam beamforming, weight-based dynamic beamforming, attribute-based dynamic beamforming, channel-information-based beamforming, and/or DMRS based beamforming. In the delay request, the delay parameters may be associated with the beamforming method. The delay parameters value may be associated with a combination of SCS and bandwidth. The delay parameters value for a specific beamforming method may be a delta value different from the default delay parameters value, where the default delay parameters value is common for multiple beamforming methods.

**[0049]** Some embodiments of the present disclosure introduce the timing advance between the antenna connector of a RU and the transmission or reception. Some embodiments of the present disclosure define behaviours of a DU. For example, for an uplink LLS-C message, the position of the reception window in time domain shall not be shifted. For an uplink LLS-U message, the DU may shift the position of the reception window earlier in time domain with the external delay, for an optimization or adjustment. For a downlink LLS-C, the position of the transmission window in time domain shall not be shifted. For a downlink LLS-U message, the DU may shift the position of the transmission window later in time domain with the external delay, for an optimization or adjustment.

**[0050]** In the present disclosure, a RU refers to a logical node hosting Low-PHY layer based on an LLS. In some cases, a RU may also host other functionalities, e.g., RF processing. A RU may also be named as "a RU hosting low physical layers," "a network node hosting low physical layers," or "a base station (BS) hosting low physical layers" or the like. A DU refers to a logical node hosting High-PHY layers based on an LLS. In some cases, a DU may also host other functionalities, e.g., PDCP layer, RRC layer, SDAP layer, RLC layer or MAC layer. A DU may also be named as "a DU hosting high physical layers," "a network node hosting high physical layers," or "a base station (BS) hosting high physical layers" or the like.

**[0051]** A RU transmission window may also be named as "a transmission window of a RU," "a transmission window at a RU," "a transmitting window of a RU" or the like. A RU reception window may also be named as "a reception window of a RU," "a reception window at a RU," "a receiving window of a RU" or the like. A DU transmission window may also be named as "a transmission window of a DU," "a transmission window at a DU," "a transmitting window of a DU" or the like. A DU reception window may also be named as "a reception window of a DU," "a reception window at a DU," "a receiving window of a DU" or the like.

**[0052]** A delay parameter may also be named as "a delay time parameter," "a time parameter," "an offset time parameter," "a time difference parameter," "a timing difference parameter" or the like. A delay value corresponding to a delay parameter refers to a value of a delay parameter, and may also be named as "a delay parameter value," "a delay time value," an offset time value," "a time difference value," "a timing difference value" or the like.

**[0053]** More details of the embodiments of the present disclosure will be illustrated in the following text in combination with the appended drawings.

**[0054]** **Figure 1** illustrates an example of a wireless communications system 100 in accordance with some aspects of the present disclosure. The wireless communications system 100 may include one or more NE 102, one or more UE 104, and a core network (CN) 106. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a

4G network, such as a long term evolution (LTE) network or an LTE-advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be a new radio (NR) network, such as a 5G network, a 5G-advanced (5G-A) network, or a 5G ultrawideband (5G-UWB) network. In other implementations, the wireless communications system 100 may be a combination of a 4G network and a 5G network, or other suitable radio access technology including institute of electrical and electronics engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G, for example, 6G. Additionally, the wireless communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

**[0055]** The one or more NE 102 may be dispersed throughout a geographic region to form the wireless communications system 100. One or more of the NE 102 described herein may be or include or may be referred to as a network node, a base station, a network element, a network function, a network entity, a radio access network (RAN), a NodeB, an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. An NE 102 and a UE 104 may communicate via a communication link, which may be a wireless or wired connection. For example, an NE 102 and a UE 104 may perform wireless communication (e.g. receive signaling, transmit signaling) over a Uu interface.

**[0056]** An NE 102 may provide a geographic coverage area for which the NE 102 may support services for one or more UEs 104 within the geographic coverage area. For example, an NE 102 and a UE 104 may support wireless communication of signals related to services (e.g. voice, video, packet data, messaging, broadcast, etc.) according to one or multiple radio access technologies. In some implementations, an NE 102 may be moveable, for example, a satellite associated with a non-terrestrial network (NTN). In some implementations, different geographic coverage areas associated with the same or different radio access technologies may overlap, but the different geographic coverage areas may be associated with different NE 102.

**[0057]** The one or more UE 104 may be dispersed throughout a geographic region of the wireless communications system 100. A UE 104 may include or may be referred to as a remote unit, a mobile device, a wireless device, a remote device, a subscriber device, a transmitter device, a receiver device, or some other suitable terminology. In some implementations, the UE 104 may be referred to as a unit, a station, a terminal, or a client, among other examples. Additionally, or alternatively, the UE 104 may be referred to as an internet-of-things (IoT) device, an internet-of-everything (IoE) device, or machine-type communication (MTC) device, among other examples.

**[0058]** A UE 104 may be able to support wireless communication directly with other UEs 104 over a communication link. For example, a UE 104 may support wireless communication directly with another UE 104 over a device-to-device (D2D) communication link. In some implementations, such as vehicle-to-vehicle (V2V) deployments, vehicle-to-everything (V2X) deployments, or cellular-V2X deployments, the communication link may be referred to as a sidelink. For example, a UE 104 may support wireless communication directly with another UE 104 over a PC5 interface.

**[0059]** An NE 102 may support communications with the CN 106, or with another NE 102, or both. For example, an NE 102 may interface with other NE 102 or the CN 106 through one or more backhaul links (e.g. S1, N2, or network interface). In some implementations, the NE 102 may communicate with each other directly. In some other implementations, the NE 102 may communicate with each other or indirectly (e.g. via the CN 106. In some implementations, one or more NE 102 may include subcomponents, such as an access network entity, which may be an example of an access node controller (ANC). An ANC may communicate with the one or more UEs 104 through one or more other access network transmission entities, which may be referred to as a radio heads, smart radio heads, or transmission-reception points (TRPs).

**[0060]** The CN 106 may support user authentication, access authorization, tracking, connectivity, and other access, routing, or mobility functions. The CN 106 may be an evolved packet core (EPC), or a 5G core (5GC), which may include a control plane entity that manages access and mobility (e.g. a mobility management entity (MME), an access and mobility management functions (AMF)) and a user plane entity that routes packets or interconnects to external networks (e.g. a serving gateway (S-GW), a packet data network (PDN) gateway (P-GW), or a user plane function (UPF)). In some implementations, the control plane entity may manage non-access stratum (NAS) functions, such as mobility, authentication, and bearer management (e.g. data bearers, signal bearers, etc.) for the one or more UEs 104 served by the one or more NE 102 associated with the CN 106.

**[0061]** The CN 106 may communicate with a packet data network over one or more backhaul links (e.g. via an S1, N2, or another network interface). The packet data network may include an application server. In some implementations, one or more UEs 104 may communicate with the application server. A UE 104 may establish a session (e.g. a protocol data unit (PDU) session, or the like) with the CN 106 via an NE 102. The CN 106 may route traffic (e.g. control information, data, and the like) between the UE 104 and the application server using the established session (e.g. the established PDU session). The PDU session may be an example of a logical connection between the UE 104 and the CN 106 (e.g. one or more network functions of the CN 106).

**[0062]** In the wireless communications system 100, the NEs 102 and the UEs 104 may use resources of the wireless communications system 100 (e.g. time resources (e.g. symbols, slots, subframes, frames, or the like) or frequency resources (e.g. subcarriers, carriers)) to perform various operations (e.g. wireless communications). In some implementations, the NEs 102 and the UEs 104 may support different resource structures. For example, the NEs 102 and the UEs 104 may support different frame structures. In some implementations, such as in 4G, the NEs 102 and the UEs 104 may support a single frame structure. In some other implementations, such as in 5G and among other suitable radio access technologies, the NEs 102 and the UEs 104 may support various frame structures (i.e. multiple frame structures). The NEs 102 and the UEs 104 may support various frame structures based on one or more numerologies.

**[0063]** One or more numerologies may be supported in the wireless communications system 100, and a numerology may include a subcarrier spacing and a cyclic prefix. A first numerology (e.g. $\mu$=0) may be associated with a first subcarrier spacing (e.g. 15 kHz) and a normal cyclic prefix. In some implementations, the first numerology (e.g. $\mu$=0) associated with the first subcarrier spacing (e.g. 15 kHz) may utilize one slot per subframe. A second numerology (e.g. $\mu$=1) may be associated with a second subcarrier spacing (e.g. 30 kHz) and a normal cyclic prefix. A third numerology (e.g. $\mu$=2) may be associated with a third subcarrier spacing (e.g. 60 kHz) and a normal cyclic prefix or an extended cyclic prefix. A fourth numerology (e.g. $\mu$=3) may be associated with a fourth subcarrier spacing (e.g. 120

kHz) and a normal cyclic prefix. A fifth numerology (e.g. $\mu$=4) may be associated with a fifth subcarrier spacing (e.g. 240 kHz) and a normal cyclic prefix.

**[0064]** A time interval of a resource (e.g. a communication resource) may be organized according to frames (also referred to as radio frames). Each frame may have a duration, for example, a 10 millisecond (ms) duration. In some implementations, each frame may include multiple subframes. For example, each frame may include 10 subframes, and each subframe may have a duration, for example, a 1 ms duration. In some implementations, each frame may have the same duration. In some implementations, each subframe of a frame may have the same duration.

**[0065]** Additionally or alternatively, a time interval of a resource (e.g. a communication resource) may be organized according to slots. For example, a subframe may include a number (e.g. quantity) of slots. The number of slots in each subframe may also depend on the one or more numerologies supported in the wireless communications system 100. For instance, the first, second, third, fourth, and fifth numerologies (i.e. $\mu$=0, $\mu$=1, $\mu$=2, $\mu$=3, $\mu$=4) associated with respective subcarrier spacings of 15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz may utilize a single slot per subframe, two slots per subframe, four slots per subframe, eight slots per subframe, and 16 slots per subframe, respectively. Each slot may include a number (e.g. quantity) of symbols (e.g. OFDM symbols). In some implementations, the number (e.g. quantity) of slots for a subframe may depend on a numerology. For a normal cyclic prefix, a slot may include 14 symbols. For an extended cyclic prefix (e.g. applicable for 60 kHz subcarrier spacing), a slot may include 12 symbols. The relationship between the number of symbols per slot, the number of slots per subframe, and the number of slots per frame for a normal cyclic prefix and an extended cyclic prefix may depend on a numerology. It should be understood that reference to a first numerology (e.g. $\mu$=0) associated with a first subcarrier spacing (e.g. 15 kHz) may be used interchangeably between subframes and slots.

**[0066]** In the wireless communications system 100, an electromagnetic (EM) spectrum may be split, based on frequency or wavelength, into various classes, frequency bands, frequency channels, etc. By way of example, the wireless communications system 100 may support one or multiple operating frequency bands, such as frequency range designations FR1 (310 MHz – 7.125 GHz), FR2 (24.25 GHz – 52.6 GHz), FR3 (7.125 GHz – 24.25 GHz), FR4 (52.6 GHz – 114.25 GHz), FR4a or FR4-1 (52.6 GHz – 71 GHz), and FR5 (114.25 GHz

– 200 GHz). In some implementations, the NEs 102 and the UEs 104 may perform wireless communications over one or more of the operating frequency bands. In some implementations, FR1 may be used by the NEs 102 and the UEs 104, among other equipment or devices for cellular communications traffic (e.g. control information, data). In some implementations, FR2 may be used by the NEs 102 and the UEs 104, among other equipment or devices for short-range, high data rate capabilities.

**[0067]** FR1 may be associated with one or multiple numerologies (e.g. at least three numerologies). For example, FR1 may be associated with a first numerology (e.g. $\mu$=0), which includes 15 kHz subcarrier spacing; a second numerology (e.g. $\mu$=1), which includes 30 kHz subcarrier spacing; and a third numerology (e.g. $\mu$=2), which includes 60 kHz subcarrier spacing. FR2 may be associated with one or multiple numerologies (e.g. at least 2 numerologies). For example, FR2 may be associated with a third numerology (e.g. $\mu$=2), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g. $\mu$=3), which includes 120 kHz subcarrier spacing.

**[0068]** **Figure 2** illustrates an example of a processor 200 in accordance with some aspects of the present disclosure. The processor 200 may be an example of a processor configured to perform various operations in accordance with examples as described herein. The processor 200 may include a controller 202 configured to perform various operations in accordance with examples as described herein. The processor 200 may optionally include at least one memory 204, which may be, for example, an L1/L2/L3 cache. Additionally, or alternatively, the processor 200 may optionally include one or more arithmetic-logic units (ALUs) 206. One or more of these components may be in electronic communication or otherwise coupled (e.g. operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g. buses).

**[0069]** The processor 200 may be a processor chipset and include a protocol stack (e.g. a software stack) executed by the processor chipset to perform various operations (e.g. receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) in accordance with examples as described herein. The processor chipset may include one or more cores, one or more caches (e.g. memory local to or included in the processor chipset (e.g. the processor 200) or other memory (e.g. random access memory (RAM), read-only memory (ROM), dynamic RAM (DRAM), synchronous dynamic RAM (SDRAM), static RAM (SRAM), ferroelectric RAM (FeRAM), magnetic RAM (MRAM), resistive RAM (RRAM), flash memory, phase change memory (PCM), and others).

**[0070]** The controller 202 may be configured to manage and coordinate various operations (e.g. signaling, receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) of the processor 200 to cause the processor 200 to support various operations in accordance with examples as described herein. For example, the controller 202 may operate as a control unit of the processor 200, generating control signals that manage the operation of various components of the processor 200. These control signals include enabling or disabling functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

**[0071]** The controller 202 may be configured to fetch (e.g. obtain, retrieve, receive) instructions from the memory 204 and determine subsequent instruction(s) to be executed to cause the processor 200 to support various operations in accordance with examples as described herein. The controller 202 may be configured to track memory address of instructions associated with the memory 204. The controller 202 may be configured to decode instructions to determine the operation to be performed and the operands involved. For example, the controller 202 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 200 to cause the processor 200 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 202 may be configured to manage flow of data within the processor 200. The controller 202 may be configured to control transfer of data between registers, arithmetic logic units (ALUs), and other functional units of the processor 200.

**[0072]** The memory 204 may include one or more caches (e.g. memory local to or included in the processor 200 or other memory, such RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc. In some implementations, the memory 204 may reside within or on a processor chipset (e.g. local to the processor 200). In some other implementations, the memory 204 may reside external to the processor chipset (e.g. remote to the processor 200).

**[0073]** The memory 204 may store computer-readable, computer-executable code including instructions that, when executed by the processor 200, cause the processor 200 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. The controller 202 and/or the processor 200 may be configured to execute computer-readable instructions stored in the memory 204 to cause the processor 200 to perform various functions. For example, the processor 200 and/or the controller 202 may be coupled with or to the memory 204, the processor 200, the controller 202, and the memory 204 may be configured to perform various functions described herein. In some examples, the processor 200 may include multiple processors and the memory 204 may include multiple memories. One or more of the multiple processors may be coupled with one or more of the multiple memories, which may, individually or collectively, be configured to perform various functions herein.

**[0074]** The one or more ALUs 206 may be configured to support various operations in accordance with examples as described herein. In some implementations, the one or more ALUs 206 may reside within or on a processor chipset (e.g. the processor 200). In some other implementations, the one or more ALUs 206 may reside external to the processor chipset (e.g. the processor 200). One or more ALUs 206 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 206 may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 206 be configured with a variety of logical and arithmetic circuits, including adders, subtractors, shifters, and logic gates, to process and manipulate the data according to the operation. Additionally, or alternatively, the one or more ALUs 206 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 206 to handle conditional operations, comparisons, and bitwise operations.

**[0075]** The processor 200 may support wireless communication in accordance with examples as disclosed herein.

**[0076]** In some implementations, the processor 200 may be configured to support means for performing operations of a BS as described with respect to Figure 7. For example, the processor 200 may be configured to or operable to support: a means for receiving a set of delay values corresponding to a set of delay parameters from a BS over an lower layer split (LLS) interface between the processor 200 and the BS; and a means for determining at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the processor 200 can transmit data to the BS over the LLS interface within the transmission window, and the processor 200 can receive data from the BS over the LLS interface within the reception window.

**[0077]** It should be appreciated by persons skilled in the art that the components in exemplary processor 200 may be changed, for example, some of the components in exemplary processor 200 may be omitted or modified or new component(s) may be added to exemplary processor 200, without departing from the spirit and scope of the disclosure. For example, in some embodiments, the processor 200 may not include the ALUs 206.

**[0078]** **Figure 3** illustrates an example of a NE 300 in accordance with some aspects of the present disclosure. The NE 300 may include a processor 302, a memory 304, a controller 306, and a transceiver 308. The processor 302, the memory 304, the controller 306, or the transceiver 308, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described herein. These components may be coupled (e.g. operatively, communicatively, functionally, electronically, electrically) via one or more interfaces.

**[0079]** The processor 302, the memory 304, the controller 306, or the transceiver 308, or various combinations or components thereof may be implemented in hardware (e.g. circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), or other programmable logic device, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure.

**[0080]** The processor 302 may include an intelligent hardware device (e.g. a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, or any combination thereof). In some implementations, the processor 302 may be configured to operate the memory 304. In some other implementations, the memory 304 may be integrated into the processor 302. The processor 302 may be configured to execute computer-readable instructions stored in the memory 304 to cause the NE 300 to perform various functions of the present disclosure.

**[0081]** The memory 304 may include volatile or non-volatile memory. The memory 304 may store computer-readable, computer-executable code including instructions when executed by the processor 302 cause the NE 300 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such the memory 304 or another type of memory. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer.

**[0082]** In some implementations, the processor 302 and the memory 304 coupled with the processor 302 may be configured to cause the NE 300 to perform one or more of the functions described herein (e.g. executing, by the processor 302, instructions stored in the memory 304). For example, the processor 302 may support wireless communication at the NE 300 in accordance with examples as disclosed herein. For example, the NE 300 may be configured to support means for performing the operations as described with respect to Figures 5 and 6 as described below.

**[0083]** In some implementations, the NE 300 may be a BS as described with respect to Figure 7. The NE 300 may be configured to support: a means for receiving a set of delay values corresponding to a set of delay parameters from another NE over an lower layer split (LLS) interface between the NE 300 and the another NE; and a means for determining at least one of a transmission window or a reception window in a time domain based on the set of delay values, wherein the NE 300 can transmit data to the another NE over the LLS interface within the transmission window, and the NE 300 can receive data from the another NE over the LLS interface within the reception window.

**[0084]** The controller 306 may manage input and output signals for the NE 300. The controller 306 may also manage peripherals not integrated into the NE 300. In some implementations, the controller 306 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 306 may be implemented as part of the processor 302.

**[0085]** In some implementations, the NE 300 may include at least one transceiver 308. In some other implementations, the NE 300 may have more than one transceiver 308. The transceiver 308 may represent a wireless transceiver. The transceiver 308 may include one or more receiver chains 310, one or more transmitter chains 312, or a combination thereof. The means for receiving or the means for transmitting abovementioned in the processor 302 may be implemented via at least one transceiver 308.

**[0086]** A receiver chain 310 may be configured to receive signals (e.g. control information, data, packets) over a wireless medium. For example, the receiver chain 310 may include one or more antennas for receive the signal over the air or wireless medium. The receiver chain 310 may include at least one amplifier (e.g. a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 310 may include at least one demodulator configured to demodulate the receive signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receiver chain 310 may include at least one decoder for decoding the processing the demodulated signal to receive the transmitted data.

**[0087]** A transmitter chain 312 may be configured to generate and transmit signals (e.g. control information, data, packets). The transmitter chain 312 may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmitter chain 312 may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmitter chain 312 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

**[0088]** It should be appreciated by persons skilled in the art that the components in exemplary NE 300 may be changed, for example, some of the components in exemplary NE 300 may be omitted or modified or new component(s) may be added to exemplary NE 300, without departing from the spirit and scope of the disclosure. For example, in some embodiments, the NE 300 may not include the controller 306.

**[0089]** **Figure 7** illustrates a flowchart of a method for an optimization of a time window in an LLS RAN architecture in accordance with some aspects of the present disclosure. The operations of the method may be implemented by a base station (BS), e.g. a DU or a RU, as described herein. In some implementations, the BS may execute a set of instructions to control the function elements of the BS to perform the described functions. In some implementations, aspects of operations 702 and 704 may be performed by NE 300 as described with reference to Figure 3. Each of operations 702 and 704 may be performed in accordance with examples as described herein. Specific examples are described in the embodiments of Figures 8 and 9 as follows.

**[0090]** At 702, the method includes receiving, a set of delay values corresponding to a set of delay parameters by a BS (denoted as BS #1) from another BS (denoted as BS #2) over an LLS interface between BS #1 and BS #2.

**[0091]** For instance, at least one delay value within the set of delay values may be associated with one or more beamforming methods and/or one or more combinations of SCS and bandwidth. At least one delay parameter within the set of delay parameters may be associated with one or more beamforming methods and/or one or more combinations of SCS and bandwidth. For example, the beamforming methods may include: predefined-beam beamforming; weight-based dynamic beamforming; attribute-based dynamic beamforming; channel-information-based beamforming; and/or DMRS based beamforming.

**[0092]** In some implementations, at least one delay value within the set of delay values is a delta value related to a default delay value. The default delay value may be common for multiple beamforming methods or common for multiple combinations of SCS and bandwidth.

**[0093]** At 704, the method includes determining, by BS #1, at least one of a transmission window or a reception window in a time domain based on the set of delay values. BS #1 can transmit data to BS #2 over the LLS interface within the transmission window. BS #1 can receive data from BS #2 over the LLS interface within the reception window. In some embodiments, BS #1 may be a DU hosting high physical layers, and BS #2 may be a RU hosting low physical layers. In some other embodiments, BS #1 may be a RU hosting low physical layers, and BS #2 may be a DU hosting high physical layers.

**[0094]** In some implementations of the method, BS #1 may transmit, to BS #2 over the LLS interface, a message (e.g. a delay request) for requesting BS #2 to report the set of delay values corresponding to the set of delay parameters. In some embodiments, the message includes the set of delay parameters. In some other embodiments, the message includes a bitmap of one or more positions, and each position in the bitmap indicates one delay parameter within the set of delay parameters that BS #2 is requested to report a delay value corresponding to the one delay parameter.

**[0095]** In some implementations, the message includes information indicating: a periodic reporting manner; and a periodicity for delay value reporting. In some other implementations, the message includes information indicating: an event-triggered reporting manner; and one or more events for delay value reporting. For example, the one or more events for delay value reporting include a set of reporting levels. BS #2 may be configured to divide the set of delay values into at least one reporting level within the set of reporting levels.

**[0096]** In some implementations, BS #1 may receive, from BS #2, information (denoted as information #1) which indicates at least one of the following, for example, in case that BS #1 is a DU and BS #2 is a RU:

(1) BS #2 is capable to provide one or more delay values corresponding to delay parameters requested by BS #1 may, e.g. information #1 is included in a delay request response.

(2) At least one delay value corresponding to the delay parameters requested by BS #1 may cannot be provided, e.g. information #1 is included in a delay request failure.

**[0097]** In some other implementations, BS #1 may transmit information #1 to BS #2, for example, in case that BS #1 is a RU and BS #2 is a DU.

**[0098]** In some implementations of the method, to determine the reception window of BS #1 at 704, BS #1 may use one or more delay values corresponding to transmission window related parameters at BS #2 as a minimum delay associated with the reception window at BS #1. In other words, based on received one or more delay values corresponding to transmission window related parameters at BS #2, BS #1 may determine a minimum delay associated with the reception window at BS #1.

**[0099]** In case that BS #1 is a DU hosting high physical layers, and BS #2 is a RU hosting low physical layers, the set of delay parameters may include at least one of the following:

(1) timing difference (denoted as delay #1, e.g. P1) between receiving a data packet over the LLS interface and transmitting an IQ sample corresponding to the data packet at an antenna of the RU (e.g. T2a between R2 and Ra as shown in Figure 5);

(2) timing difference (denoted as delay #2, e.g. P2) between receiving a DL LLS-C message over the LLS interface and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU;

(3) timing difference (denoted as delay #3, e.g. P3) between an output of a DL signal at an antenna connector of the RU and a transmission of the DL signal over an air interface (e.g. Tda between Rd and Ra as shown in Figure 6);

(4) timing difference (denoted as delay #4, e.g. P4) between receiving an IQ sample corresponding to a data packet at the antenna of the RU and transmitting the data packet over the LLS interface (e.g. Ta3 between Ra and R3 as shown in Figure 5);

(5) timing difference (denoted as delay #5, e.g. P5) between receiving a LLS-C message from the DU over the LLS interface and receiving an IQ sample from a UE at the antenna of the RU; or

(6) timing difference (denoted as delay #6, e.g. P6) between a reception of a UL signal over the air interface and an input of the UL signal at the antenna connector of the RU (e.g. Tau between Ra and Ru as shown in Figure 6).

**[0100]** In some implementations, to determine the transmission window of the DU at 704, the DU may use a delay value corresponding to delay #1 (e.g. D1) as a minimum delay of a start time point of the transmission window for the data packet.

**[0101]** In some other implementations, to determine the transmission window of the DU at 704, the DU may use a difference between a preconfigured time value and a delay value corresponding to delay #1 (e.g. T – D1) as a maximum size of the transmission window for the DL LLS-U message; and use a difference between the preconfigured time value and a delay value corresponding to delay #2 (e.g. T – D2) as a maximum size of the transmission window for the DL LLS-C message.

**[0102]** In some embodiments, the DU may shift a position of the transmission window of the DU for a DL LLS-U message later in the time domain, by a delay value corresponding to delay #3 (e.g. D3).

**[0103]** In some implementations, to determine the reception window of the DU at 704, the DU may use a delay value corresponding to delay #4 (e.g. D4) as a minimum delay of a start time point of the reception window for the data packet.

**[0104]** In some other implementations, to determine the reception window of the DU at 704, the DU may use a difference between the preconfigured time value and a delay value corresponding to delay #5 (e.g. T – D5) as a maximum size of the reception window for the UL LLS-U message.

**[0105]** In some embodiments, the DU may shift a position of the reception window of the DU for a UL LLS-U message earlier in the time domain, by a delay value corresponding to delay #6 (e.g. D6). Specific examples are described in the embodiments of Figure 8 as follows.

**[0106]** In case that BS #1 is a RU hosting low physical layers, and BS #2 is a DU hosting high physical layers, the set of delay values may include at least one of the following:

(1) a delay value (denoted as value #1, e.g. D7) corresponding to timing difference between transmitting a DL LLS-U data message and transmitting an IQ sample corresponding to the DL LLS-U data message;

(2) an amount of time (denoted as value #2, e.g. D8) which the DU requires to transmit all DL LLS-U messages for a symbol;

(3) a delay value (denoted as value #3, e.g. D9) corresponding to timing difference between receiving an initial UL LLS-U message for a first symbol and receiving a last UL LLS-U message for the first symbol; or

(4) a delay value (denoted as value #4, e.g. D10) corresponding to timing difference between transmitting a DL LLS-C data message and transmitting an IQ sample corresponding to the DL LLS-C data message.

**[0107]** In some implementations, to determine the reception window of the RU at 704, the RU may increase a size (or length) of the reception window, if at least one of value #1, value #2, or value #4 is greater than a threshold. In some other implementations, the RU may decrease the size (or length) of the reception window, if at least one of value #1, value #2, or value #4 is less than the threshold.

**[0108]** In some implementations, to determine the transmission window of the RU at 704, the RU may increase a size (or length) of the transmission window, if value #3 is greater than a threshold. In some other implementations, the RU may decrease the size (or length) of the transmission window, if value #3 is less than the threshold.

**[0109]** In some implementations of the method, the set of delay values received at 702 is denoted as delay values set #1, and the RU may transmit another set of delay values (denoted as delay values set #2) to the DU over the LLS interface. Delay values set #2 may include one or more delay values corresponding to at least one of the following:

(1) timing difference (i.e. delay #1 as described above, e.g. P1) between receiving a data packet over the LLS interface and transmitting an IQ sample corresponding to the data packet at an antenna of the RU (e.g. T2a between R2 and Ra as shown in Figure 5);

(2) timing difference (i.e. delay #2 as described above, e.g. P2) between receiving a DL LLS-C message over the LLS interface and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU;

(3) timing difference (i.e. delay #3 as described above, e.g. P3) between an output of a DL signal at an antenna connector of the RU and a transmission of the DL signal over an air interface (e.g. Tda between Rd and Ra as shown in Figure 6);

(4) timing difference (i.e. delay #4 as described above, e.g. P4) between receiving an IQ sample corresponding to a data packet at the antenna of the RU and transmitting the data packet over the LLS interface (e.g. Ta3 between Ra and R3 as shown in Figure 5);

(5) timing difference (i.e. delay #5 as described above, e.g. P5) between receiving a LLS-C message from the DU over the LLS interface and receiving an IQ sample from a UE at the antenna of the RU; or

(6) timing difference (i.e. delay #6 as described above, e.g. P6) between a reception of a UL signal over the air interface and an input of the UL signal at the antenna connector of the RU (e.g. Tau between Ra and Ru as shown in Figure 6).

**[0110]** It should be noted that the method described in Figure 7 describes possible implementations, and that the operations and the steps may be rearranged or otherwise eliminated or modified and that other implementations are possible, without departing from the spirit and scope of the disclosure. Following text describe specific embodiments of Figure 7 according to different cases.

**[0111]** **Figure 8** illustrates a schematic diagram of an optimization of a time window in an LLS RAN architecture in accordance with some aspects of the present disclosure. The embodiments of Figure 8 provide solutions for an optimization or adjustment of a transmission or reception window in time domain in a DU.

**[0112]** At 801, a DU may send a delay request to a RU, to request the RU to provide one or more delay values. The delay request may include one or more delay parameters to be reported. The delay parameters may include at least one of the following:

(1) RU reception window related parameters for a DL, including:

a) P1: Delay (e.g. T2a as shown in Figure 5) between receiving a data packet over an LLS interface (e.g. R2 as shown in Figure 5) and transmitting an IQ sample corresponding to the data packet at the antenna of the RU (e.g. Ra as shown in Figure 5).

b) P2: Delay (e.g. T2a as shown in Figure 5) between receiving DL LLS-C message over the LLS interface (e.g. R2 as shown in Figure 5) and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU (e.g. Ra as shown in Figure 5).

c) P3: Timing advance (e.g. Tda as shown in Figure 6) between the output of DL signal at the antenna connector of RU (e.g. Rd as shown in Figure 6) and the transmission over the air of the RU (e.g. Ra as shown in Figure 6).

(2) RU transmission window related parameters for a UL, including:

a) P4: Delay (e.g. Ta3 as shown in Figure 5) between receiving an IQ sample at the antenna (e.g. Ra as shown in Figure 5) and transmitting the corresponding a data packet over the LLS interface (e.g. R3 as shown in Figure 5).

b) P5: Delay between receiving a LLS-C message from the DU over the LLS interface (e.g. R2 as shown in Figure 5) and receiving an IQ sample from a UE at the antenna (e.g. Ra as shown in Figure 5).

c) P6: Timing advance (e.g. Tau as shown in Figure 6) between the reception of a UL signal over the air interface (e.g. Ra as shown in Figure 6) and an input of the UL signal at the antenna connector of the RU (e.g. Ru as shown in Figure 6).

**[0113]** The delay request at 801 may be associated with one or more beamforming methods or manners. The beamforming methods may include at least one of the following:

(1) Predefined-beam beamforming: beam indices are conveyed from the DU to the RU to indicate which beam to apply to the DL or the UL data.

(2) Weight-based dynamic beamforming: the DU generates beamforming weights and sends the beamforming weights to the RU, which are to be used by the RU to create a beam.

(3) Attribute-based dynamic beamforming: the DU provides beamforming attributes to the RU, which are to be used by the RU to create beam. The beamforming attributes include the azimuth beamforming pointing angle in degrees, the zenith beamforming pointing angle in degrees, the azimuth beamforming 3dB down beam width in degrees, the zenith beamforming 3dB down beam width in degrees, the azimuth beamforming sidelobe suppression value in dB, the zenith beamforming sidelobe suppression value in dB.

(4) Channel-information-based beamforming: the DU provides channel information per UE periodically, and then on a slot-by-slot basis the DU provides scheduling information which the RU uses along with the channel information to calculate the proper beamforming weights for the specific slot with its co-scheduled UEs.

(5) DMRS based beamforming: the RU computes UE channel estimates based on the received UE UL DMRS symbols, and then computes beamforming weights based on those channel estimates and applies the beamforming weights to the UE UL data.

**[0114]** The delay request at 801 may be associated with a combination of SCS and bandwidth, where the SCS is the distance between two adjacent subcarriers in an orthogonal frequency division multiplexing signal, e.g., 15 kHz, 30 kHz, 60 kHz, or 120 kHz.

**[0115]** The delay request at 801 may include an indicator indicating one or more reporting methods or manners which is used by the RU to report the one or more delay values. The reporting methods may be one of the following:

(1) Periodic reporting. For instance, the delay request further indicates the periodicity that can be used for reporting of the RU delay value. For example, the periodicity is 500 ms.

(2) Event-triggered reporting. For instance, the delay request further indicates the event for RU delay value reporting. For example, the event is a number of reporting levels. The RU may divide the delay scale into the indicated number of reporting levels, even distributed on a linear scale. The RU may send the delay values each time the delay parameters changes from one reporting level to another reporting level.

**[0116]** In one example, the delay parameters are included in the delay request at 801 explicitly. In another example, the delay parameters are included in the delay request using a bitmap, where each position in the bitmap indicates the delay parameter that the RU is requested to report. For example, first bit = P1, second bit = P2, third bit = P3, fourth bit = P4, fifth bit = P5, sixth bit = P6, and other bits are reserved for further use.

**[0117]** Therefore, as a combination of above descriptions, an example of delay request based on RAN LLS-C using eCPRI (enhanced Common Public Radio Interface) may be shown as below.

Format 1 of delay request

| **Delay Measurement (Type x)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **0 (msb)** | **1** | **2** | **3** | **4** | **5** | **6** | **7 (lsb)** | **number of bytes** | |
| ecpriVersion | | | | ecpriReserved | | | ecpriConcatenation | 1 | Octet 1 |
| ecpriMessage = x | | | | | | | | 1 | Octet 2 |
| ecpriPayloadSize | | | | | | | | 2 | Octet 3+4 |
| Measurement ID | | | | | | | | 1 | Octet 5 |
| P1 | P2 | P3 | P4 | P5 | P6 | reserved | | 1 | Octet 6 |
| Beamforming method | | | SCS and bandwidth | | | Reporting method | | 1 | Octet 7 |

- **Type x**: the type of the message is x which is to be defined.
- **msb**: the most significant bit.
- **lsb**: the least significant bit.
- **ecpriVersion**: indicates the protocol version, which is a positive integer value.
- **ecpriReserved**: reserved for future use.
- **ecpriConcatenation**: value 0 indicates the eCPRI message is the last one inside the eCPRI protocol data unit; and value 1 indicates that another eCPRI message follows this one within the eCPRI protocol data unit.
- **ecpriMessage**: indicates the type of service conveyed by the message.
- **ecpriPayloadSize**: indicates the size in bytes of the payload part corresponding to the eCPRI message.
- **Measurement ID**: the value used by the sender of the request when the response is received to distinguish between measurements, i.e. the receiver of the request shall copy the ID from the request into the response message.

**[0118]** At 802 (optional), the RU may send a delay request response or a delay request failure to the DU. For example, if the RU is capable to provide the values of all requested delay parameters received in the delay request at 801, the RU may initiate the measurement as requested by the DU, and respond with a delay request response at 802. If any of the requested delay parameters measurement cannot be initiated, the RU may send a delay request failure to the DU at 802.

**[0119]** At 803, the RU may report one or more delay values to the DU by sending a delay report. The delay values may be named as "RU delay values." The delay report may include the delay values corresponding to the delay parameters received in the delay request at 801. For example, the delay report includes the value of P1 (i.e. D1), the value of P2 (i.e. D2), the value of P3 (i.e. D3), the value of P4 (i.e. D4), the value of P5 (i.e. D5), and/or the value of P6 (i.e. D6).

**[0120]** If the beamforming method is received in the delay request at 801, the delay report at 803 may include the delay value corresponding to the beamforming method. Otherwise, if the beamforming method is not included in the delay request at 801, the delay report at 803 may include multiple instances of the delay value, wherein each instance of delay value is associated with a beamforming method. For example, the delay report includes multiple instances of D1, e.g. 1 ns (nanosecond), 2 ns, and 4 ns, wherein 1 ns is associated with a Weight-based dynamic beamforming method, 2 ns is associated with a Predefined-beam beamforming method, while 4 ns is associated with a Channel-information-based beamforming method.

**[0121]** In some embodiments, the delay value in the delay report at 803 may be a delta value on top of a default delay value, where the default delay value is common for multiple beamforming methods. For example, the default delay value is pre-configured at the DU and the RU by the management system.

**[0122]** If the combination of SCS and bandwidth is received in the delay request at 801, the delay report at 803 may include the delay value corresponding to the combination of SCS and bandwidth. Otherwise, if the combination of SCS and bandwidth is not included in the delay request at 801, the delay report at 803 may include multiple instances of the delay value, where each instance of delay value is associated with a combination of SCS and bandwidth. For example, the delay report includes multiple instances of D3, e.g. 3 ns, 6 ns, and 8 ns, wherein 3 ns is associated with a combination of 15 kHz and bandwidth 40 kHz, 6 ns is associated with a combination of 60 kHz and bandwidth 50 kHz, while 8 ns is associated with a combination of 120 kHz and bandwidth 60 kHz.

**[0123]** If the reporting method is received in the delay request at 801, and the reporting method is a periodic reporting, the RU may send the delay report at 803 to the DU periodically corresponding to the periodicity.

**[0124]** If the reporting method is received in the delay request at 801, and the reporting method is an event-triggered reporting, the RU may send the delay report at 803 to the DU if an event is detected by the RU. For example, the RU sends the delay report to the DU each time the delay changes from one reporting level to another reporting level.

**[0125]** If the reporting method is not received in the delay request at 801, the RU may send the delay report to the DU one time.

**[0126]** If some delay values of the delay parameters are missing from the delay report at 803, the DU may consider that these delay values were not available at the RU.

**[0127]** Therefore, as a combination of above descriptions, an example of delay report based on RAN LLS-C using eCPRI may be shown as below. The fields in Format 2 of delay request are the same or similar to those as describe above in Format 1 of delay request. For example, Type y means that the type of the message is y which is to be defined.

Format 2 of delay request

<table>
<tr><th colspan="10">Delay Measurement (Type y)</th></tr>
<tr><th>0 (msb)</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7 (lsb)</th><th>number of bytes</th><th></th></tr>
<tr><td colspan="4">ecpriVersion</td><td colspan="3">ecpriReserved</td><td>ecpriConcatenation</td><td>1</td><td>Octet 1</td></tr>
<tr><td colspan="8">ecpriMessage = y</td><td>1</td><td>Octet 2</td></tr>
<tr><td colspan="8">Measurement ID</td><td>1</td><td>Octet 3</td></tr>
<tr><td colspan="8">D1</td><td>1</td><td>Octet 4</td></tr>
<tr><td colspan="8">D2</td><td>1</td><td>Octet 5</td></tr>
<tr><td colspan="8">D3</td><td>1</td><td>Octet 6</td></tr>
<tr><td colspan="8">D4</td><td>1</td><td>Octet 7</td></tr>
<tr><td colspan="8">D5</td><td>1</td><td>Octet 8</td></tr>
<tr><td colspan="8">D6</td><td>1</td><td>Octet 9</td></tr>
<tr><td colspan="3">Beamforming method</td><td colspan="3">SCS and bandwidth</td><td colspan="2">reserved</td><td>1</td><td>Octet 10</td></tr>
</table>

**[0128]** At 804, the DU determines or decides the transmission window and/or reception window of the DU considering the received one or more RU delay values at 801.

**[0129]** For the transmission window needed by the DU, the DU may use D1 and D2 as the minimum delay to be used. For example, the position (in time domain) of the transmission window at the DU for a data packet shall not be later than (D1 + transport delay

#1), where transport delay #1 is the delay between a transmission interface at the DU (e.g. R1 as shown in Figure 5 or Figure 6) and a reception interface at the RU (e.g. R2 as shown in Figure 5 or Figure 6).

**[0130]** In addition, the maximum size of the transmission window of LLS-U shall not be greater than (T – D1), and the maximum size of the transmission window of LLS-C shall not be greater than (T – D2), where the T is a time value preconfigured by the management system.

**[0131]** In some embodiments, if D3 is provided by the RU in the delay report at 803, the position (in time domain) of the transmission window for the LLS-C shall not be shifted, while the position (in time domain) of the transmission window for the DL LLS-U will be shifted by D3 later in time domain, for an optimization or adjustment of the transmission window. For example, the transmission window starts at time point #5 in time domain, without considering D3. Taking D3 into consideration, the transmission window starts at (time point #5 + D3) in time domain.

**[0132]** For the reception window needed by the DU, the DU may use D4 and D5 as the minimum delay to be used. For example, the position (in time domain) of the reception window at the DU for a data packet shall not be earlier than (D4 + transport delay #2) in time domain, where transport delay #2 is the delay between a reception interface at the DU (e.g. R4 as shown in Figure 5 or Figure 6) and a transmission interface at the RU (e.g. R3 as shown in Figure 5 or Figure 6). Transport delay #2 may be equal to transport delay #1.

**[0133]** In addition, the maximum size of the reception window shall not be greater than (T – D5), where the T is a time value preconfigured by the management system.

**[0134]** In some embodiments, if D6 is provided by the RU in the delay report at 803, the position (in time domain) of the reception window will be shifted by D6 earlier in time for the UL LLS-U message, for an optimization or adjustment of the reception window, while the position (in time domain) of the reception window for the UL LLS-C message shall not be shifted.

**[0135]** **Figure 9** illustrates another schematic diagram of an optimization of a time window in an LLS RAN architecture in accordance with some aspects of the present disclosure. The embodiments of Figure 9 provide solutions for an optimization or adjustment of a transmission or reception window in time domain in a RU.

**[0136]** At 901, a DU may send a delay request to a RU, including one or more delay values of the DU, i.e. one or more DU delay values. The DU delay values may include at least one of the following:

(1) D7: delay between transmitting a DL LLS-U data message and transmitting an IQ sample corresponding to the DL LLS-U data message.

(2) D8: amount of time which the DU requires to transmit all DL LLS-U messages for a symbol.

(3) D9: delay between receiving an initial UL LLS-U message for a symbol and receiving the last UL LLS-U message for the symbol.

(4) D10: delay between transmitting a DL LLS-C data message and transmitting an IQ sample corresponding to the DL LLS-C data message.

**[0137]** The DU delay values may be associated with one or more beamforming methods. The beamforming methods may include: predefined-beam beamforming, weight-based dynamic beamforming, attribute-based dynamic beamforming, channel-information-based beamforming, and/or DMRS based beamforming.

**[0138]** The DU delay values may be associated with a combination of SCS and bandwidth, where the SCS is the distance between two adjacent subcarriers in an orthogonal frequency division multiplexing signal, e.g., 15 kHz, 30 kHz, 60 kHz, or 120 kHz.

**[0139]** Therefore, as a combination of above descriptions, an example of delay request based on O-RAN LLS-C using eCPRI is shown as below. The fields in Format 3 of delay request are the same or similar to those as describe above in Format 1 of delay request. For example, Type z means that the type of the message is z which is to be defined. P1 to P6 in Format 3 of delay request are the same as describe above in the embodiments of Figure 8. In some embodiments, P1 to P6 may be not included in Format 3 of delay request. In some embodiments, the fields in Format 3 of delay request is different from the fields in Format 1 of delay request.

Format 3 of delay request

| Delay Measurement (Type z) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **0 (msb)** | **1** | **2** | **3** | **4** | **5** | **6** | **7 (lsb)** | **number of bytes** | |
| ecpriVersion | | | | ecpriReserved | | | ecpriConcatenation | 1 | Octet 1 |
| ecpriMessage = z | | | | | | | | 1 | Octet 2 |
| ecpriPayloadSize | | | | | | | | 2 | Octet 3+4 |
| Measurement ID | | | | | | | | 1 | Octet 5 |
| P1 | P2 | P3 | P4 | P5 | P6 | reserved | | 1 | Octet 6 |
| D7 | | | | | | | | 1 | Octet 7 |
| D8 | | | | | | | | 1 | Octet 8 |
| D9 | | | | | | | | 1 | Octet 9 |
| D10 | | | | | | | | 1 | Octet 10 |
| Beamforming method | | | SCS and bandwidth | | | Reporting method | | 1 | Octet 11 |

**[0140]** At 902 (optional), the RU may send a delay request response or a delay request failure to the DU. For example, if the RU is capable to provide the values of all requested delay parameters received in the delay request at 901, the RU may initiate the measurement as requested by the DU, and respond with a delay request response at 902. If any of the requested delay parameters measurement cannot be initiated, the RU may send a delay request failure to the DU at 902.

**[0141]** At 903 (optional), the RU may report one or more delay values to the DU by sending a delay report. In one example, the delay report may include the RU delay values as defined in operation 803 of the embodiments of Figure 8. In another example, the delay report may not include the RU delay values.

**[0142]** At 904, the RU determines or decides a transmission window and/or a reception window of the RU considering the received one or more DU delay values at 901.

**[0143]** In one example, based on the received D7, D8, and/or D10, the RU may optimize the reception window and buffering adaptively. For example, if D7, D8 and/or D10 are greater than a threshold, the RU will increase a length (or size) of the reception window in time domain. Otherwise, if D7, D8 and/or D10 are less than a threshold, the RU will decrease the length (or size) of the reception window in time domain.

**[0144]** In another example, based on the received D9, the RU may optimize the transmission window adaptively. For example, if D9 is greater than a threshold, the RU will increase a length (or size) of the transmission window in time domain. Otherwise, if D9 is less than a threshold, the RU will decrease the length (or size) of the transmission window in time domain.

**[0145]** In some other embodiments, the DU may provide the DU delay values to the RU using other LLS-C messages, instead of the delay request at 901. In this case, operations 902 and 903 are not needed to be performed.

**[0146]** At 905 (optional), the DU may determine or decide a transmission window and/or a reception window of the DU considering the received one or more RU delay values at 903. The operation 905 is similar to operation 804 as described in the embodiments of Figure 8.

**[0147]** The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

What is claimed:

1. A first base station (BS), comprising:
   at least one memory; and
   at least one processor coupled to the at least one memory and configured to cause the first BS to:
      receive a set of delay values corresponding to a set of delay parameters from a second BS over an lower layer split (LLS) interface between the first BS and the second BS; and
      determine at least one of a transmission window or a reception window in a time domain based on the set of delay values,
      wherein the first BS can transmit data to the second BS over the LLS interface within the transmission window, and the first BS can receive data from the second BS over the LLS interface within the reception window.

2. The first BS of Claim 1, wherein the at least one processor is configured to cause the first BS to transmit, to the second BS over the LLS interface, a first message for requesting the second BS to report the set of delay values corresponding to the set of delay parameters.

3. The first BS of Claim 2, wherein the first message includes a bitmap of one or more positions, and each position in the bitmap indicates one delay parameter within the set of delay parameters that the second BS is requested to report a delay value corresponding to the one delay parameter.

4. The first BS of Claim 2, wherein the first message includes information indicating:
   a periodic reporting manner and a periodicity for delay value reporting; or
   an event-triggered reporting manner and one or more events for delay value reporting.

5. The first BS of Claim 4, wherein the one or more events for delay value reporting include a set of reporting levels, and the second BS is configured to divide the set of delay values into at least one reporting level within the set of reporting levels.

6. The first BS of Claim 1, wherein the at least one processor is configured to cause the

first BS to receive first information from the second BS or transmit the first information to the second BS, wherein the first information indicates at least one of the following:

the second BS is capable to provide one or more delay values corresponding to delay parameters requested by the first BS; or

at least one delay value corresponding to the delay parameters requested by the first BS cannot be provided.

7. The first BS of Claim 1, wherein the first BS is a distributed unit (DU) hosting high physical layers, and the second BS is a radio unit (RU) hosting low physical layers, the set of delay parameters includes at least one of the following:

first timing difference between receiving a data packet over the LLS interface and transmitting an in-phase quadrature (IQ) sample corresponding to the data packet at an antenna of the RU;

second timing difference between receiving a downlink (DL) LLS control plane (LLS-C) message over the LLS interface and transmitting an IQ sample corresponding to the DL LLS-C message at the antenna of the RU;

third timing difference between an output of a DL signal at an antenna connector of the RU and a transmission of the DL signal over an air interface;

fourth timing difference between receiving an IQ sample corresponding to a data packet at the antenna of the RU and transmitting the data packet over the LLS interface;

fifth timing difference between receiving a LLS-C message from the DU over the LLS interface and receiving an IQ sample from a user equipment (UE) at the antenna of the RU; or

sixth timing difference between a reception of a uplink (UL) signal over the air interface and an input of the UL signal at the antenna connector of the RU.

8. The first BS of Claim 7, wherein to determine the transmission window, the at least one processor is configured to cause the DU to:

use a delay value corresponding to the first timing difference as a minimum delay of a start time point of the transmission window for the data packet.

9. The first BS of Claim 7, wherein to determine the transmission window, the at least

one processor is configured to cause the DU to:

use a difference between a preconfigured time value and a delay value corresponding to the first timing difference as a maximum size of the transmission window for the DL LLS-U message; and

use a difference between the preconfigured time value and a delay value corresponding to the second timing difference as a maximum size of the transmission window for the DL LLS-C message.

10. The first BS of Claim 7, wherein to determine the transmission window, the at least one processor is configured to cause the DU to shift a position of the transmission window for a downlink (DL) LLS user plane (LLS-U) message later in the time domain, by a delay value corresponding to the third timing difference.

11. The first BS of Claim 7, wherein to determine the reception window, the at least one processor is configured to cause the DU to:

use a delay value corresponding to the fourth timing difference as a minimum delay of a start time point of the reception window for the data packet.

12. The first BS of Claim 7, wherein to determine the reception window, the at least one processor is configured to cause the DU to:

use a difference between the preconfigured time value and a delay value corresponding to the fifth timing difference as a maximum size of the reception window for the UL LLS-U message.

13. The first BS of Claim 7, wherein to determine the reception window, the at least one processor is configured to cause the DU to shift a position of the reception window for a UL LLS-U message earlier in the time domain, by a delay value corresponding to the sixth timing difference.

14. The first BS of Claim 1, wherein the first BS is a radio unit (RU) hosting low physical layers, and the second BS is a distributed unit (DU) hosting high physical layers, and the set of delay values includes at least one of the following:

a first delay value corresponding to timing difference between transmitting a DL LLS-U data message and transmitting an IQ sample corresponding to the DL LLS-U data message;

an amount of time which the DU requires to transmit all DL LLS-U messages for a symbol;

a second delay value corresponding to timing difference between receiving an initial UL LLS-U message for a first symbol and receiving a last UL LLS-U message for the first symbol; or

a third delay value corresponding to timing difference between transmitting a DL LLS-C data message and transmitting an IQ sample corresponding to the DL LLS-C data message.

15. The first BS of Claim 14, wherein to determine the reception window, the at least one processor is configured to cause the RU to:

increase a size of the reception window if at least one of the first delay value, the amount of time, or the third delay value is greater than a threshold; or

decrease the size of the reception window if at least one of the first delay value, the amount of time, or the third delay value is less than the threshold.

16. The first BS of Claim 14, wherein to determine the transmission window, the at least one processor is configured to cause the RU to:

increase a size of the transmission window if the second delay value is greater than a threshold; or

decrease the size of the transmission window if the second delay value is less than the threshold.

17. The first BS of Claim 1, wherein at least one delay value within the set of delay values or at least one delay parameter within the set of delay parameters is associated with at least one of the following:

one or more beamforming methods; or

one or more combinations of sub carrier spacing (SCS) and bandwidth.

18. The first BS of Claim 17, wherein the one or more beamforming methods include at least one of the following:

predefined-beam beamforming;

weight-based dynamic beamforming;

attribute-based dynamic beamforming;

channel-information-based beamforming; or

demodulation reference signal (DMRS) based beamforming.

19. A processor for wireless communication, comprising:

at least one controller coupled with at least one memory and configured to cause the processor to:

receive a set of delay values corresponding to a set of delay parameters from a base station (BS) over an lower layer split (LLS) interface between the processor and the BS; and

determine at least one of a transmission window or a reception window in a time domain based on the set of delay values,

wherein the processor can transmit data to the BS over the LLS interface within the transmission window, and the processor can receive data from the BS over the LLS interface within the reception window.

20. A method performed by a first base station (BS), comprising:

receiving a set of delay values corresponding to a set of delay parameters from a second BS over an lower layer split (LLS) interface between the first BS and the second BS; and

determining at least one of a transmission window or a reception window in a time domain based on the set of delay values,

wherein the first BS can transmit data to the second BS over the LLS interface within the transmission window, and the first BS can receive data from the second BS over the LLS interface within the reception window.

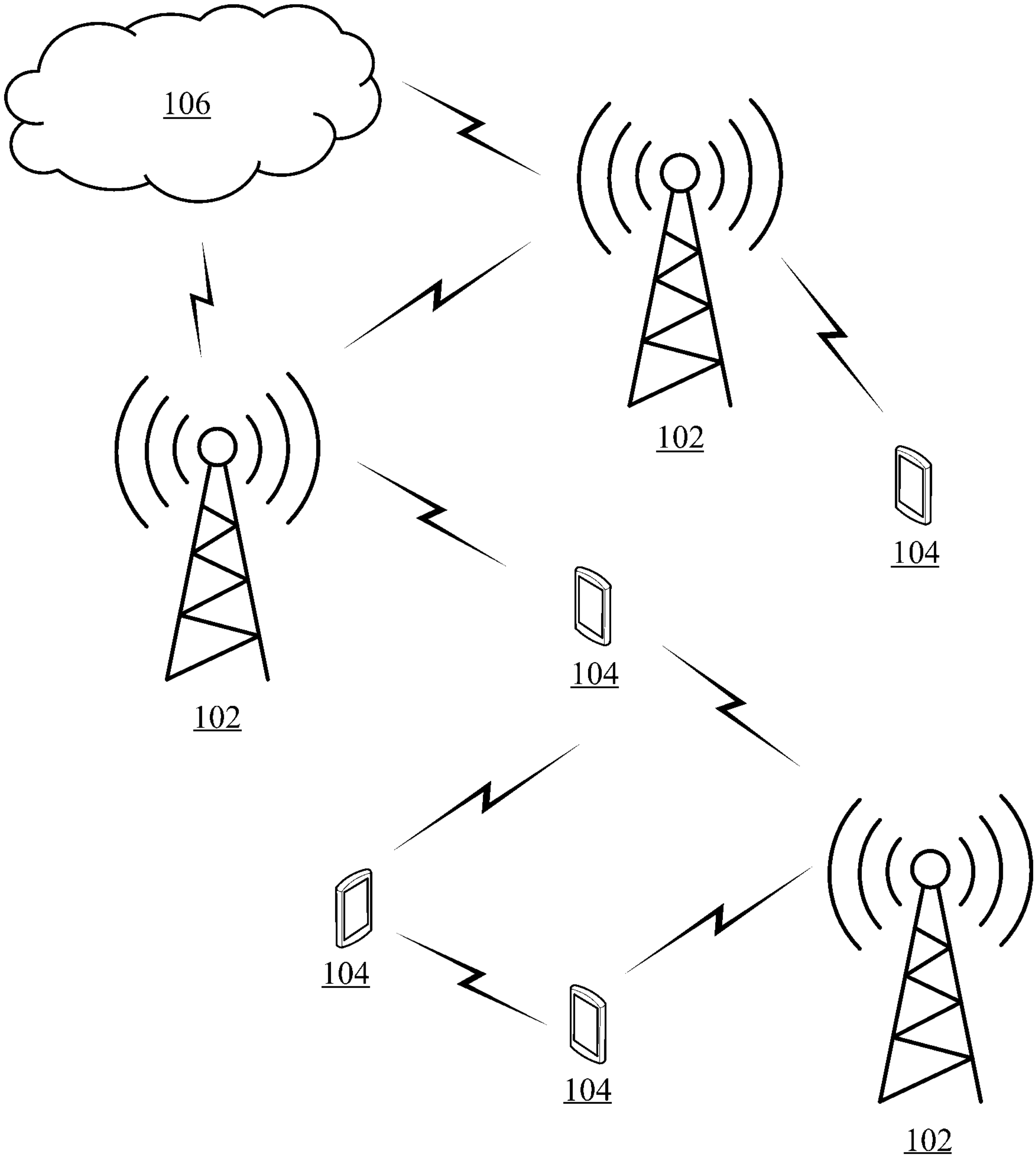


Figure 1

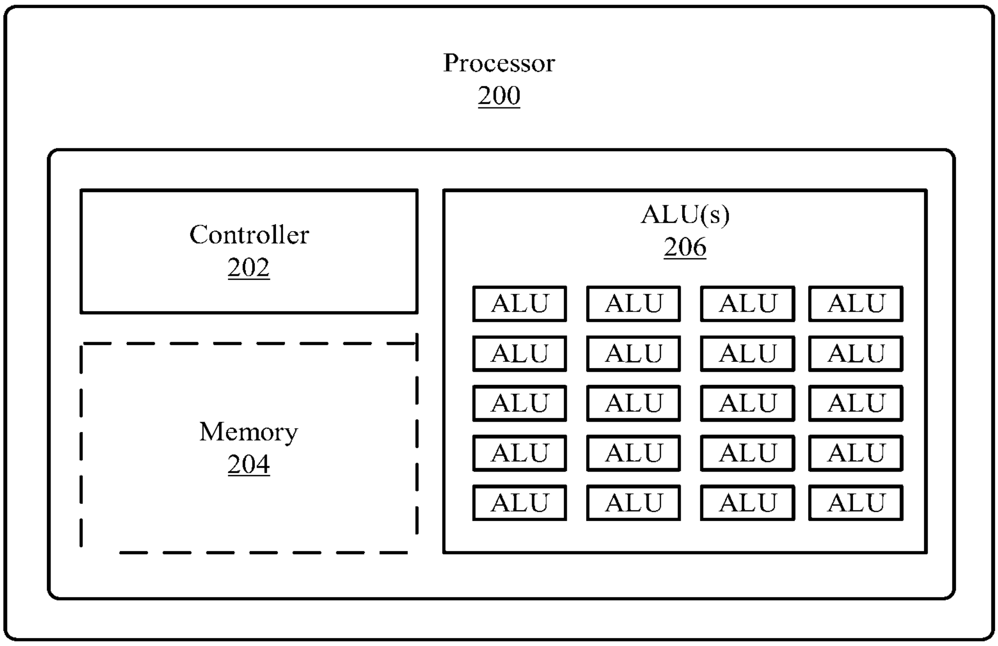


Figure 2

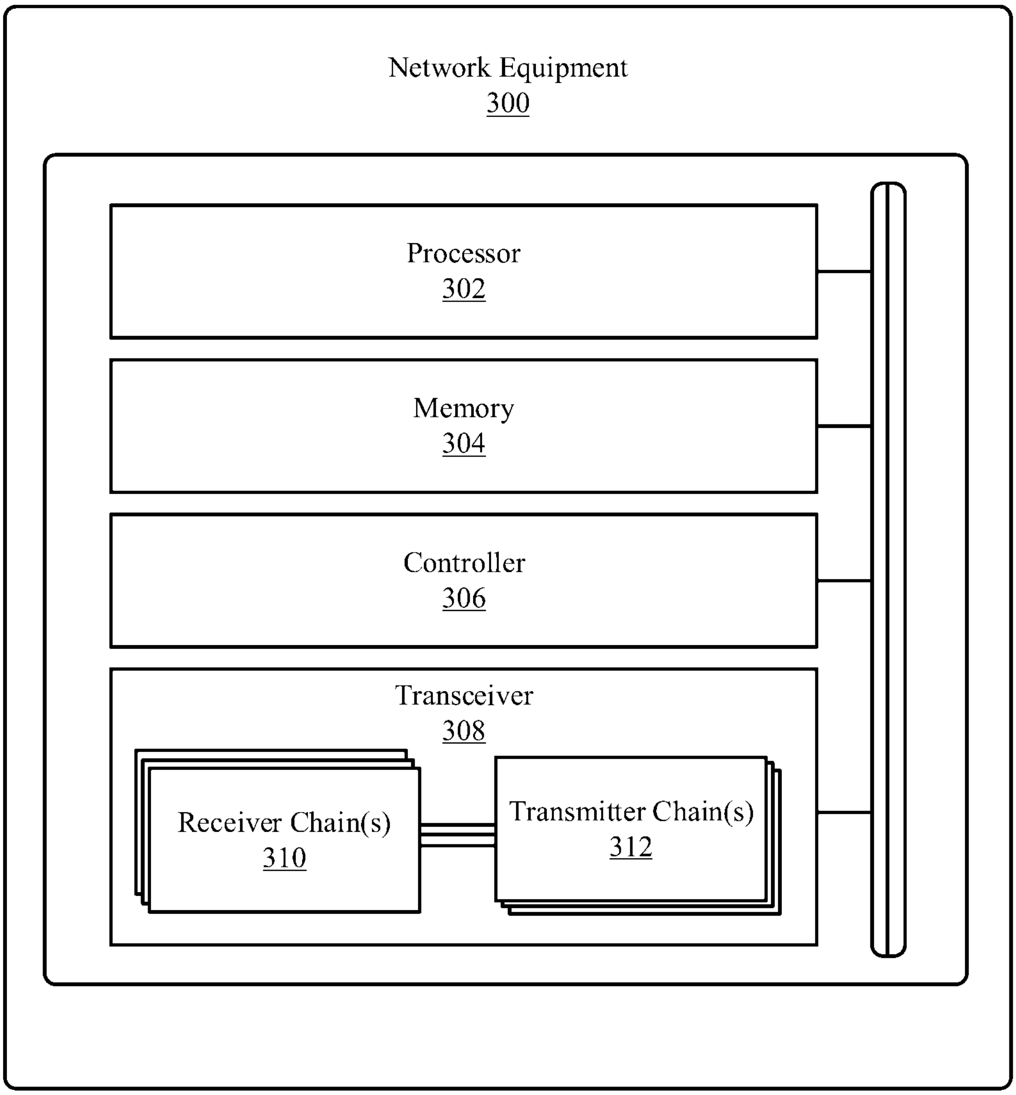


Figure 3

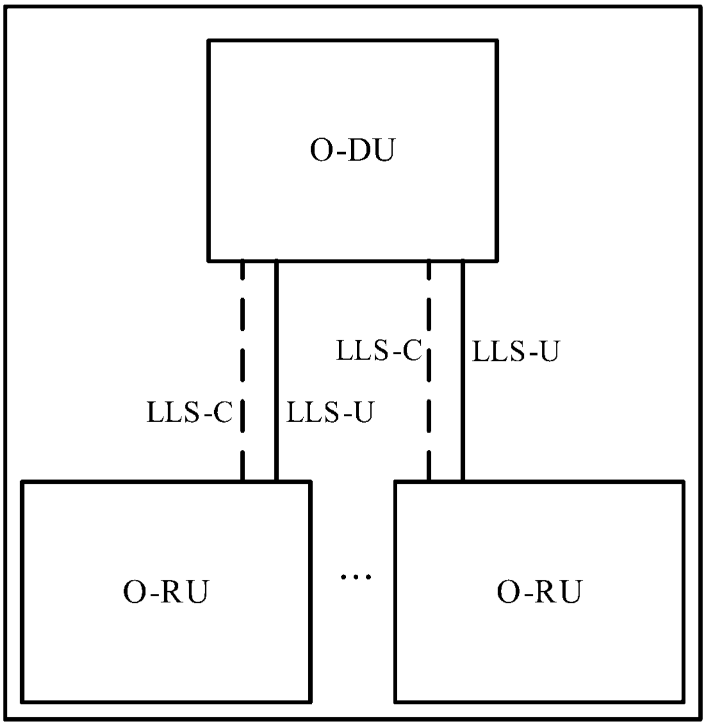


Figure 4

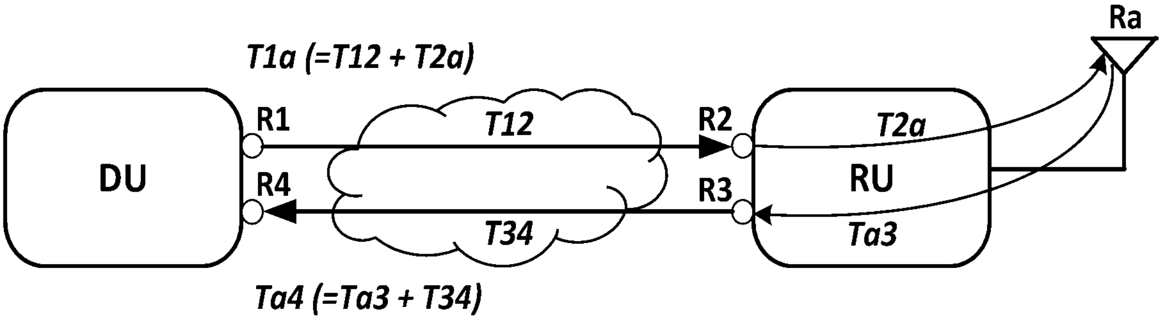


Figure 5

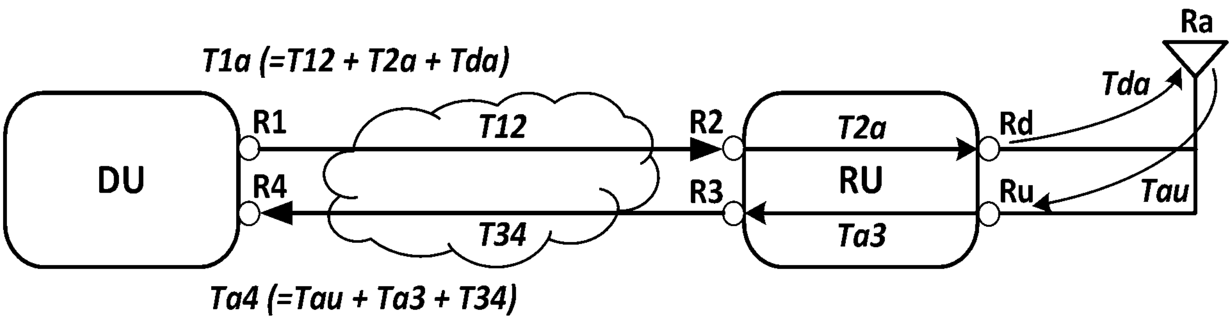


Figure 6

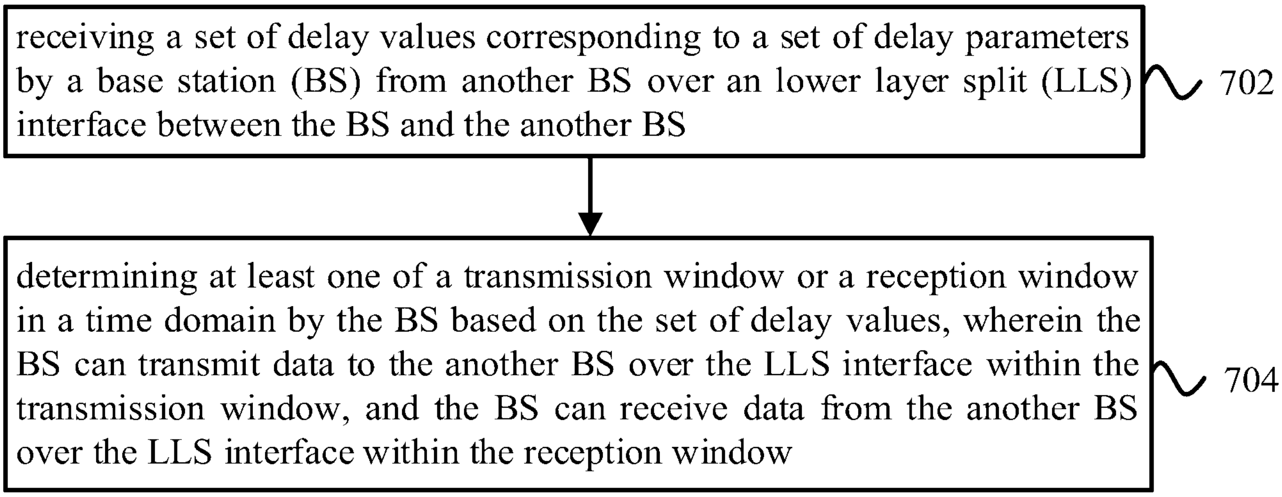


Figure 7

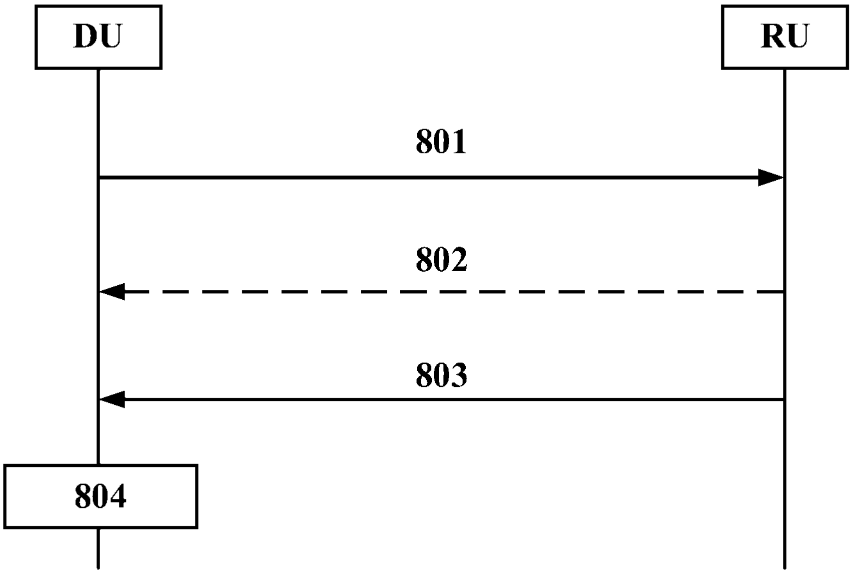


Figure 8

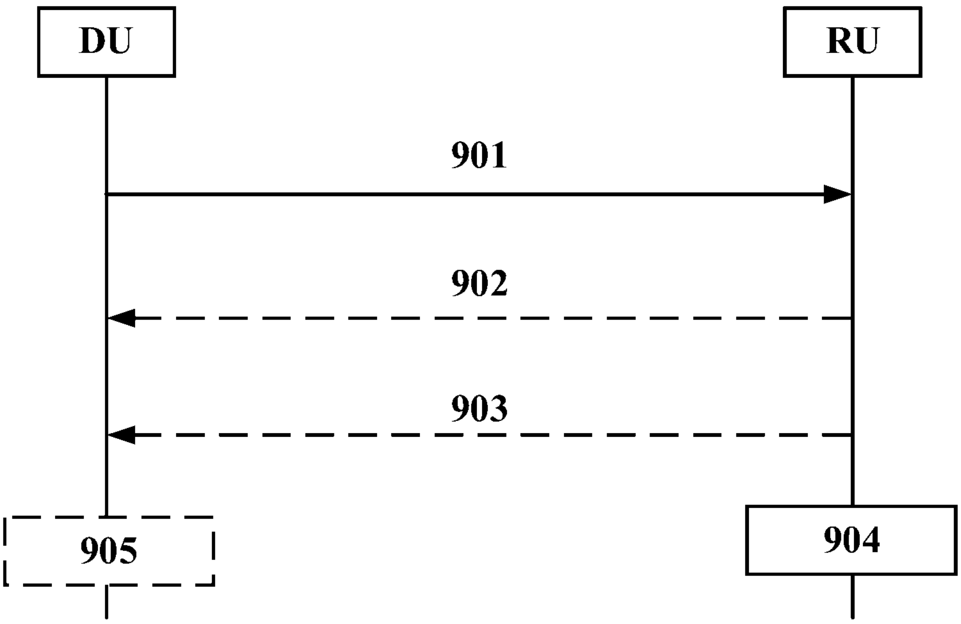


Figure 9

## A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/0446(2023.01)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)

IPC:H04W

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

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

ENTXT,CNTXT,ENTXTC,CNKI,VCN,VEN,3GPP:DU RU Lower Layer Split LLS report delay window BS IQ time value

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 2022272594 A1 (CISCO TECHNOLOGY, INC.) 25 August 2022 (2022-08-25)<br>description,paragraphs 13-100 | 1-20 |
| A | CN 117424921 A (NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS) 19 January 2024 (2024-01-19)<br>the whole document | 1-20 |
| A | US 11659444 B1 (T-MOBILE USA, INC.) 23 May 2023 (2023-05-23)<br>the whole document | 1-20 |
| A | US 2020195521 A1 (VERIZON PATENT AND LICENSING INC.) 18 June 2020 (2020-06-18)<br>the whole document | 1-20 |
| A | US 2022086684 A1 (HUAWEI TECHNOLOGIES CO., LTD.) 17 March 2022 (2022-03-17)<br>the whole document | 1-20 |

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

* Special categories of cited documents:
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- "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
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- "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 2025** | **30 April 2025** |

Name and mailing address of the ISA/CN

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| Patent document cited in search report | | | Publication date (day/month/year) | Patent family member(s) | | | Publication date (day/month/year) |
|---|---|---|---|---|---|---|---|
| US | 2022272594 | A1 | 25 August 2022 | US | 11758455 | B2 | 12 September 2023 |
| | | | | WO | 2022177874 | A1 | 25 August 2022 |
| CN | 117424921 | A | 19 January 2024 | | None | | |
| US | 11659444 | B1 | 23 May 2023 | | None | | |
| US | 2020195521 | A1 | 18 June 2020 | US | 2021399956 | A1 | 23 December 2021 |
| | | | | US | 11588710 | B2 | 21 February 2023 |
| | | | | US | 11128545 | B2 | 21 September 2021 |
| US | 2022086684 | A1 | 17 March 2022 | EP | 3949297 | A1 | 09 February 2022 |
| | | | | WO | 2020233821 | A1 | 26 November 2020 |
| | | | | US | 12245069 | B2 | 04 March 2025 |
| | | | | CN | 113853771 | A | 28 December 2021 |