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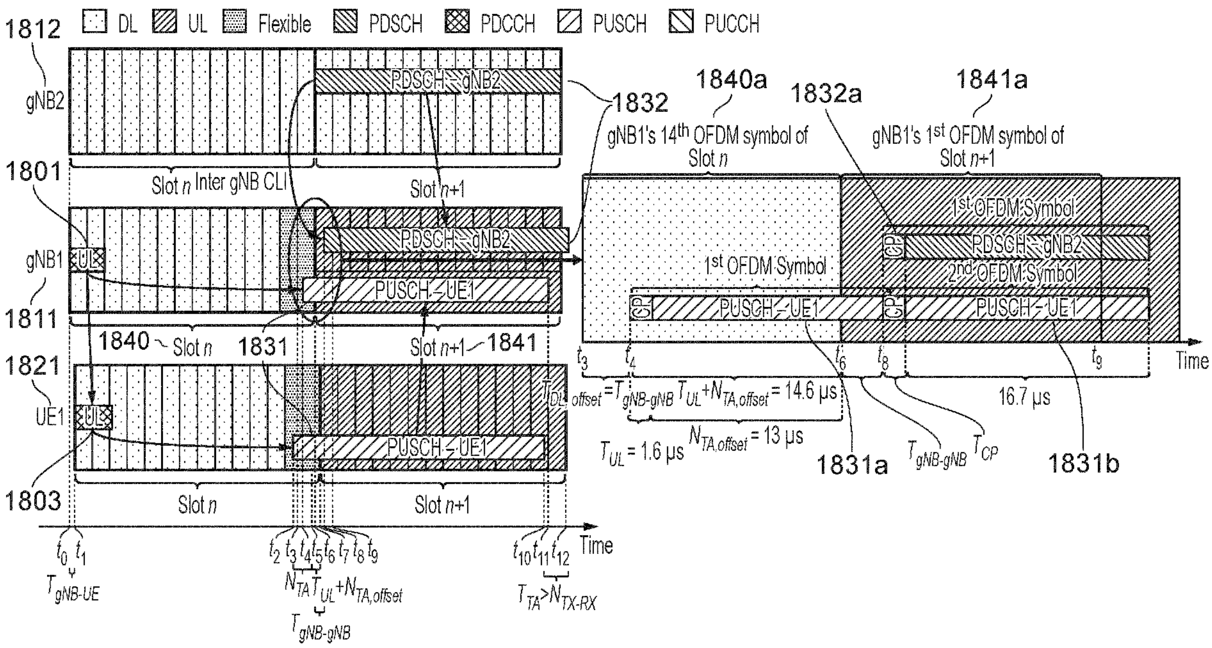

FIG. 18

(57) Abstract: Embodiments of the present technique provide communications devices, infrastructure equipment and methods of operation thereof for communication. An embodiment of the present technique provides a method of communicating, by a communications device, via a wireless communications network, the method comprising, receiving, by the communications device, from an infrastructure equipment forming part of the wireless communications network, an indication of uplink communications resources for transmitting uplink signals by the communications device, and transmitting, by the communications device, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment. A timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the

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infrastructure equipment at a time that aligns with a potential interfering signal.

METHODS, COMMUNICATIONS DEVICES AND INFRASTRUCTURE EQUIPMENT

BACKGROUND

Field of Disclosure

The present disclosure relates to communications devices, infrastructure equipment and methods of operating communications devices and infrastructure equipment in a wireless communications network.

The present application claims the Paris Convention priority from European Patent Application Number EP23157134.0, the contents of which are hereby incorporated by reference in their entirety.

Description of Related Art

The “background” description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

Previous generation mobile telecommunication systems, such as those based on the 3GPP defined UMTS and Long Term Evolution (LTE) architecture, are able to support a wider range of services than simple voice and messaging services offered by previous generations of mobile telecommunication systems. For example, with the improved radio interface and enhanced data rates provided by LTE systems, a user is able to enjoy high data rate applications such as mobile video streaming and mobile video conferencing that would previously only have been available via a fixed line data connection. The demand to deploy such networks is therefore strong and the coverage area of these networks, i.e. geographic locations where access to the networks is possible, is expected to continue to increase rapidly.

Current and future wireless communications networks are expected to routinely and efficiently support communications with an ever-increasing range of devices associated with a wider range of data traffic profiles and types than existing systems are optimised to support. For example, it is expected future wireless communications networks will be expected to efficiently support communications with devices including reduced complexity devices, machine type communication (MTC) devices, high resolution video displays, virtual reality headsets, extended Reality (XR) and so on. Some of these different types of devices may be deployed in very large numbers, for example low complexity devices for supporting the “The Internet of Things”, and may typically be associated with the transmissions of relatively small amounts of data with relatively high latency tolerance. Other types of device, for example supporting high-definition video streaming, may be associated with transmissions of relatively large amounts of data with relatively low latency tolerance. Other types of device, for example used for autonomous vehicle communications and for other critical applications, may be characterised by data that should be transmitted through the network with low latency and high reliability. A single device type might also be associated with different traffic profiles / characteristics depending on the application(s) it is running. For example, different consideration may apply for efficiently supporting data exchange with a smartphone when it is running a video streaming application (high downlink data) as compared to when it is running an Internet browsing application (sporadic uplink and downlink data) or being used for voice communications by an emergency responder in an emergency scenario (data subject to stringent reliability and latency requirements).

In view of this there is expected to be a desire for current wireless communications networks, for example those which may be referred to as 5G or new radio (NR) systems / new radio access technology (RAT) systems, or indeed future 6G wireless communications, as well as future iterations / releases of existing systems, to efficiently support connectivity for a wide range of devices associated with different applications and different characteristic data traffic profiles and requirements.

One example of a new service is referred to as Ultra Reliable Low Latency Communications (URLLC) services which, as its name suggests, requires that a data unit or packet be communicated with a high reliability and with a low communications delay. Another example of a new service is enhanced Mobile Broadband (eMBB) services, which are characterised by a high capacity with a requirement to support up to 20 Gb/s. URLLC and eMBB type services therefore represent challenging examples for both LTE type communications systems and 5G/NR communications systems.

5G NR has continuously evolved and the current work plan includes 5G-NR-advanced in which some further enhancements are expected, especially to support new use-cases/scenarios with higher requirements. The desire to support these new use-cases and scenarios gives rise to new challenges for efficiently handling communications in wireless communications systems that need to be addressed.

SUMMARY OF THE DISCLOSURE

The present disclosure can help address or mitigate at least some of the issues discussed above.

Embodiments of the present technique can provide a method of communicating, by a communications device, via a wireless communications network, the method comprising, receiving, by the communications device, from an infrastructure equipment forming part of the wireless communications network, an indication of uplink communications resources for transmitting uplink signals by the communications device, and transmitting, by the communications device, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment. A timing of the uplink transmission is advanced by an alignment offset, wherein information on the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal. For example the information on the alignment offset indicated by the infrastructure equipment could be a downlink timing offset or a number of OFDM symbols from which the communications device can determine the alignment offset.

According to example embodiments an alignment offset which is applied to the transmission of uplink signals by a communications device has an effect of advancing this transmission such that one or more OFDM symbols of the uplink transmitted signals substantially align with OFDM symbols of potential cross-link interfering signals, at a receiving infrastructure equipment with the effect that orthogonality exists between the uplink transmitted signals and the cross-link interfering signals.

Respective aspects and features of the present disclosure are defined in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary, but are not restrictive, of the present technology. The described embodiments, together with further advantages, will be best understood by reference to the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein like reference numerals designate identical or corresponding parts throughout the several views, and wherein:

Figure 1 schematically represents some aspects of an LTE-type wireless telecommunication system which may be configured to operate in accordance with certain embodiments of the present disclosure;
Figure 2 schematically represents some aspects of a new radio access technology (RAT) wireless telecommunications system which may be configured to operate in accordance with certain embodiments of the present disclosure;

Figure 3 is a schematic block diagram of an example infrastructure equipment and communications device which may be configured to operate in accordance with certain embodiments of the present disclosure;

Figure 4 schematically illustrates an example of inter-cell cross link interference;

Figure 5 illustrates an example approach for accounting for inter-cell cross link interference;

Figure 6 illustrates an example of a subband FD-TDD configuration with three subbands;

Figure 7 illustrates an example of a subband FD-TDD configuration with two subbands;

Figure 8 illustrates an example of inter sub-band interference;

Figure 9 schematically illustrates an example of intra-cell cross link interference;

Figure 10 illustrates an example of intra sub-band interference

Figure 11 illustrates an example of a gNB scheduling uplink and downlink communications with a UE, and illustrating switching time between reception and transmission;

Figure 12 illustrates an example of intra-subband self-interference at a gNB when scheduling uplink transmission from one UE and a downlink transmission to another UE;

Figure 13 illustrates an example of inter-gNB CLI and misalignment of cyclic prefixes of the transmissions;

Figure 14 illustrates a proposal to address intra-gNB self-interference;

Figure 15 illustrates a proposal to address intra-gNB self-interference;

Figure 16 illustrates a proposal containing several timing offsets for addressing inter-gNB interference at different distances;

Figure 17 illustrates an example of UL and DL collision at the gNB, where a UE and/or a gNB is provided insufficient time to switch reception to transmission or vice versa;

Figure 18 illustrates an embodiment of the present invention, where a timing offset is applied to the scheduling of uplink and inter-gNB interference addressed;

Figure 19 illustrates an embodiment of the present invention, where the timing offset is applied to SBFD communications at a gNB.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Long Term Evolution Advanced Radio Access Technology (4G)

Figure 1 provides a schematic diagram illustrating some basic functionality of a mobile telecommunications network / system 6 operating generally in accordance with LTE principles, but which may also support other radio access technologies, and which may be adapted to implement embodiments of the disclosure as described herein. Various elements of Figure 1 and certain aspects of their respective modes of operation are well-known and defined in the relevant standards administered by the 3GPP (RTM) body, and also described in many books on the subject, for example, Holma H. and Toskala A [1]. It will be appreciated that operational aspects of the telecommunications networks discussed herein which are not specifically described (for example in relation to specific communication protocols and physical channels for communicating between different elements) may be implemented in accordance with any known techniques, for example according to the relevant standards and known proposed modifications and additions to the relevant standards.

The network 6 includes a plurality of base stations 1 connected to a core network 2. Each base station provides a coverage area 3 (i.e. a cell) within which data can be communicated to and from communications devices 4. Although each base station 1 is shown in Figure 1 as a single entity, the skilled person will appreciate that some of the functions of the base station may be carried out by disparate, inter-connected elements, such as antennas (or antennae), remote radio heads, amplifiers, etc. Collectively, one or more base stations may form a radio access network.

Data is transmitted from base stations 1 to communications devices 4 within their respective coverage areas 3 via a radio downlink. Data is transmitted from communications devices 4 to the base stations 1 via a radio uplink. The core network 2 routes data to and from the communications devices 4 via the respective base stations 1 and provides functions such as authentication, mobility management, charging and so on. Terminal devices may also be referred to as mobile stations, user equipment (UE), user terminal, mobile radio, communications device, and so forth. Services provided by the core network 2 may include connectivity to the internet or to external telephony services. The core network 2 may further track the location of the communications devices 4 so that it can efficiently contact (i.e. page) the communications devices 4 for transmitting downlink data towards the communications devices 4.

Base stations, which are an example of network infrastructure equipment, may also be referred to as transceiver stations, nodeBs, e-nodeBs, eNB, g-nodeBs, gNB and so forth. In this regard different terminology is often associated with different generations of wireless telecommunications systems for elements providing broadly comparable functionality. However, certain embodiments of the disclosure may be equally implemented in different generations of wireless telecommunications systems, and for simplicity certain terminology may be used regardless of the underlying network architecture. That is to say, the use of a specific term in relation to certain example implementations is not intended to indicate these implementations are limited to a certain generation of network that may be most associated with that particular terminology.

New Radio Access Technology (5G)

Systems incorporating NR technology are expected to support different services (or types of services), which may be characterised by different requirements for latency, data rate and/or reliability. For example, Enhanced Mobile Broadband (eMBB) services are characterised by high capacity with a requirement to support up to 20 Gb/s. The requirements for Ultra Reliable and Low Latency Communications (URLLC) services are for one transmission of a 32 byte packet to be transmitted from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface within 1 ms with a reliability of 1 – 10^{-5} (99.999 %) or higher (99.9999%) [2].

Massive Machine Type Communications (mMTC) is another example of a service which may be supported by NR-based communications networks. In addition, systems may be expected to support further enhancements related to Industrial Internet of Things (IIoT) in order to support services with new requirements of high availability, high reliability, low latency, and in some cases, high-accuracy positioning.

An example configuration of a wireless communications network which uses some of the terminology proposed for and used in NR and 5G is shown in Figure 2. In Figure 2 a plurality of transmission and reception points (TRPs) 10 are connected to distributed control units (DUs) 41, 42 by a connection interface represented as a line 16. Each of the TRPs 10 is arranged to transmit and receive signals via a wireless access interface within a radio frequency bandwidth available to the wireless communications network. Thus, within a range for performing radio communications via the wireless access interface, each of the TRPs 10, forms a cell of the wireless communications network as represented by a circle 12. As such, wireless communications devices 14 which are within a radio communications range provided by the cells 12 can transmit and receive signals to and from the TRPs 10 via the wireless access interface. Each of the distributed units 41, 42 are connected to a central unit (CU) 40 (which may be referred to as a controlling node) via an interface 46. The central unit 40 is then connected to the core network 20 which may contain all other functions required to transmit data for communicating to and from the wireless communications devices and the core network 20 may be connected to other networks 30.

The elements of the wireless access network shown in Figure 2 may operate in a similar way to corresponding elements of an LTE network as described with regard to the example of Figure 1. It will be appreciated that operational aspects of the telecommunications network represented in Figure 2, and of other networks discussed herein in accordance with embodiments of the disclosure, which are not specifically described (for example in relation to specific communication protocols and physical channels for communicating between different elements) may be implemented in accordance with any known techniques, for example according to currently used approaches for implementing such operational aspects of wireless telecommunications systems, e.g. in accordance with the relevant standards.

The TRPs 10 of Figure 2 may in part have a corresponding functionality to a base station or eNodeB of an LTE network. Similarly, the communications devices 14 may have a functionality corresponding to the UE devices 4 known for operation with an LTE network. It will be appreciated therefore that operational aspects of a new RAT network (for example in relation to specific communication protocols and physical channels for communicating between different elements) may be different to those known from LTE or other known mobile telecommunications standards. However, it will also be appreciated that each of the core network component, base stations and communications devices of a new RAT network will be functionally similar to, respectively, the core network component, base stations and communications devices of an LTE wireless communications network.

In terms of broad top-level functionality, the core network 20 connected to the new RAT telecommunications system represented in Figure 2 may be broadly considered to correspond with the core network 2 represented in Figure 1, and the respective central units 40 and their associated distributed units / TRPs 10 may be broadly considered to provide functionality corresponding to the base stations 1 of Figure 1. The term network infrastructure equipment / access node may be used to encompass these elements and more conventional base station type elements of wireless telecommunications systems. Depending on the application at hand the responsibility for scheduling transmissions which are scheduled on the radio interface between the respective distributed units and the communications devices may lie with the controlling node / central unit and / or the distributed units / TRPs. A communications device 14 is represented in Figure 2 within the coverage area of the first communication cell 12. This communications device 14 may thus exchange signalling with the first central unit 40 in the first communication cell 12 via one of the distributed units / TRPs 10 associated with the first communication cell 12.

It will further be appreciated that Figure 2 represents merely one example of a proposed architecture for a new RAT based telecommunications system in which approaches in accordance with the principles described herein may be adopted, and the functionality disclosed herein may also be applied in respect of wireless telecommunications systems having different architectures.

Thus, certain embodiments of the disclosure as discussed herein may be implemented in wireless telecommunication systems / networks according to various different architectures, such as the example architectures shown in Figures 1 and 2. It will thus be appreciated the specific wireless telecommunications architecture in any given implementation is not of primary significance to the principles described herein. In this regard, certain embodiments of the disclosure may be described generally in the context of communications between network infrastructure equipment / access nodes and a communications device, wherein the specific nature of the network infrastructure equipment / access node and the communications device will depend on the network infrastructure for the implementation at hand. For example, in some scenarios the network infrastructure equipment / access node may comprise a base station, such as an LTE-type base station 1 as shown in Figure 1 which is adapted to provide functionality in accordance with the principles described herein, and in other examples the network infrastructure equipment may comprise a control unit / controlling node 40 and / or a TRP 10 of the kind shown in Figure 2 which is adapted to provide functionality in accordance with the principles described herein.

A more detailed diagram of some of the components of the network shown in Figure 2 is provided by Figure 3. In Figure 3, a TRP 10 as shown in Figure 2 comprises, as a simplified representation, a wireless transmitter 30, a wireless receiver 32 and a controller or controlling processor 34 which may operate to control the transmitter 30 and the wireless receiver 32 to transmit and receive radio signals to one or more UEs 14 within a cell 12 formed by the TRP 10. As shown in Figure 3, an example UE 14 is shown to include a corresponding transmitter 49, a receiver 48 and a controller 44 which is configured to control the transmitter 49 and the receiver 48 to transmit signals representing uplink data to the wireless communications network via the wireless access interface formed by the TRP 10 and to receive downlink data as signals transmitted by the transmitter 30 and received by the receiver 48 in accordance with the conventional operation.

The transmitters 30, 49 and the receivers 32, 48 (as well as other transmitters, receivers and transceivers described in relation to examples and embodiments of the present disclosure) may include radio frequency filters and amplifiers as well as signal processing components and devices in order to transmit and receive radio signals in accordance for example with the 5G/NR standard. The controllers 34, 44 (as well as other controllers described in relation to examples and embodiments of the present disclosure) may be, for example, a microprocessor, a CPU, or a dedicated chipset, etc., configured to carry out instructions which are stored on a computer readable medium, such as a non-volatile memory. The processing steps described herein may be carried out by, for example, a microprocessor in conjunction with a random access memory, operating according to instructions stored on a computer readable medium. The transmitters, the receivers and the controllers are schematically shown in Figure 3 as separate elements for ease of representation. However, it will be appreciated that the functionality of these elements can be provided in various different ways, for example using one or more suitably programmed programmable computer(s), or one or more suitably configured application-specific integrated circuit(s) / circuitry / chip(s) / chipset(s). As will be appreciated the infrastructure equipment / TRP / base station as well as the UE / communications device will in general comprise various other elements associated with its operating functionality.

As shown in Figure 3, the TRP 10 also includes a network interface 50 which connects to the DU 42 via a physical interface 16. The network interface 50 therefore provides a communication link for data and signalling traffic from the TRP 10 via the DU 42 and the CU 40 to the core network 20.

The interface 46 between the DU 42 and the CU 40 is known as the F1 interface which can be a physical or a logical interface. The F1 interface 46 between CU and DU may operate in accordance with specifications 3GPP TS 38.470 and 3GPP TS 38.473, and may be formed from a fibre optic or other wired or wireless high bandwidth connection. In one example the connection 16 from the TRP 10 to the DU 42 is via fibre optic. The connection between a TRP 10 and the core network 20 can be generally referred to as a backhaul, which comprises the interface 16 from the network interface 50 of the TRP 10 to the DU 42 and the F1 interface 46 from the DU 42 to the CU 40.

Full Duplex Time Division Duplex (FD-TDD)

NR/5G networks can operate using Time Division Duplex (TDD), where an entire frequency band or carrier is switched to either downlink or uplink transmissions for a time period and can be switched to the other of downlink or uplink transmissions at a later time period. Currently, TDD operates in Half Duplex mode (HD-TDD) where the gNB or UE can, at a given time, either transmit or receive packets, but not both at the same time. As wireless networks transition from NR to 5G-Advanced networks, a proposed new feature of such networks is to enhance duplexing operation for Time Division Multiplexing (TDD) by enabling Full Duplex operation in TDD (FD-TDD) [3], [4].

In FD-TDD, a gNB can transmit and receive data to and from the UEs at the same time on the same frequency band. In addition, a UE can operate either in HD-TDD or FD-TDD mode, depending on its capability. For example, when UEs are only capable of supporting HD-TDD, FD-TDD is achieved at the gNB by scheduling a DL transmission to a first UE and scheduling an UL transmission from a second UE within the same orthogonal frequency division multiplexing (OFDM) symbol (i.e. at the same time). Conversely, when UEs are capable of supporting FD-TDD, FD-TDD may be achieved both at the gNB and the UE, where the gNB can simultaneously schedule this UE with DL and UL transmissions within the same OFDM symbol by scheduling the DL and UL transmissions at different frequencies (e.g. physical resource blocks (PRBs)) of the system bandwidth. A UE supporting FD-TDD requires more complex hardware than a UE that only supports HD-TDD. Development of current 5G networks is focused primarily on enabling FD-TDD at the gNB with UEs operating in HD-TDD mode.

Motivations for enhancing duplexing operation for TDD include an improvement in system capacity, reduced latency, and improved uplink coverage. For example, in current HD-TDD systems, OFDM symbols are allocated only for either a DL or UL direction in a semi-static manner. Hence, if one direction experiences less or no data, the spare resources cannot be used in the other direction, or are, at best, under-utilized. However, if resources can be used for DL data and UL data (as in FD-TDD) at the same time, the resource utilization in the system can be improved. Furthermore, in current HD-TDD systems, a UE can receive DL data, but cannot transmit UL data at the same time, which causes delays in the UL. If a gNB or UE is allowed to transmit and receive data at the same time (as with FD-TDD), the traffic latency will be improved. In addition, UEs are usually coverage limited in the UL transmissions when located close to the edge of a cell. While the UE coverage at the cell-edge can be improved if more time domain resources are assigned to UL transmissions (e.g. repetitions), if the UL direction is assigned more time resources, fewer time resources can be assigned to the DL direction, which can lead to system imbalance. Enabling FD-TDD would help allow a UE to be assigned more UL time resources when required, without sacrificing DL time resources.

Inter-Cell Cross Link Interference (CLI)

In NR systems, a slot format (i.e. the allocation of DL and UL OFDM symbols in a slot) can be semi-statically or dynamically configured, where each OFDM symbol (OS) in a slot can be configured as Downlink (DL), Uplink (UL) or Flexible (F). An OFDM symbol that is semi-statically configured to be Flexible can be indicated dynamically as DL, UL or remain as Flexible by a Dynamic Slot Format Indicator (SFI), which is transmitted in a Group Common (GC) DCI using DCI Format 2_0, where the CRC of the GC-DCI is masked with SFI-RNTI. Flexible OFDM Symbols that remain Flexible after instruction from the SFI can be changed to a DL symbol or an UL symbol by a DL Grant or a UL Grant respectively. That is, a DL Grant scheduling a PDSCH that overlaps Flexible OFDM Symbols would convert these Flexible OFDM Symbols to DL and similarly an UL Grant scheduling a PUSCH that overlaps Flexible OFDM Symbols would convert these Flexible OFDM Symbols to UL.

Since each gNB in a network can independently change the configuration of each OFDM symbol, either semi-statically or dynamically, it is possible that in a particular OFDM symbol, one gNB is configured for UL and a neighbour gNB is configured for DL. This causes inter-cell Cross Link Interference (CLI) among the conflicting gNBs (due to the UL/DL symbol clash for one or more symbols). Inter-cell CLI occurs when a UE's UL transmission interferes with a DL reception by another UE in another cell, or when a gNB's DL transmission interferes with an UL reception by another gNB. That is, inter-cell CLI is caused by non-aligned (conflicting) slot formats among neighbouring cells. An example is shown in Figure 4, where gNB1 411 and gNB2 412 have synchronised slots. At a given slot, gNB1's 411 slot format = {D, D, D, D, D, D, D, D, D, D, U, U, U, U} whilst gNB2's 412 slot format = {D, D, D, D, D, D, D, D, D, D, D, U, U, U}, where 'D' indicates DL and 'U' indicates UL. Inter-cell CLI occurs during an 11th OFDM symbol, OS, of a slot, where gNB1 411 is performing UL whilst gNB2 412 is performing DL. Specifically, inter-cell CLI 441 occurs between gNB1 411 and gNB2 412, where gNB2's 412 DL transmission 431 interferes with gNB1's 411 UL reception 432. CLI 442 also occurs between UE1 421 and UE2 422, where UE1's 421 UL transmission 432 interferes with UE2's 422 DL reception 431. In situations where there is interference, for example, between the two gNBs 411 and 412, or between UEs 421 and 422, the transmitting entity may be referred to as an aggressor entity and the receiving entity as the victim entity. In the example of Figure 4, gNB1 411 and UE2 422 are receiving in the 11th OS where interference is caused, and so they would be the victim gNB and victim UE, whereas gNB2 412 and UE1 421 are the transmitting entities, so they may be known as the aggressor gNB and the aggressor UE.

Some legacy implementations attempt to reduce inter-cell CLI in TDD networks caused by flexible and dynamic slot format configurations. Two CLI measurement reports to manage and coordinate the scheduling among neighbouring gNBs include: sounding reference signal (SRS) reference signal received power (RSRP) and CLI received signal strength indicator (RSSI). In SRS-RSRP, a linear average of the power contribution of an SRS transmitted by a UE is measured by a UE in a neighbour cell. This is measured over the configured resource elements within the considered measurement frequency bandwidth, in the time resources in the configured measurement occasions. In CLI-RSSI, a linear average of the total received power observed is measured only at certain OFDM symbols of the measurement time resource(s), in the measurement bandwidth, over the configured resource elements for measurement by a UE.

Both SRS-RSRP and CLI-RSSI are RRC measurements and are performed by a UE, for use in mitigating against UE to UE inter-cell CLI. For SRS-RSRP, an aggressor UE (i.e. a UE whose UL transmissions cause interference at another UE in a neighbouring cell) would transmit an SRS in the uplink and a victim UE (i.e. a UE that experiences interference due to an UL transmission from the UE in the neighbouring cell) in a neighbour cell would be configured with a measurement configuration including the aggressor UE's SRS parameters, in order to allow the interference from the aggressor UE to be measured. An example is shown in Figure 5 where, at a particular slot, the 11th OS (OFDM symbol) of gNB1 511 and gNB2 512 causes inter-cell CLI. Here, gNB1 511 has configured UE1 521, the aggressor UE, to transmit an SRS 540 and gNB2 512 has configured UE2 522, the victim UE, to measure that SRS 540. UE2 522 is provided with UE1's 521 SRS configured parameters, e.g. RS sequence used, frequency resource, frequency transmission comb structure and time resources, so that UE2 522 can measure the SRS 540. In general, a UE can be configured to monitor 32 different SRSs, at a maximum rate of 8 SRSs per slot.

For CLI-RSSI measurements, the UE measures the total received power, i.e. signal and interference, following a configured periodicity, start and end OFDM symbols of a slot, and a set of frequency Resource Blocks (RBs). Since SRS-RSRP measures a transmission by a specific UE, the network can target a specific aggressor UE to reduce its transmission power and in some cases not schedule the aggressor UE at the same time as a victim UE that reports a high SRS-RSRP measurement. In contrast, CLI-RSSI cannot be used to identify a specific aggressor UE's transmission, but CLI-RSSI does provide an overall estimate of the inter-cell CLI experienced by the victim UE.

Subband Full Duplex (SBFD)

Subband Full Duplex is an object of current research [5], and being considered in the Rel-18 Duplex Evolution Study Item. In SBFD, the frequency resource at the UE/gNB of a TDD system bandwidth or Bandwidth Part (BWP) within a carrier is divided into multiple subbands, where any one particular subband can be used for DL and UL at different times, and different subbands may be scheduled for UL or DL simultaneously [5]. Guard subbands may be used between DL and UL subbands to reduce inter subband interference. In Rel-18, up to three non-overlapping subbands, comprising one UL subband and one or two DL subbands, are considered. An example configuration is shown in Figure 6, where a TDD system bandwidth is divided into three non-overlapping subbands by frequency where Subband#1 606 and Subband#3 602 are used for DL transmissions and Subband#2 604 is used for UL transmission. In this example, guard subbands 608 and 610 are added between the DL and UL subbands. Although Rel-18 is limited to three non-overlapping subbands any number of subbands may be used in other releases or different configurations. For example, four subbands could be used, where, for instance, two down and two uplink bands could be interspersed in the frequency dimension, with guard bands between the transmission subbands.

Example configurations with two subbands are shown in Figure 7, where on the left-hand side, the UL subband is at the lower portion of the bandwidth, Subband#1 702, whilst the DL subband, Subband#2 704 is at the upper portion of the bandwidth. As in the previous figure, a guard subband 706 is present between the other two subbands. In the right-hand side of Figure 7, the DL subband, Subband#1 712, and the UL subband, Subband#2 708, are at the lower and upper portion of the bandwidth respectively. Again, a guard subband 710 is inserted between the subbands.

Inter Subband Interference

In addition to inter-cell Cross Link Interference, CLI, SBFD also suffers from inter (and intra) subband interferences, which may be caused by transmission leakage and receiver selectivity as shown in Figure 8. Although a transmission is typically scheduled within a specific frequency channel (or subband) i.e. a specific set of resource blocks RBs, transmission power can leak out to other channels. This occurs due to the channel filters not being perfect and the roll-off of the filter causing power to leak into channels adjacent to the intended specific frequency channel. While the following discussion uses the term “channel”, the term “subband” such as the subbands shown in Figures 6 and 7, may be used instead.

In Figure 8, transmission from one subband leaks into the reception of another subband, and reception in one subband selects transmission in another subband (i.e. the receiver inadvertently receives some signal from an adjacent subband). Here the wanted transmission (Tx) power is the transmission power in the selected frequency band (i.e. the aggressor channel 810). Due to roll-off of the transmission filter and nonlinearities in components of the transmitter, some transmission power is leaked into adjacent channels (including an adjacent victim channel 820), as shown in Figure 8. The leakage power 851 will cause interference at a receiver that is receiving the signal in the adjacent channels 820.

Similarly, a receiver’s filter is also not perfect and will receive unwanted power from adjacent channels due to its own filter roll-off. An example of filter roll-off at a receiver is shown by receiver selectivity 852 of Figure 8. Here, a receiver is configured to receive transmissions in an assigned channel 820. However, the imperfect nature of the receiver filter means that some transmission power 852 can be received in adjacent channels 810. Therefore, if a signal is transmitted on an adjacent channel, such as 810 by the aggressor transmitter, the receiver will inadvertently receive the adjacent signal in the adjacent channel 810, to an extent.

In particular, an aggressor, for example a gNB such as gNB2 412, transmits a signal 810 in an adjacent channel at a lower frequency than the frequency of the receiving channel 820 of the victim, such as gNB1 411. The interference 850 caused by the aggressor’s transmission includes the includes the Adjacent Channel Leakage, ACL, 851 caused by the aggressor’s transmitting filter and the Adjacent Channel Selectivity, ACS, 852 caused by the victim’s receiving filter. One of the causes of this interference is the imperfect functioning of the aggressor’s, and victim’s, filters. In other words, the receiver will experience interference 850 in the adjacent channel interference, ACI, frequency range shown in Figure 8.

As such, due to adjacent channel interference (ACI), cross link interference (CLI) will still occur despite the use of different sub-bands 602, 604, 606 for DL and UL transmissions in a FD-TDD cell as shown in the example of Figure 6.

Inter subband interference causes intra-cell Cross Link Interference, CLI, at the gNB and at the UE. An example is shown in Figure 9, where gNB1 910 is capable of FD-TDD and is simultaneously receiving an UL transmission 931 from UE1 921 and transmitting a DL transmission 942 to UE2 922. At gNB1 910 intra-cell CLI is caused by the DL transmission

942 in a DL subband at the gNB's 910 transmitter self-interfering 941 with its own receiver that is trying to decode UL signals 931 in an adjacent UL subband. At the UE side of the interaction, intra-cell CLI is caused by an aggressor UE, e.g. UE1 921 transmitting UL signals 931 in an UL subband whilst a victim UE, e.g. UE2 922, is receiving a DL signal 942 in an adjacent DL subband.

The intra-cell CLI at the gNB due to self-interference is very significant as the difference in power between the DL transmission and the UL reception can be over 100 dB. Complex radio frequency, RF, hardware and interference cancellation are required to isolate this self-interference. In order to reduce self-interference at the gNB due to inter-subband interference, guard subbands may be inserted between two subbands of different link directions as shown in Figures 6 and 7.

Intra Subband Interference

Intra subband interference can occur if the subband configurations among gNBs in the frequency domain are not aligned. Here, CLI may occur in the overlapping frequencies of inter-cell sub-bands. An example is shown Figure 10, where gNB1's 1011 system bandwidth is divided into UL subband UL-SB#1 1052 occupying f_0 to f_2 and DL subband DL-SB#1 1051 occupying f_2 to f_3, whilst gNB2's 1012 system bandwidth is divided into UL subband UL-SB#2 1054 occupying f_0 to f_1 and DL subband DL-SB#2 1053 occupying f_1 to f_3. The non-aligned subband configurations (in the frequency region between f_1 and f_2) cause UL-SB#1 1052 to overlap with DL-SB#2 1053 thereby causing intra subband CLI within the overlapping frequencies f_1 to f_2. In this example we have intra subband CLI from gNB2's 1012 DL transmission 1032 within f_1 to f_2 in DL-SB#2 1053 interfering with gNB1's 1011 reception of UL signals 1031 within f_1 to f_2 in UL-SB#1 1052, and UE1's 1021 UL transmission 1031 within f_1 to f_2 interfering with UE2's 1022 DL reception 1032 within f_1 to f_2 in DL-SB#2 1053. In this way it is seen that there is both intra subband interference at the gNB side and the UE side of the interaction.

UL to DL switching time

For a half duplex UE that cannot receive and transmit at the same time, transmission and reception need to be separated by an amount of time referred to as a switching time N_{TX-RX}, between an end of an UL transmission and a start of a DL reception, in order to switch from an UL transmission to a DL reception. The value of N_{TX-RX} is set as 13 μs or 7 μs for FR1 and FR2 respectively. Furthermore, the UE may perform a timing advance of N_{TA}, to compensate for a propagation delay between a gNB and the UE, which would lead to an UL transmission ending N_{TA} earlier, thereby creating a time gap at the end of UL and start of the next DL transmissions. However, in a typical deployment, for example with a cell size of 500 m to 1000 m cell, the N_{TA} is 3.3 μs to 6.6 μs, which is a fraction of N_{TX-RX}, and so N_{TA} alone would not provide sufficient time for the UE to switch from UL to DL.

The UL to DL switching time N_{TX-RX} can be provided by a common timing advance offset $N_{TA,offset}$ which is indicated in the SIB and can be configured to {0, 13, 20} μs. In addition to $N_{TA,offset}$, the UE needs to perform timing advance of N_{TA} to compensate for propagation delay between gNB and the UE, that is the UE will perform an overall timing advance $T_{TA} = N_{TA} + N_{TA,offset}$. An example is shown in Figure 11, where a gNB 1111 transmits an UL Grant 1101 at time t_0 to a UE 1121 to schedule a PUSCH 1131 to start in Slot n+1 1141. Due to propagation delay $T_{gNB\text{-}UE}$, the UL Grant 1101 arrives 1103 at the UE 1121 at time t_1, and in order for the PUSCH 1131 to arrive at the start of Slot n+1 1141 at the gNB 1111, the UE 1121 would timing advance its PUSCH 1131 by $N_{TA} = 2 \times T_{gNB\text{-}UE}$. To ensure there is at least $N_{TX\text{-}RX}$ between the UL and DL transmissions, the gNB 1111 sets $N_{TA,offset}$ = 13 µs and so in addition to N_{TA}, the UE 1121 further time advances the PUSCH 1131 by $N_{TA,offset}$ giving an overall timing advance $T_{TA} = N_{TA} + N_{TA,offset}$. This provides at least $N_{TX\text{-}RX}$ time gap 1160 at the UE 1121 between the end of PUSCH 1131 at time t_6 and the start of the PDSCH 1132 at time t_8, for the UE 1121 to perform UL to DL switching.

Loss of Cyclic Prefix orthogonality

Uplink transmission in an UL subband of an SBFD slot using $N_{TA,offset}$ may worsen the inter subband self-interference at the gNB [6] (i.e., 941 in Figure 9 where DL transmission by a gNB in a DL subband interferes with UL reception in an UL subband of the gNB), due to misalignment between DL and UL transmissions. Figure 12 shows a depiction of the scheduling for communication in a network such as shown in Figure 9, and the right-hand-side shows an expanded view of a slot boundary, showing misalignment of OFDM symbols in the UL and DL directions. For example, in Figure 12 the gNB 1211 transmits an UL Grant 1201 at time t_0 to schedule a PUSCH 1231 for UE1 1221 to start at the beginning of Slot n+1 1241. Due to propagation delay of $T_{gNB\text{-}UE}$, the UL Grant 1201 arrives 1203 at the UE 1221 at time t_1 and in order for the PUSCH 1231 to arrive at the gNB 1211 at the start of Slot n+1 1241 at time t_5, the UE 1221 time advances PUSCH 1231 by $N_{TA} = 2 \times T_{gNB\text{-}UE}$. To ensure the UE 1221 has $N_{TX\text{-}RX}$ time to switch from UL to DL, the gNB 1211 sets $N_{TA,offset}$=13 µs. The UE 1221 transmits PUSCH 1231 at time t_2 using $T_{TA} = N_{TA} + N_{TA,offset}$, and the PUSCH 1231 arrives at the gNB 1211 at time t_3, which is $N_{TA,offset}$ prior to the start of Slot n+1 1241. At the start of Slot n+1 1241, the gNB 1211 transmits a PDSCH 1232 to UE2, which is not OFDM symbol aligned with the received PUSCH 1231 from UE1 1221.

The right-hand-side of Figure 12 shows the first two OFDM symbols of the PUSCH 1231 from UE1 1221 and the 1st OFDM symbol of the PDSCH 1232 for UE2, where here we assume a 60 kHz subcarrier spacing. Due to the common timing advance $N_{TA,offset}$, PUSCH 1231 from UE1 1221 and PDSCH 1232 for UE2 are not within each other's cyclic prefix, which results in a loss of orthogonality between them making it difficult for the gNB's 1211 receiver to remove the inter subband self-interference of the PDSCH 1232 from the received PUSCH 1231. It should be noted that in the legacy operation, $N_{TA,offset}$ is not an issue since it is a common timing advance offset and UL transmissions occur in UL only OFDM symbols (i.e. no self interference caused by DL transmission at the gNB), and so all UEs' transmissions would arrive at the gNB that is $N_{TA,offset}$ from the start of the scheduled slot or OFDM symbols and they would all be aligned, i.e. their transmissions are within the cyclic prefix. The introduction of SBFD in a slot thereby causes this misalignment. The timing advance detailed above therefore also plays the role of introducing interference to a gNB or UE operating in a FD-TDD mode, or rather increasing the efforts that may be required to be taken to combat interference for the same reduction in interference, since there is in this example a loss of orthogonality.

Cyclic Prefix misalignment and Inter-gNB CLI

In addition to the intra-cell interference above, the common timing advance offset $N_{TA,offset}$, may also cause misalignment issues due to inter gNB CLI at a victim gNB receiver, between UL reception and CLI caused by an aggressor gNB's DL transmissions in dynamic/flexible

TDD [7]. This is caused by the early arrival of UL transmissions from UEs at the victim gNB's receiver, which are misaligned at the OFDM symbol level with DL CLI from an aggressor gNB's DL transmission. Figure 13 depicts the scheduling of a FD-TDD gNB in a synchronised network with one other gNB and a UE, and an expanded view of the start of a second slot where misalignment of a DL transmission from the other gNB and an UL transmission from the UE may be seen.

An example of this inter-cell interference is shown in Figure 13, where gNB1 1311 and gNB2 1312 are operating dynamic/flexible TDD in a synchronised network, i.e., their slots start at the same time. At time t_0, gNB1 1311 transmits an UL Grant 1301 to UE1 1321 scheduling a PUSCH 1331 to start at the beginning of Slot n+1 1341. The UE 1321 time advances the PUSCH 1331 by $T_{TA} = N_{TA} + N_{TA,offset}$ and transmits the PUSCH 1331 at time t_2 so that it arrives at time t_3, i.e. $N_{TA,offset}$ prior to the start of Slot n+1 1341 at gNB1 1311. In Slot n+1 1341, gNB1 1311 is operating in the UL whilst gNB2 1312 is operating in the DL, causing CLI where gNB1 1311 is the victim gNB and gNB2 1312 is the aggressor gNB. Here gNB2 1312 transmits a PDSCH 1332 to one of its UEs and that transmission reaches gNB1's 1311 receiver at time t_7, after propagation delay of $T_{gNB\text{-}gNB}$, i.e., it arrives at gNB1 1311 after the start of Slot n+1 1341 at gNB1 1311. The PDSCH 1332 from gNB2 1312 causes CLI to gNB1's 1311 reception of the PUSCH 1331 from UE1 1321.

The right hand side of Figure 13 shows the first two OFDM symbols of the PUSCH 1331, where here the PUSCH 1331 and the interfering PDSCH 1332 are misaligned by $N_{TA,offset}$ + $T_{gNB\text{-}gNB}$, which may also lead to misalignment of their cyclic prefixes, i.e, their cyclic prefixes do not overlap, and as a result have lost their orthogonality. The orthogonality between the PUSCH 1331 signal and the PDSCH interferer 1332 may make it difficult for the victim gNB1 1311 to perform interference cancellation of the PDSCH 1332.

Proposed Prior Art solutions

In [6], it is proposed that the network set $N_{TA,offset} = 0$, causing the UE to time advance by a total timing advance $T_{TA} = N_{TA}$, compensating for the gNB to UE propagation delay $T_{gNB\text{-}UE}$ only and ensuring the UE uplink transmission would arrive at the gNB's slot or OFDM symbol boundary and in an SBFD slot. In essence, the approach of the prior art is to reduce the timing advance applied to the transmission, so that the orthogonality of the transmissions can be maintained. This would not cause the UL reception and DL transmission to lose orthogonality at the gNB, and thus the interference of the DL transmission could be mitigated. It is further proposed that two $N_{TA,offset}$ are introduced, e.g. $N_{TA,offset1}$ and $N_{TA,offset2}$, such that the UE uses $N_{TA,offset1} = 0$, for UL transmissions in an UL subband and $N_{TA,offset2} > 0$, for UL transmissions in an UL slot.

An example is shown in Figure 14, where a slot pattern with 1 DL slot (Slot n) 1440, 3 SBFD slots (Slot n+1, n+2 and n+3) 1441, 1442, 1443, and 1 UL slot (Slot n+4) 1444 are repeated. At time t_0, the gNB 1411 transmits an UL Grant 1401 to UE1 1421 to schedule PUSCH#1 1431 to start at Slot n+1 1441. Due to propagation delay $T_{gNB\text{-}UE}$, the UL Grant 1403 arrives at UE1 1421 at time t_1. Using the proposed method in [6], UE1 1421 uses the common time advance offset $N_{TA,offset1} = 0$ and therefore time advances PUSCH#1 1431 by only $N_{TA} = 2 \times T_{gNB\text{-}UE}$, such that PUSCH#1 1431 arrives at the start of Slot n+1 1441 at time t_3. In Slot n+1 1441, the gNB 1411 schedules PDSCH#1 1432 to UE2 at the start of Slot n+1 1441 and here PUSCH#1 1431 and PDSCH#1 1432 are aligned thereby maintaining their orthogonality. UE1 1421 is also configured with CG-PUSCH, which UE1 1421 will utilise to transmit CG-PUSCH#2 1433 in an occasion in Slot n+4 1444. Since Slot n+4 1444 is UL only slot, UE1 1421 uses $N_{TA,offset2}$ = 13 μs thereby timing advance CG-PUSCH#2 1433 by $T_{TA} = N_{TA} + N_{TA,offset2}$, which provides at least N_{TX-RX} time gap between the end of CG-PUSCH#2 1433 and a DL reception in the next slot.

However, the method in [6] where a separate common TA offset $N_{TA,offset1} = 0$ for UL transmissions in SBFD would lead to an insufficient time gap for switching the transmitter/receiver at the UE between UL to DL between SBFD slots or within a single SBFD slot. An example is shown in Figure 15, where at time t_0, the gNB 1511 transmits an UL Grant 1501 to UE1 1521 to schedule a PUSCH#1 1531 in Slot n+1 1541, which after propagation delay T_{gNB-UE}, the UL Grant 1503 is received at UE1 1521 at time t_1. Similar to the example in Figure 11, the UE 1521 uses $N_{TA,offset1} = 0$ on PUSCH#1 1531 since it is scheduled in an UL subband thereby enabling PUSCH#1 1531 to arrive at the gNB 1511 at the start of Slot n+1 1541 at time t_4, which maintains its orthogonality with a DL transmission, PDSCH#1 1532 to UE2 as intended. It is common for network to configure PDCCH search spaces at the start of a slot to send DL or UL Grants to UEs, for example in Figure 12, the gNB 1511 transmits another UL Grant 1505 at time t_6 to UE1 1521 which reaches UE1 1521 at time t_7. However, since PUSCH#1 1531 was time advanced by only N_{TA}, i.e. ending at time t_5 at UE1 1521, it does not provide sufficient time for it to switch from UL to DL in order to receive the UL Grant 1508 at time t_7, that is, the time between the start of the UL Grant 1508 at time t_7 and the end of PUSCH#1 1531 at time t_5 is less than the required UL to DL switching time N_{TX-RX}. The UL Grant 1505 in Slot n+2 1542 schedules another PUSCH, PUSCH#2 1535 with a duration of 6 OFDM symbols, for UE1 1521 to start at the beginning of Slot n+3 1543 and again the UE 1521 applies $N_{TA,offset1} = 0$ thereby timing advance PUSCH#2 1535 by N_{TA}. UE1 is also scheduled PDSCH#2 1536 at the 7th OFDM symbol of Slot n+3 1543, where PDSCH#2 1536 may be a semi-persistent transmission, i.e., an SPS PDSCH that occurs periodically. The time gap between the end of PUSCH#2 1535 transmission at time t_{11} and the start of PDSCH#2 1536 at time t_{12} is approximate N_{TA} which is less than the required N_{TX-RX} time gap required for UL to DL switching. Hence, the method in [6] which uses separate common TA offsets for SBFD and non-SBFD slots may not provide sufficient time gap between UL transmission and DL reception between two SBFD slots or within a single SBFD slot.

In [7] it is proposed to allow $N_{TA,offset}$ to be set to 0 or negative values, i.e. $N_{TA,offset} \leq 0$ to align UL transmissions with DL interference from aggressor gNB in dynamic/flexible TDD operations. $N_{TA,offset} = 0$ can be used to align with DL interference from aggressor gNBs that are closer in distance to the victim gNB, i.e. below a threshold distance from the victim gNB, where the DL interference arrives within the cyclic prefix of the UL transmission, and $N_{TA,offset} < 0$ can be used to align with DL interference from an aggressor gNB that is further in distance from the victim gNB. An example is shown in Figure 16, where gNB1 1611 is the victim and gNB2 1612 and gNB3 1613 are the aggressors and in a particular slot, gNB1 1611 is receiving in the UL whilst gNB2 1612 and gNB3 1613 are transmitting in the DL. Here gNB2 1612 and gNB3 1613 are 500 m and 1000 m away from gNB1 1611 respectively, which corresponds to propagation delay of $T_{gNB1-gNB2} = 1.67\ \mu s$ and $T_{gNB1-gNB3} = 3.33\ \mu s$. The gNBs operate in a subcarrier spacing of 30 kHz which has a cyclic prefix length $T_{CP} = 2.3\ \mu s$ followed by data part of 33.3 μs. gNB1 1611 schedules a PUSCH 1631 for UE1 1621 to start at the beginning of the UL slot. Since the DL 1632 from gNB2 1612 reaches gNB1 1611 receiver at $T_{gNB1-gNB2} = 1.67\ \mu s$ offset from the UL slot boundary, gNB1 1611 can use $N_{TA,offset} = 0$ so that UE1's

1621 PUSCH 1631 arrives at the UL slot boundary of gNB1 1611, where their cyclic prefix overlaps as shown in the left hand side of Figure 16. The DL interference from gNB3 1613 arrives $T_{gNB1\text{-}gNB3}$ = 3.33 μs later at gNB1 1611, which would be outside of the 2.3 μs cyclic prefix of an UL transmission 1634 that arrives at gNB1 1611 at the slot boundary. To align gNB1's 1611 UL reception 1634 with DL interference 1633 from gNB3 1613, gNB1 1611 can configure $N_{TA,offset} < 0$ so that UE1's 1621 PUSCH 1634 arrives later in the UL slot, where its cyclic prefix overlaps with the cyclic prefix of the DL interference from gNB3 1613 as shown in the right hand side of Figure 16.

The method in [7] of setting $N_{TA,offset} = 0$ for dynamic/flexible TDD would face the same problem as that in [6], where there may be insufficient time for a UE to switch from UL transmission to DL reception, or vice versa. Setting $N_{TA,offset} < 0$ would reduce further the time gap between UL transmission and DL reception at the UE and may even cause UL and DL collision at the gNB, which leads to self-interference at the gNB and UL & DL transmissions collision at the UE. An example of this collision is shown in Figure 17, where in Slot n+1 1741, gNB1 1711 is operating in the UL and gNB3 1713 is operating in the DL, i.e., gNB3 1713 is the aggressor and gNB1 1711 is the victim. Here we assume that the propagation delay between gNB3 1713 and gNB1 1711 $T_{gNB1\text{-}gNB3}$ > cyclic prefix, and as per the method in [7], gNB1 1711 would set $N_{TA,offset} < 0$. In Slot n 1740, gNB1 1711 transmits an UL Grant 1701 to UE1 1721 at time t_0, to schedule a PUSCH 1731 at the start of Slot n+1 1741. The UL Grant 1703 arrives at the UE 1721 at time t_1, after propagation delay $T_{gNB1\text{-}UE1}$ and to compensate for the propagation delay, UE1 1721 uses $N_{TA} = 2 \times T_{gNB1\text{-}UE1}$. Since $N_{TA,offset} < 0$, the PUSCH 1731 would arrive at the gNB1 1711 after the beginning of Slot n+1 1741 at time t_4, thereby aligning the PUSCH 1731 with the DL interference, i.e. PDSCH 1733, from gNB3 1713. However, the PUSCH 1731 transmission will continue beyond the end of Slot n+1 1741, i.e., ending at time t_7, which overlaps with the DL slot, Slot n+2 1742. At the start of Slot n+2 1742, gNB1 1711 transmits a DL Grant 1735 to UE1 1721 and here the DL Grant transmission 1735 overlaps with the last OFDM symbol reception of the PUSCH 1731 causing self-interference, i.e., the DL Grant 1735 interferes with the PUSCH 1731 at gNB1's 1711 receiver. It should be noted that a gNB operating dynamic/flexible TDD may not implement SBFD and therefore may not be able to mitigate against inter subband self-interference. At the UE 1721, the time period between the end of the PUSCH 1731 transmission at time t_5 and the start of the DL Grant 1736 at time t_7, is significantly less than the required UL to DL switching time $N_{TX\text{-}RX}$.

Hence, a technical problem to address is how to enable UL reception at the gNB to align with DL transmission from the gNB in SBFD operation and/or DL interference from an aggressor gNB in dynamic/flexible TDD operation but still provide sufficient time gap for UL to DL switching.

Example embodiments

An embodiment of the present technique provides a method of communicating, by a communications device, via a wireless communications network, the method comprising, receiving, by the communications device, from an infrastructure equipment forming part of the wireless communications network, an indication of uplink communications resources for transmitting uplink signals by the communications device, and transmitting, by the communications device, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment. A timing of the uplink transmission is advanced by an alignment offset, wherein the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

Example embodiments address the above-identified problems by introducing an alignment offset, T_{UL}, for UL transmissions, the offset being applied to the targeted schedule time of an UL transmission. That is the UE would apply an overall timing advance $T_{TA} = N_{TA} + N_{TA,offset} + T_{UL}$ for its UL transmissions, rather than the present $T_{TA} = N_{TA} + N_{TA,\ offset}$.

In an embodiment employing this uplink alignment offset, the value of T_{UL} is selected such that the UL transmission arrives at the gNB within the cyclic prefix of the DL interferer, thereby maintaining the orthogonality between the UL transmission and the DL interferer, and at the same time provide at least N_{TX-RX} time gap at the UE, between the end of the UL transmission and the start of a DL reception.

In another embodiment, the alignment offset T_{UL} may be a function of the DL interferer time offset $T_{DL,offset}$, relative to the victim gNB's OFDM symbol. This recognizes that the aim of T_{UL} is to align with the DL interferer at the gNB's receiver and hence the amount of additional timing advance used should take $T_{DL,offset}$ into account. For self-interference in SBFD, where the DL interferer is the gNB's own DL transmission, $T_{DL,offset} = 0$ and for inter-gNB CLI where the DL interferer is an aggressor gNB, $T_{DL,offset}$ may be a function of, in some cases proportional to, the propagation delay between the aggressor gNB and the victim gNB $T_{gNB-gNB}$. For example, in a sychronised network $T_{DL,offset} = T_{gNB-gNB}$.

In another embodiment, the alignment offset T_{UL} takes the common TA offset $N_{TA,offset}$ into account. This embodiment is to ensure that T_{UL} provides at least $N_{TA,offset}$ time gap at the UE between the end of the UL transmission and the start of a DL reception for UL to DL switching.

In another embodiment, the time alignment offset T_{UL} moves the UL transmission earlier by one or more OFDM symbols at the victim gNB, i.e., earlier by N_{OFDM} OFDM symbols, and then forward by an amount proportional to the time offset between the DL interferer and OFDM symbol boundary of the victim gNB.

In another embodiment, the time alignment offset T_{UL} aligns the 2nd or later OFDM symbol of an UL transmission with the 1st OFDM symbol of the DL interferer at the gNB's receiver.This recognizes that to maintain orthogonality between the UL transmission and the DL interferer at the gNB, it is not necessary to align the 1st OFDM symbol of the UL transmission with the 1st OFDM symbol of the DL interferer, but instead any OFDM symbol of the UL transmission can be aligned with the 1st OFDM symbol of the DL interferer is sufficient to maintain orthogonality.

In an example implementation, taking into account the previous embodiments, i.e., where T_{UL} is a function of $T_{DL,offset}$, $N_{TA,offset}$ and N_{OFDM}, $T_{UL} = (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset}$, where N_{OFDM} is the number of OFDM symbols, T_{OFDM} is the duration of an OFDM symbol and $T_{DL,Offset}$ is the time offset between the DL interferer and the boundary of the OFDM symbol where the DL interferer arrives at the victim gNB. That is, the $N_{OFDM} \times T_{OFDM}$ is the said one or more OFDM symbols and $T_{DL,Offset}$ is the time offset, i.e. time delay of the DL interferer at the gNB's receiver. Then, in this example, the applied time alignment could be represented as

$$T_{TA} = N_{TA} + N_{TA,\ offset} + T_{UL} = N_{TA} + N_{TA,\ offset} + (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset}$$
$$= N_{TA} + (N_{OFDM} \times T_{OFDM}) - T_{DL,\ offset}$$

The said number of OFDM symbol N_{OFDM} is selected such that $T_{UL} \geq N_{TX\text{-}RX}$. That is, the said one or more OFDM symbol is the required number of OFDM symbols that ensures that there is at least $N_{TX\text{-}RX}$ time gap at the UE, between the end of its UL transmission and the start of its DL reception. Effectively, N_{OFDM} aligns the N_{OFDM}+1 OFDM symbol of the UL transmission with the 1st OFDM symbol of the DL interferer at the gNB's receiver. For example, if N_{OFDM} = 1, then the N_{OFDM}+1 = 2nd OFDM symbol of the UL transmission is aligned with the 1st OFDM symbol of the DL interferer.

An example is shown in Figure 18 representing a 60 kHz subcarrier spacing operation with T_{OFDM} = 17.9 μs, where in Slot n 1840, gNB1 1811 transmits an UL Grant 1801 at time t_0 to UE1 1821, which schedules a PUSCH 1831 at the start of Slot n+1 1841. The UL Grant 1803 is received by UE1 1821 at time t_1 due to propagation delay $T_{gNB\text{-}UE}$ and consequently, UE1 1821 compensates this delay by applying timing advance $N_{TA} = 2 \times T_{gNB\text{-}UE}$. In Slot n+1 1841 gNB1 1811 and gNB2 1812 are operating in the UL and DL respectively, thereby gNB2's 1812 PDSCH 1832 transmissions causes DL CLI to gNB1's 1811 PUSCH 1831 reception, where gNB2's 1812 PDSCH 1832 arrives at gNB1 1811 at time t_8 after a gNB-gNB propagation delay $T_{gNB\text{-}gNB}$. In this example the gNBs 1811 and 1812 are sychronised and gNB2 1812 is 1000 m away from gNB1 1811 and so $T_{gNB\text{-}gNB}$ = 3.333 μs, which is greater than the cyclic prefix length T_{CP} = 1.2 μs, i.e., $T_{gNB\text{-}gNB}$ > cyclic prefix. As per this embodiment, the UE 1821 applies the alignment offset T_{UL} to its uplink transmission, using $T_{DL,offset} = T_{gNB\text{-}gNB}$ (as explained above, because the gNBs 1811 and 1812 are operating in a sychronised network) and N_{OFDM} = 1. Here we assume $N_{TA,offset}$ = 13 μs, as per the legacy operation and so T_{UL} = 1.6 μs. The UE 1821 applies overall timing advance $T_{TA} = N_{TA} + N_{TA,offset} + T_{UL}$ to the PUSCH 1831 and transmits it at time t_2, where the PUSCH 1831 reaches gNB1 1811 at time t_4. As shown in the right hand side of Figure 18, the PUSCH 1831 arrives at gNB1 1811 with an offset of $T_{DL,offset} = T_{gNB\text{-}gNB}$, i.e. it aligns with the DL interferer, i.e. PDSCH 1832 from gNB2 1812.

It should be appreciated that unlike the prior art which uses $N_{TA,offset} < 0$ to align the 1st OFDM symbol 1831a of the PUSCH 1831 with the 1st OFDM symbol 1832a of gNB2's 1812 PDSCH 1832, thereby leaving no time gap between the end of the PUSCH 1831 and the start of a potential DL reception at the UE 1821, this invention aligns any OFDM symbol, in this example any OFDM symbol of the PUSCH 1831, with the DL interferer 1832 to provide sufficient time gap at the UE between the end of a PUSCH transmission 1831 and the start of a DL reception for UL to DL switching. In the example in Figure 18, the 2nd OFDM symbol 1831b (instead of the 1st OFDM symbol 1831a as in the prior art) is aligned with the DL interferer i.e., PDSCH 1832 from gNB2 1812, thereby enabling the UE 1821 to finish the PUSCH 1831 transmission at time t_9 leaving a time gap > $N_{TX\text{-}RX}$ before the start of a potential DL reception at time t_{12}.

DL Interferer Time Offset $T_{DL,Offset}$

In a particular embodiment if $T_{DL,offset} < T_{CP}$, then $T_{DL,offset}$ is set to 0 for the determination of the alignment offset T_{UL}. The said DL interferer time offset $T_{DL,offset}$ is the time offset of the DL interferer relative to the victim gNB OFDM boundary and if $T_{DL,offset}$ is less than the cyclic prefix, then the cyclic prefixes of DL interferer and the UL channel reception at the gNB overlap, which maintains their orthogonality. For the SBFD case, $T_{DL,offset}$ = 0 anyway, since the DL interferer is self-interference from the gNB and there is no propagation delay within itself, or viewed another way the propagation delay from the transmitting antenna to the receiving antenna, assuming they are different, is still negligible. For dynamic/flexible TDD case of a synchronised network, since $T_{DL,offset} = T_{gNB-gNB}$ then if the aggressor gNB is close to the victim gNB such that the gNB-gNB propagation delay $T_{gNB-gNB} < T_{CP}$, then $T_{DL,offset}$ can be set to zero.

When $T_{DL,offset}$ = 0, the alignment offset $T_{UL} = (N_{OFDM} \times T_{OFDM}) - N_{TA,offset}$, and the OFDM symbols of the UL transmission are aligned with the OFDM boundary at the gNB's receiver. An example is in Figure 19, showing Slot n 1940 and Slot n+1 1941, which are DL and SBFD slots respectively. Here the gNB 1911 operates in 60 kHz subcarrier spacing with an OFDM symbol duration of 17.9 μs, where the cyclic prefix length T_{CP} = 1.2 μs. The gNB 1911 transmits an UL Grant 1901 at time t_0 to UE1 1921 to schedule a PUSCH 1931 to start at the beginning of SBFD Slot n+1 1941. After propagation delay T_{gNB-UE}, the UL Grant 1903 arrives at UE1 1921 at time t_1, and the UE 1921 compensates its UL transmission with $N_{TA} = 2 \times T_{gNB-UE}$. In Slot n+1 1941, the gNB 1921 transmits a PDSCH 1932 to UE2, thereby causing self-interference to its UL reception. As per this embodiment, the UE 1921 applies an additional offset T_{UL} using N_{OFDM} = 1 and, using $N_{TA,offset}$ = 13 μs as per legacy configuration, this gives T_{UL} = 17.9 – 13 = 4.9 μs. The application of T_{UL} effectively caused the PUSCH 1931 to arrive 1 OFDM symbol early at the gNB 1911, i.e., the PUSCH 1931 arrives at the start of the 14th OFDM symbol 1940a of Slot n 1940 at time t_3 and this causes the 2nd OFDM symbol 1931b of PUSCH 1931 to align with the boundary of Slot n+1 1941, which aligns with DL transmissions, i.e., PDSCH 1932 for UE2, at the gNB 1911.

That is, instead of trying to align the start of the UL transmission with the start of the slot boundary, this embodiment aligns one of the OFDM symbol of the UL transmission with the slot boundary, which would lead to the UL transmission aligning with any DL transmission at the gNB 1911, thereby enabling the UL and DL cyclic prefixes to overlap. Since the PUSCH 1931 in this example is transmitted early by 1 OFDM symbol, this provides sufficient time gap at the UE 1921 between the end of the PUSCH 1931 at time t_8 and a potential start of a DL reception, such as PDCCH or PDSCH, at time t_{10}, for the UE 1921 to switch from UL to DL, i.e. time between t_8 and $t_{10} > N_{TX-RX}$. In contrast, the prior art of setting $N_{TA,offset}$ = 0 would lead to insufficient time gap for UL to DL switching.

In another embodiment, for a sychronised network, the DL interferer time offset $T_{DL,offset}$ is set as the propagation delay between the aggressor gNB and the victim gNB, if this propagation delay is greater than the cyclic prefix length, i.e. $T_{DL,offset} = T_{gNB-gNB}$, if $T_{gNB-gNB} > T_{CP}$. This embodiment is for cases where the DL interferer is from an aggressor gNB that is far from the victim gNB such that $T_{gNB-gNB} > T_{CP}$. An example of this embodiment is already explained in Figure 18.

The value of $T_{DL,offset}$ can be determined by the gNB and is based on the target DL interferer. For SBFD case, $T_{DL,offset}$ = 0 as the target DL interferer is the self-interference from the gNB's own DL transmission.

For the dynamic/flexible TDD case of a sychronised network, $T_{DL,offset}$ depends on $T_{gNB-gNB}$ and here a gNB can target the dominant aggressor gNB, i.e., if $T_{gNB-gNB}$ between the dominant aggressor gNB and the victim gNB is less than T_{CP}, then $T_{DL,offset} = 0$, otherwise $T_{DL,offset} = T_{gNB-gNB}$. This does not need to be done frequently as the physical location of the gNBs in a network, upon which the propagation delay between gNBs depends, are unlikely to change frequently, and so $T_{DL,offset}$ for use against inter gNB CLI is also unlikely to change frequently. It is of course possible that the gNB may wish to target more than one aggressor gNB. For example, the victim gNB may be a small cell in a heterogeneous network and it may wish to target DL interferer from an aggressor Macro gNB which may have $T_{DL,offset} > T_{CP}$ and another target may be an aggressor gNB from another nearby small cell with $T_{DL,offset} = 0$. Here, the victim gNB may use multiple $T_{DL,offset}$ and thereby have different T_{UL} values targeting different aggressor gNBs. It would be apparent to one skilled in the art that an uplink transmission can only be advanced by one timing advance amount, and so only one of these aggressor gNBs could be addressed with respect to any one uplink transmission. In certain embodiments, the gNB may decide to mitigate the interference of the aggressor gNB that causes the greatest amount of interference with the reception of the uplink transmission.

N_{OFDM}

In an embodiment, N_{OFDM} is selected to provide at least $N_{TX\text{-}RX}$ time gap at the UE between the end of an UL transmission and the start of a DL reception whilst minimising T_{UL}, i.e., minimizes the amount of timing advance needed to align with the target DL interferer.

In another embodiment, $N_{OFDM} = \left\lceil \frac{N_{TA,offset} + T_{DL,offset}}{T_{OFDM}} \right\rceil$, where $\lceil\rceil$ is the ceiling function which rounds up the number to the nearest integer. This embodiment ensures that T_{UL} would leave $N_{TA,offset}$ time gap at the UE between the end of its UL transmission and the start of a DL reception. Here, it is assumed that $N_{TA,offset} \geq N_{TX\text{-}RX}$, which is typically the case. This embodiment would also determine the minimum N_{OFDM} required to ensure the UE has sufficient UL to DL switching time. That is, it is the minimum number of OFDM symbols by which to advance the transmission in order to ensure that $N_{TA,offset}$ is provided for the switching of the UE or gNB between UL and DL.

In another embodiment, $N_{OFDM} = \left\lceil \frac{N_{TX-RX} + T_{DL,offset}}{T_{OFDM}} \right\rceil$, where $\lceil\rceil$ is the ceiling function which rounds up the number to the nearest integer. This embodiment ensures that T_{UL} would leave at least $N_{TX\text{-}RX}$ time gap at the UE between the end of its UL transmission and the start of a DL reception for UL to DL switching with the minimum value of N_{OFDM}. This recognizes that it is not necessary that $N_{TA,offset} \geq N_{TX\text{-}RX}$ since $N_{TA,offset}$ can be configured to be zero and $T_{DL,offset}$ can also be zero, in which case this embodiment ensures that the UL transmission is time advanced so that the UL transmission arrives early by 1 OFDM symbol at the gNB. That is, this embodiment can be used when $N_{TA,offset} = 0$ or $N_{TA,offset} < N_{TX\text{-}RX}$ to ensure that the transmission is timing advanced, and that the interference may be mitigated whilst not creating an issue with switching time between UL and DL or vice versa.

Signalling

Alignment offset T_{UL}

In an embodiment, the gNB may signal the value of T_{UL} to the UE. That is, the gNB performs the calculation of T_{UL} and signals the calculated T_{UL} to the UE.

In another embodiment, the parameter T_{UL} is signalled to the UE semi-statically via the SIBs or UE dedicated RRC signalling or dynamically indicated to the UE via group common DCI, activation DCI for CG-PUSCH or SPS and/or UL/DL Grant. For example, Activation DCI for SPS and DL Grant may be used to indicate T_{UL} for the corresponding PUCCH carrying the HARQ-ACK for the PDSCH.

In another embodiment, the gNB may semi-statically indicate via the SIBs, or UE dedicated RRC signalling, several T_{UL} values and the gNB may dynamically indicate one of these T_{UL} values in a DCI, such as UL Grant, DL Grant or activation DCI for CG-PUSCH or SPS. The gNB may target different DL interferers with respect to mitigating the interference affecting particular uplink transmissions and hence may use different T_{UL} values for different UL transmissions. This embodiment recognises that T_{UL} may be a floating point number and would require a plurality of bits to indicate to the UE and which may not be practical to signal in a DCI. Therefore, by configuring a set of T_{UL} numbers and using the DCI to indicate the index of one of these T_{UL} numbers, the number of DCI bits is minimized.

Dynamic indication of T_{UL} provides gNB with flexibility to manage the alignment of UL transmissions, for example, the gNB may apply T_{UL} for SBFD slot where it also has overlapping DL transmissions and may not apply T_{UL} if it does not have any DL transmissions. Similarly, for inter gNB CLI in dynamic/flexible TDD, the gNB may apply T_{UL} if the DL interferer from an aggressor gNB is strong and if the DL interferer is weak it may not apply T_{UL} on its UL transmissions.

Another benefit of dynamic T_{UL} indication is the gNB may set $N_{TA,offset} = 0$, and if the gNB is aware that there is no DL transmission following the UE's UL transmission, it may not apply T_{UL} for that UL transmission and vice-versa.

DL Interferer time offset $T_{DL,\ offset}$

Alternatively or additionally, in an example embodiment, the gNB may signal the DL interferer time offset $T_{DL,offset}$ to the UE and the UE may in response calculate the T_{UL}. The parameter $T_{DL,offset}$ can be indicated in the SIB, UE dedicated RRC signalling, group common DCI, activation DCI for CG-PUSCH or SPS and/or dynamic DCI for UL/DL Grant.

In one embodiment, the value of $T_{DL,offset}$ is in multiple units of T_{CP}. This recognizes that the UL transmission does not need to align perfectly with the DL interferer but just need to fall within the cyclic prefix, that is, the cyclic prefixes only need to overlap in time, not be completely aligned. That is, if $T_{DL,offset}$ is signalled to the UE, it can be an integer number and the UE would multiply this integer number with T_{CP}, e.g., the gNB can signal $T_{DL,offset} = 2$ and if the UE operates in 60 kHz subcarrier spacing where $T_{CP} = 1.2\ \mu s$, the UE would use $T_{DL,offset} = 2 \times T_{CP} = 2.4\ \mu s$ in calculating T_{UL}. This avoids the need to signal floating point numbers to the UE and would reduce the amount of signalling overhead which is beneficial if $T_{DL,offset}$ is indicated dynamically.

In another embodiment the gNB may semi-statically configure via the SIB or UE dedicated RRC signalling a plurality of $T_{DL,offset}$ values and dynamically indicate one of these $T_{DL,offset}$ values for one or more UL transmissions. This is beneficial if the gNB determines that it is required to target more than one DL interferer, e.g., the gNB may semi-statically indicate $T_{DL,offset} = \{0, 1\}$ units of T_{CP}, where $T_{DL,offset} = 0$ can be used for self-interference in SBFD and aggressor gNBs that are close to the victim gNB, whilst $T_{DL,offset} = 1 \times T_{CP}$ can be used for DL interferer from an aggressor gNB that is further away, such as a Macro gNB in a heterogeneous network. In this example, the gNB can use 1 bit to indicate one of the two values of $T_{DL,offset}$ in a DCI. It should be noted that the number of DCI bits of course depends on the number of $T_{DL,offset}$ values that are semi-statically configured and that another number of DCI bits may be implemented.

N_{OFDM}

In an embodiment the parameter N_{OFDM} can also be indicated to the UE via SIB broadcast, UE dedicated RRC configuration, group common DCI, activation DCI for CG-PUSCH or SPS and/or UL/DL Grant. Although the UE can determine N_{OFDM} from $N_{TA,offset}$ and $T_{DL,offset}$, there may be situations where it is advantageous for the gNB to instead indicate to the UE the number of OFDM symbols to be advanced.

The following numbered paragraphs provide further example aspects and features of the present technique:

Paragraph 1. A method of communicating, by a communications device, via a wireless communications network, the method comprising,

receiving, by the communications device, from an infrastructure equipment forming part of the wireless communications network, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

transmitting, by the communications device, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information on the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

Paragraph 2. The method of paragraph 1, wherein the uplink transmission and the interfering signal each comprise one or more Orthogonal Frequency Division Modulated, OFDM, symbols, and the alignment offset applied to the uplink transmission aligns an OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at a receiver of the infrastructure equipment.

Paragraph 3. The method in paragraph 2, wherein the alignment offset applied to the uplink transmission aligns a second or later OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at the receiver of the infrastructure equipment.

Paragraph 4. The method of paragraph 3, wherein the alignment offset applied to the uplink transmission causes a cyclic prefix of the OFDM symbol of the uplink transmission to at least overlap in time with a cyclic prefix portion of the OFDM symbol of the interfering signal.

Paragraph 5. The method of any of paragraphs 1 to 4, wherein the interfering signal is a downlink interfering signal and the alignment offset T_{UL} is a function of a downlink DL interferer time offset $T_{DL,offset}$, relative to the OFDM of the infrastructure equipment's OFDM symbol.

Paragraph 6. The method of paragraph 5, wherein a total timing advance applied to uplink transmission is $T_{TA} = N_{TA} + N_{TA,\ offset} + T_{UL} = N_{TA} + N_{TA,\ offset} + (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset} = N_{TA} + (N_{OFDM} \times T_{OFDM}) - T_{DL,\ offset}$, wherein T_{TA} is a total timing advance, N_{TA} is a timing advance compensating for a propagation delay between the communications device and the infrastructure equipment, $N_{TA,\ offset}$ is a common timing advance offset, T_{UL} is the alignment offset, N_{OFDM} is a number of OFDM symbols and T_{OFDM} a duration of an OFDM symbol, and $T_{DL,Offset}$ is a downlink interferer time offset, wherein N_{OFDM} is selected such that $T_{UL} \geq N_{TX\text{-}RX}$, a switching time.

Paragraph 7. The method of any of paragraphs 1 to 6, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of one of a number of possible alignment offset values to be applied, the possible alignment offset values having been signalled to the communications device by the infrastructure equipment.

Paragraph 8. The method of paragraph 7, wherein the signalling of the possible alignment values is performed via a SIB, UE dedicated RRC signalling, group common DCI, activation DCI for CG-PUSCH, SPS, and/or UL/DL Grant.

Paragraph 9. The method of any of paragraphs 1 to 8, wherein the alignment offset is semi-statically configured.

Paragraph 10. The method of paragraph 4, 5 or 6, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the downlink interferer time offset $T_{DL,offset}$.

Paragraph 11. The method in paragraph 10, wherein the downlink interferer time offset is zero if it is less than the cyclic prefix duration, otherwise it is proportional to a propagation delay between a transmitted of the potential interfering signal and the infrastructure equipment's receiver.

Paragraph 12. The method in paragraph 10 and 11, wherein the downlink interferer time offset is indicated as multiple units of the cyclic prefix duration.

Paragraph 13. The method of paragraph 1 to 6, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the number of OFDM symbols N_{OFDM}.

Paragraph 14. A communications device for receiving and transmitting data, comprising,

a receiver, configured to receive signals from an infrastructure equipment forming part of a wireless communications network,

a transmitter, configured to transmit signals to the infrastructure equipment, and

a controller, configured to control the receiver and the transmitter,

to receive, from the infrastructure equipment, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

to transmit an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

Paragraph 15. A method of communicating, by an infrastructure equipment forming part of a wireless communications network, via the wireless communications network, the method comprising, transmitting, by the infrastructure equipment, to a communications device, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

receiving, by the infrastructure equipment, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

Paragraph 16. The method of paragraph 15, wherein the uplink transmission and the interfering signal each comprise one or more Orthogonal Frequency Division Modulated, OFDM, symbols, and the alignment offset applied to the uplink transmission aligns an OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at a receiver of the infrastructure equipment.

Paragraph 17. The method in paragraph 16, wherein the alignment offset applied to the uplink transmission aligns a second or later OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at the receiver of the infrastructure equipment.

Paragraph 18. The method of paragraph 17, wherein the alignment offset applied to the uplink transmission causes a cyclic prefix of the OFDM symbol of the uplink transmission to at least overlap in time with a cyclic prefix portion of the OFDM symbol of the interfering signal.

Paragraph 19. The method of any of paragraphs 15 to 18, wherein the interfering signal is a downlink interfering signal and the alignment offset T_{UL} is a function of a downlink DL interferer time offset $T_{DL,offset}$, relative to the OFDM of the infrastructure equipment's OFDM symbol.

Paragraph 20. The method of paragraph 19, wherein a total timing advance applied to uplink transmission is $T_{TA} = N_{TA} + N_{TA,\ offset} + T_{UL} = N_{TA} + N_{TA,\ offset} + (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset} = N_{TA} + (N_{OFDM} \times T_{OFDM}) - T_{DL,\ offset}$, wherein T_{TA} is a total timing advance, N_{TA} is a timing advance compensating for a propagation delay between the communications device and the infrastructure equipment, $N_{TA,\ offset}$ is a common timing advance offset, T_{UL} is the alignment offset, N_{OFDM} is a number of OFDM symbols and T_{OFDM} a duration of an OFDM symbol, and $T_{DL,Offset}$ is a downlink interferer time offset, wherein N_{OFDM} is selected such that $T_{UL} \geq N_{TX\text{-}RX}$, a switching time.

Paragraph 21. The method of any of paragraphs 15 to 20, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of one of a number of possible alignment offset values to be applied, the possible alignment offset values having been signalled to the communications device by the infrastructure equipment.

Paragraph 22. The method of paragraph 21, wherein the signalling of the possible alignment values is performed via a SIB, UE dedicated RRC signalling, group common DCI, activation DCI for CG-PUSCH, SPS, and/or UL/DL Grant.

Paragraph 23. The method of any of paragraphs 15 to 22, wherein the alignment offset is semi-statically configured.

Paragraph 24. The method of any of paragraphs 19 to 23, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the downlink interferer time offset $T_{DL,offset}$.

Paragraph 25. The method in paragraph 24, wherein the downlink interferer time offset is zero if it is less than the cyclic prefix duration, otherwise it is proportional to a propagation delay between a transmitted of the potential interfering signal and the infrastructure equipment’s receiver

Paragraph 26. The method in paragraph 24 or 25, wherein the downlink interferer time offset is indicated as multiple units of the cyclic prefix duration.

Paragraph 27. The method of any of paragraphs 15 to 26, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the number of OFDM symbols N_{OFDM}.

Paragraph 28. An infrastructure equipment, forming part of a wireless communications network, for receiving and transmitting data, comprising,

a receiver, configured to receive signals from a communications device,

a transmitter, configured to transmit signals to the communications device, and

a controller, configured to control the receiver and the transmitter

to transmit, to a communications device, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

to receive an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

Paragraph 29. A computer programme to execute instructions according to paragraph 1 or paragraph 15.

Paragraph 30. A storage medium storing instructions which when executed cause a processor to perform steps according to paragraph 1 or paragraph 15.

It will be appreciated that the above description for clarity has described embodiments with reference to different functional units, circuitry and/or processors. However, it will be apparent that any suitable distribution of functionality between different functional units, circuitry and/or processors may be used without detracting from the embodiments.

Described embodiments may be implemented in any suitable form including hardware, software, firmware or any combination of these. Described embodiments may optionally be implemented at least partly as computer software running on one or more data processors and/or digital signal processors. The elements and components of any embodiment may be physically, functionally and logically implemented in any suitable way. Indeed, the functionality may be implemented in a single unit, in a plurality of units or as part of other functional units. As such, the disclosed embodiments may be implemented in a single unit or may be physically and functionally distributed between different units, circuitry and/or processors.

Although the present disclosure has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in any manner suitable to implement the technique.

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CLAIMS

1. A method of communicating, by a communications device, via a wireless communications network, the method comprising,

receiving, by the communications device, from an infrastructure equipment forming part of the wireless communications network, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

transmitting, by the communications device, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information on the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

2. The method of claim 1, wherein the uplink transmission and the interfering signal each comprise one or more Orthogonal Frequency Division Modulated, OFDM, symbols, and the alignment offset applied to the uplink transmission aligns an OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at a receiver of the infrastructure equipment.

3. The method of claim 2, wherein the alignment offset applied to the uplink transmission aligns a second or later OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at the receiver of the infrastructure equipment.

4. The method of claim 3, wherein the alignment offset applied to the uplink transmission causes a cyclic prefix of the OFDM symbol of the uplink transmission to at least overlap in time with a cyclic prefix portion of the OFDM symbol of the interfering signal.

5. The method of claim 4, wherein the interfering signal is a downlink interfering signal and the alignment offset T_{UL} is a function of a downlink DL interferer time offset $T_{DL,offset}$, relative to the OFDM of the infrastructure equipment's OFDM symbol.

6. The method of claim 5, wherein a total timing advance applied to uplink transmission is $T_{TA} = N_{TA} + N_{TA,\ offset} + T_{UL} = N_{TA} + N_{TA,\ offset} + (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset} = N_{TA} + (N_{OFDM} \times T_{OFDM}) - T_{DL,\ offset}$, wherein T_{TA} is a total timing advance, N_{TA} is a timing advance compensating for a propagation delay between the communications device and the infrastructure equipment, $N_{TA,\ offset}$ is a common timing advance offset, T_{UL} is the alignment offset, N_{OFDM} is a number of OFDM symbols and T_{OFDM} a duration of an OFDM symbol, and $T_{DL,Offset}$ is a downlink interferer time offset, wherein N_{OFDM} is selected such that $T_{UL} \geq N_{TX\text{-}RX}$, a switching time.

7. The method of claim 1, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of one of a number of possible alignment offset values to be applied, the possible alignment offset values having been signalled to the communications device by the infrastructure equipment.

8. The method of claim 7, wherein the signalling of the possible alignment values is performed via a SIB, UE dedicated RRC signalling, group common DCI, activation DCI for CG-PUSCH, SPS, and/or UL/DL Grant.

9. The method of claim 1, wherein the alignment offset is semi-statically configured.

10. The method of claim 4, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the downlink interferer time offset $T_{DL,offset}$.

11. The method of claim 10, wherein the downlink interferer time offset is zero if it is less than the cyclic prefix duration, otherwise it is proportional to a propagation delay between a transmitted of the potential interfering signal and the infrastructure equipment's receiver

12. The method of claim 11, wherein the downlink interferer time offset is indicated as multiple units of the cyclic prefix duration.

13. The method of claim 1, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the number of OFDM symbols N_{OFDM}.

14. A communications device for receiving and transmitting data, comprising,

a receiver, configured to receive signals from an infrastructure equipment forming part of a wireless communications network,

a transmitter, configured to transmit signals to the infrastructure equipment, and

a controller, configured to control the receiver and the transmitter,

to receive, from the infrastructure equipment, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

to transmit an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

15. A method of communicating, by an infrastructure equipment forming part of a wireless communications network, via the wireless communications network, the method comprising,

transmitting, by the infrastructure equipment, to a communications device, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

receiving, by the infrastructure equipment, an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

16. The method of claim 15, wherein the uplink transmission and the interfering signal each comprise one or more Orthogonal Frequency Division Modulated, OFDM, symbols, and the alignment offset applied to the uplink transmission aligns an OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at a receiver of the infrastructure equipment.

17. The method of claim 16, wherein the alignment offset applied to the uplink transmission aligns a second or later OFDM symbol of the uplink transmission with one of the OFDM symbols of the interfering signal at the receiver of the infrastructure equipment.

18. The method of claim 17, wherein the alignment offset applied to the uplink transmission causes a cyclic prefix of the OFDM symbol of the uplink transmission to at least overlap in time with a cyclic prefix portion of the OFDM symbol of the interfering signal.

19. The method of claim 18, wherein the interfering signal is a downlink interfering signal and the alignment offset T_{UL} is a function of a downlink DL interferer time offset $T_{DL,offset}$, relative to the OFDM of the infrastructure equipment's OFDM symbol.

20. The method of claim 19, wherein a total timing advance applied to uplink transmission is $T_{TA} = N_{TA} + N_{TA,\ offset} + T_{UL} = N_{TA} + N_{TA,\ offset} + (N_{OFDM} \times T_{OFDM}) - N_{TA,offset} - T_{DL,Offset} = N_{TA} + (N_{OFDM} \times T_{OFDM}) - T_{DL,\ offset}$, wherein T_{TA} is a total timing advance, N_{TA} is a timing advance compensating for a propagation delay between the communications device and the infrastructure equipment, $N_{TA,\ offset}$ is a common timing advance offset, T_{UL} is the alignment offset, N_{OFDM} is a number of OFDM symbols and T_{OFDM} a duration of an OFDM symbol, and $T_{DL,Offset}$ is a downlink interferer time offset, wherein N_{OFDM} is selected such that $T_{UL} \geq N_{TX\text{-}RX}$, a switching time.

21. The method of claim 15, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of one of a number of possible alignment offset values to be applied, the possible alignment offset values having been signalled to the communications device by the infrastructure equipment.

22. The method of claim 21, wherein the signalling of the possible alignment values is performed via a SIB, UE dedicated RRC signalling, group common DCI, activation DCI for CG-PUSCH, SPS, and/or UL/DL Grant.

23. The method of claim 15, wherein the alignment offset is semi-statically configured.

24. The method of claim 19, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the downlink interferer time offset $T_{DL,offset}$.

25. The method in claim 24, wherein the downlink interferer time offset is zero if it is less than the cyclic prefix duration, otherwise it is proportional to a propagation delay between a transmitted of the potential interfering signal and the infrastructure equipment's receiver

26. The method in claim 24 or 25, wherein the downlink interferer time offset is indicated as multiple units of the cyclic prefix duration.

27. The method of claim 15, wherein the information of the alignment offset indicated by the infrastructure equipment is an indication of the number of OFDM symbols N_{OFDM}.

28. An infrastructure equipment, forming part of a wireless communications network, for receiving and transmitting data, comprising,

a receiver, configured to receive signals from a communications device,

a transmitter, configured to transmit signals to the communications device, and

a controller, configured to control the receiver and the transmitter

to transmit, to a communications device, an indication of uplink communications resources for transmitting uplink signals by the communications device, and

to receive an uplink transmission via the uplink communications resources indicated by the infrastructure equipment, wherein a timing of the uplink transmission is advanced by an alignment offset, wherein information of the alignment offset is indicated by the infrastructure equipment, the alignment offset being applied to the uplink transmission by the communications device with an effect that the uplink transmission is received by the infrastructure equipment at a time that aligns with a potential interfering signal.

29. A computer programme to execute instructions according to claim 1 or claim 15.

30. A storage medium storing instructions which when executed cause a processor to perform steps according to claim 1 or claim 15.

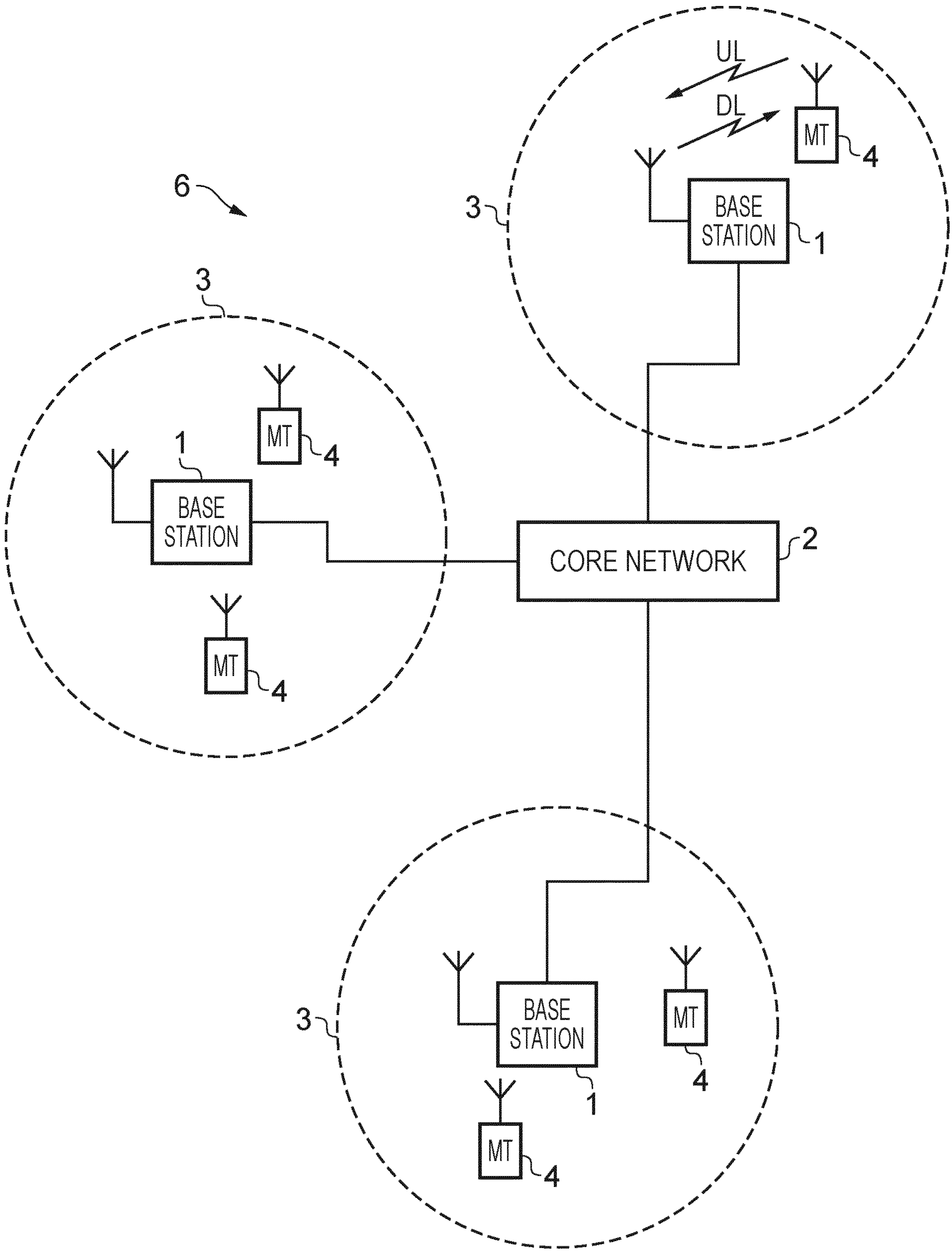

6
3
UL
DL
MT
4
BASE
STATION
1
3
1
MT
4
BASE
STATION
CORE NETWORK
2
MT
4
3
BASE
STATION
1
MT
4
MT
4

FIG. 1

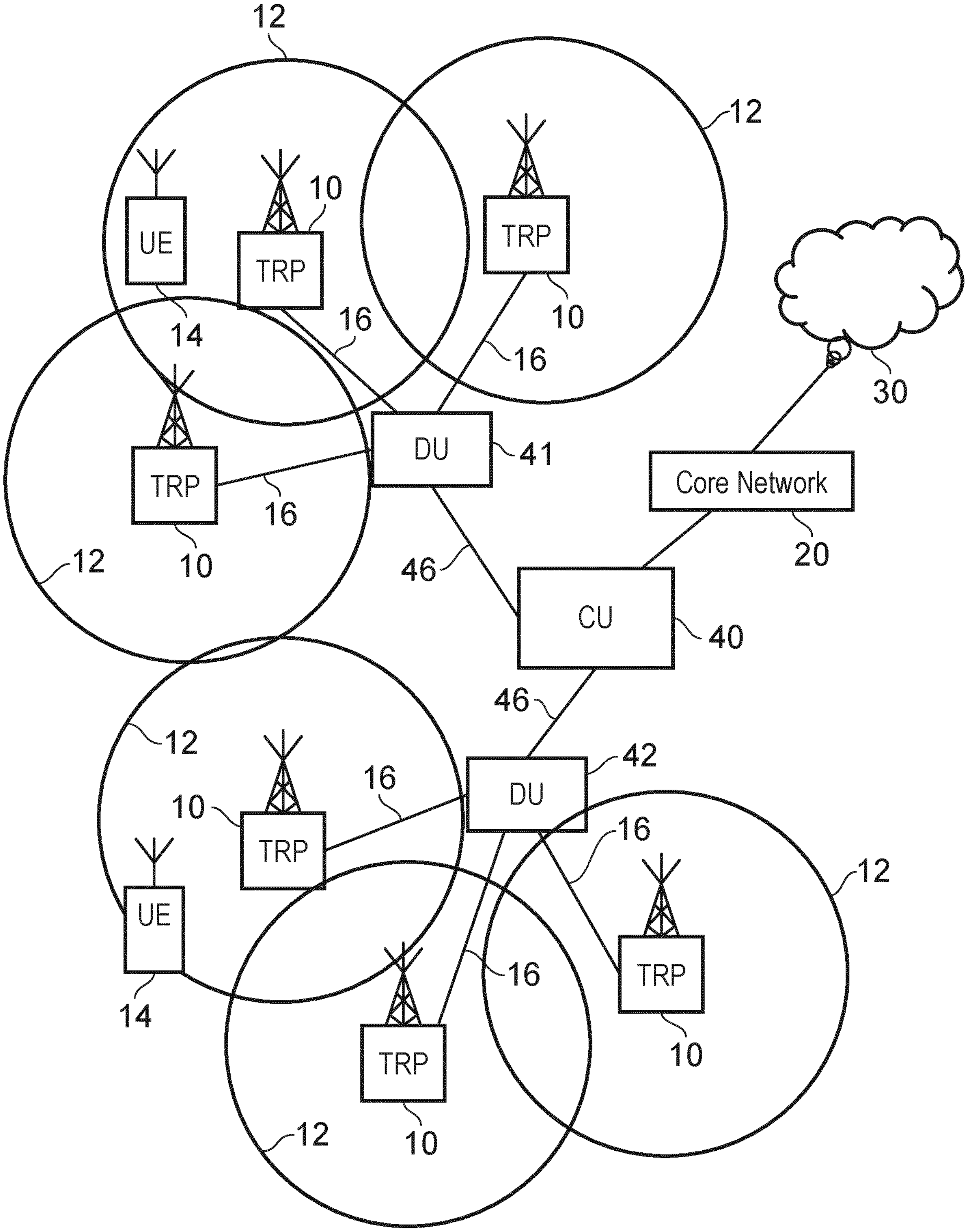

12
12
UE
TRP
10
TRP
14
16
10
16
30
TRP
DU
41
Core Network
16
12
10
46
20
CU
40
46
12
42
DU
16
10
TRP
16
12
UE
16
14
TRP
TRP
10
12
10

FIG. 2

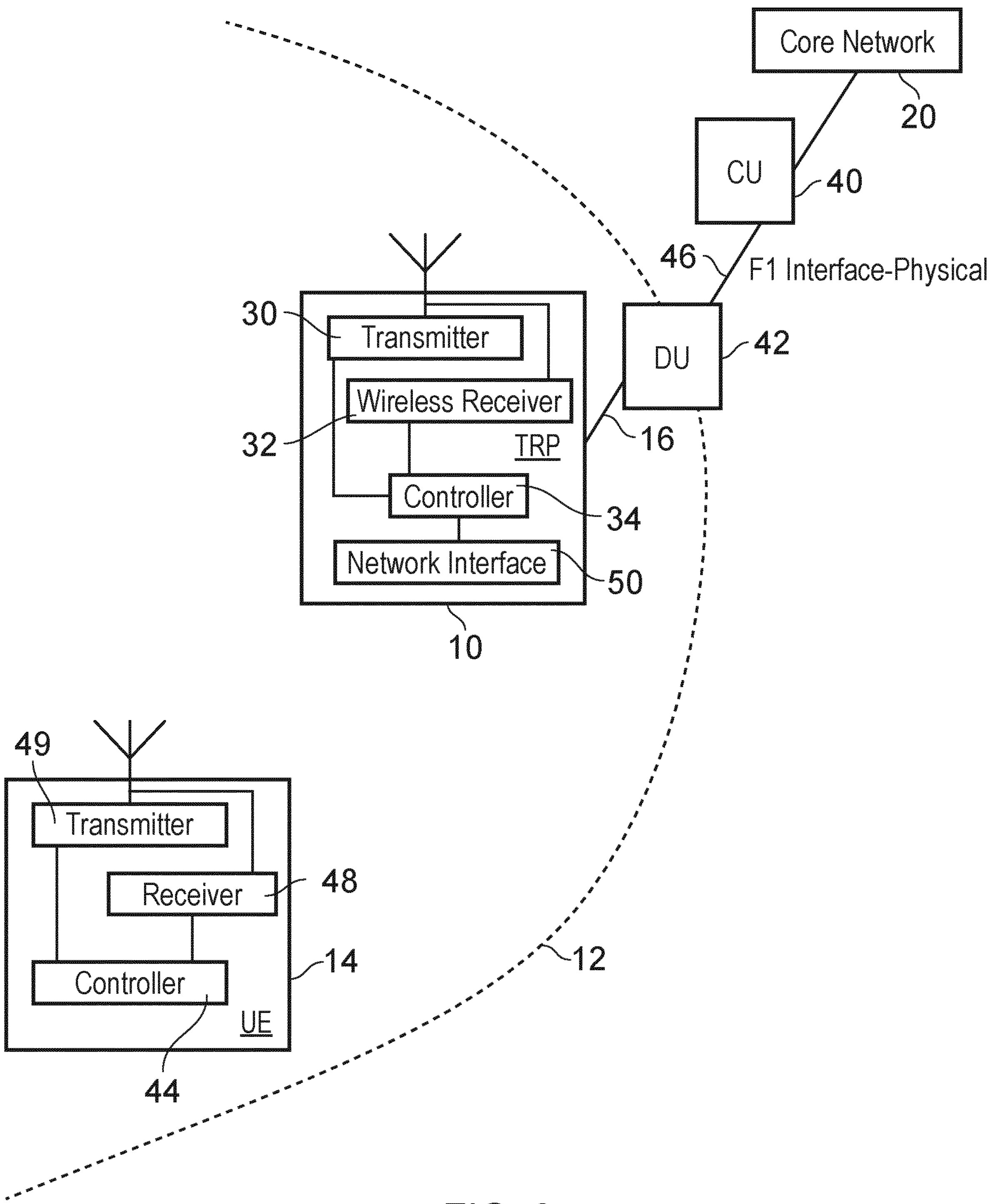

Core Network
20
CU
40
46
F1 Interface-Physical
30
Transmitter
Wireless Receiver
32
TRP
DU
42
16
Controller
34
Network Interface
50
10
49
Transmitter
Receiver
48
14
12
Controller
UE
44

FIG. 3

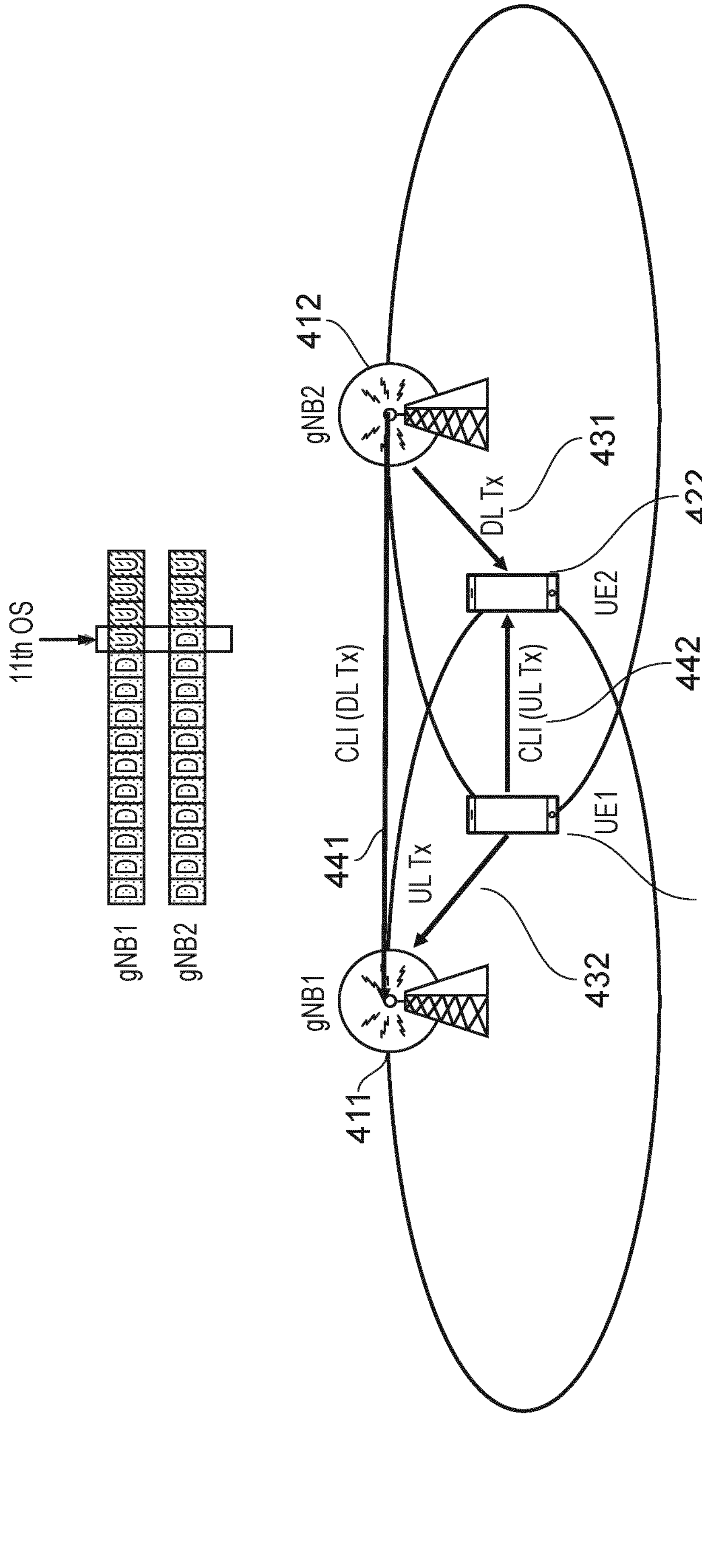

11th OS
gNB1
gNB2
D
U
gNB1
gNB2
412
411
431
DL Tx
422
UE2
CLI (DL Tx)
CLI (UL Tx)
442
UE1
441
UL Tx
421
432

FIG. 4

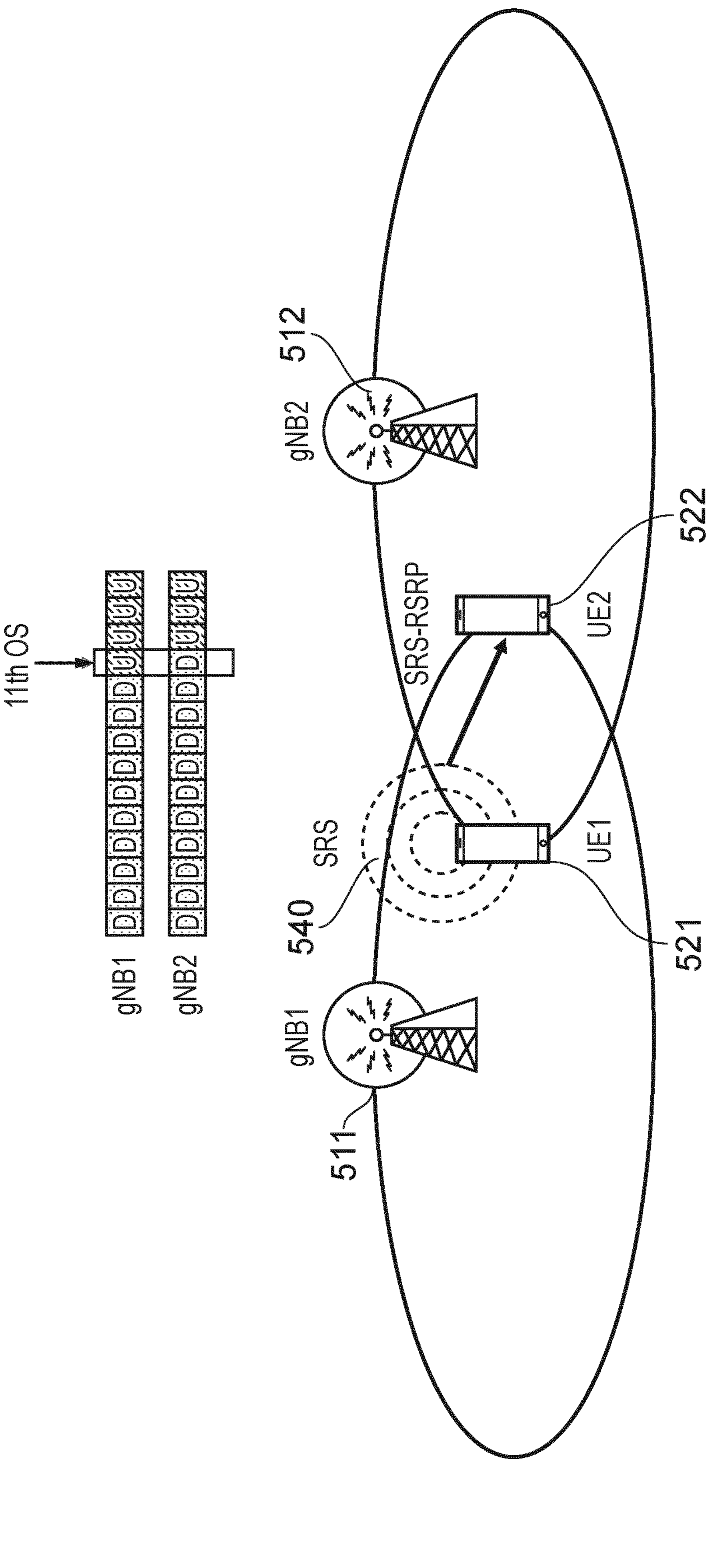

11th OS
gNB1
gNB2
D
U
gNB2
512
SRS-RSRP
UE2
522
SRS
540
UE1
521
gNB1
511

FIG. 5

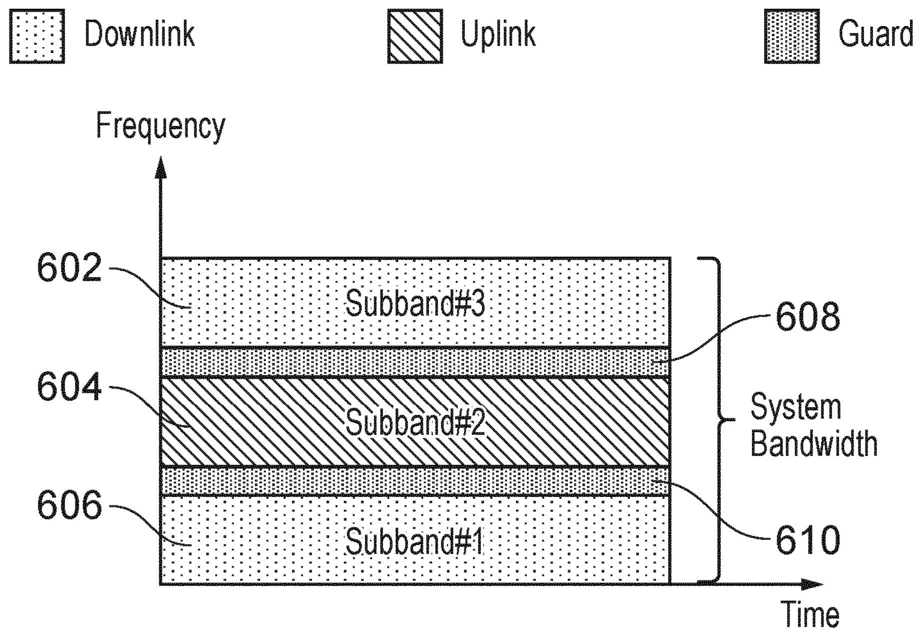

Downlink
Uplink
Guard
Frequency
602
Subband#3
608
604
Subband#2
System
Bandwidth
606
Subband#1
610
Time

FIG. 6

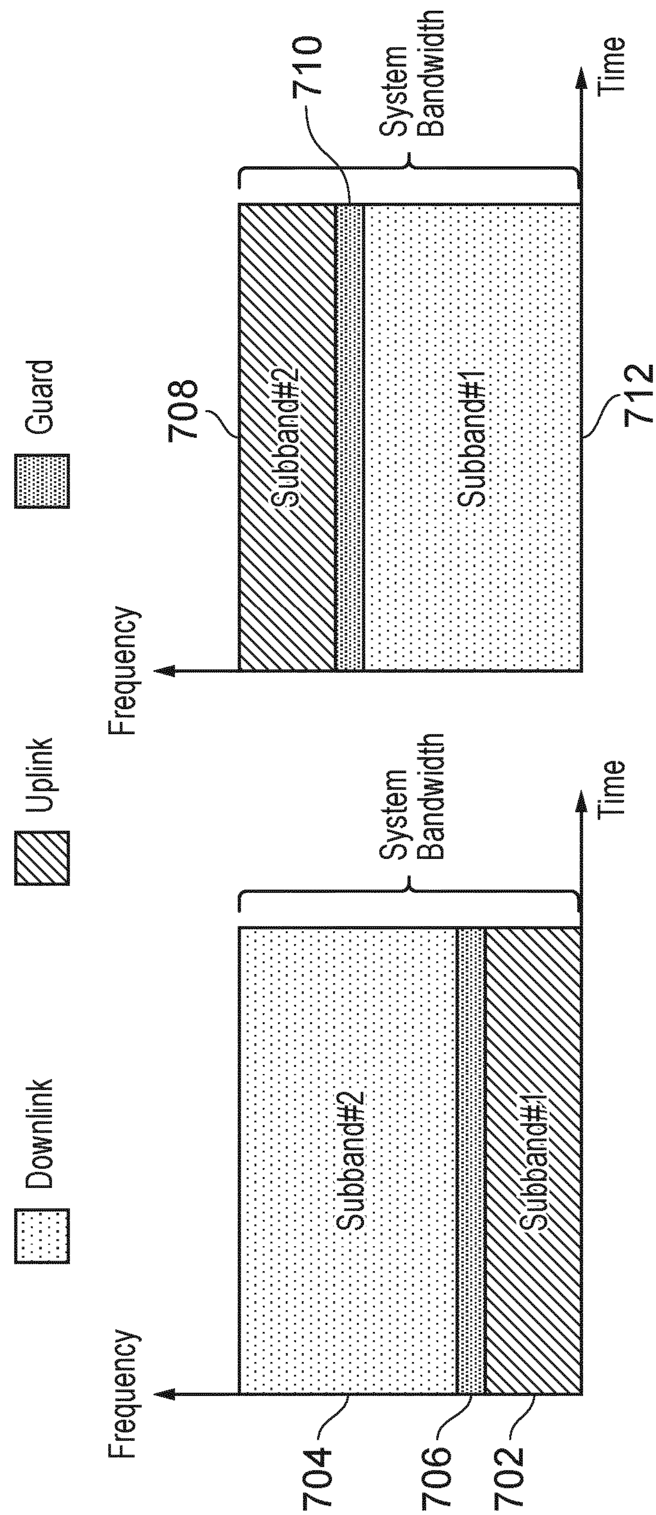

Downlink
Uplink
Guard
Frequency
Time
System Bandwidth
Subband#2
Subband#1
704
706
702
Frequency
Time
System Bandwidth
Subband#2
Subband#1
708
710
712

FIG. 7

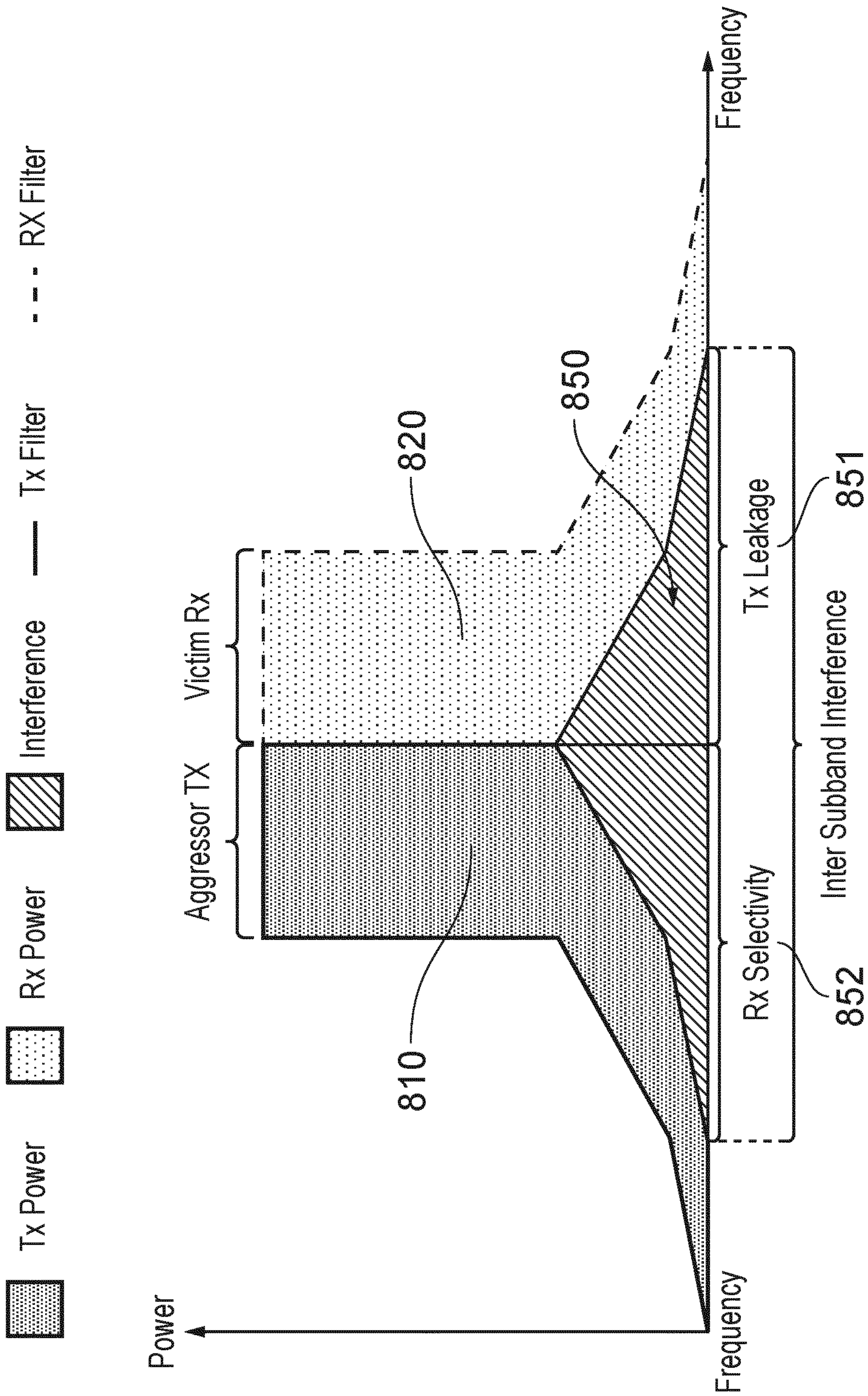

Tx Power
Rx Power
Interference
Tx Filter
RX Filter
Power
Frequency
Frequency
Aggressor TX
Victim Rx
810
820
850
Rx Selectivity
852
Tx Leakage
851
Inter Subband Interference

FIG. 8

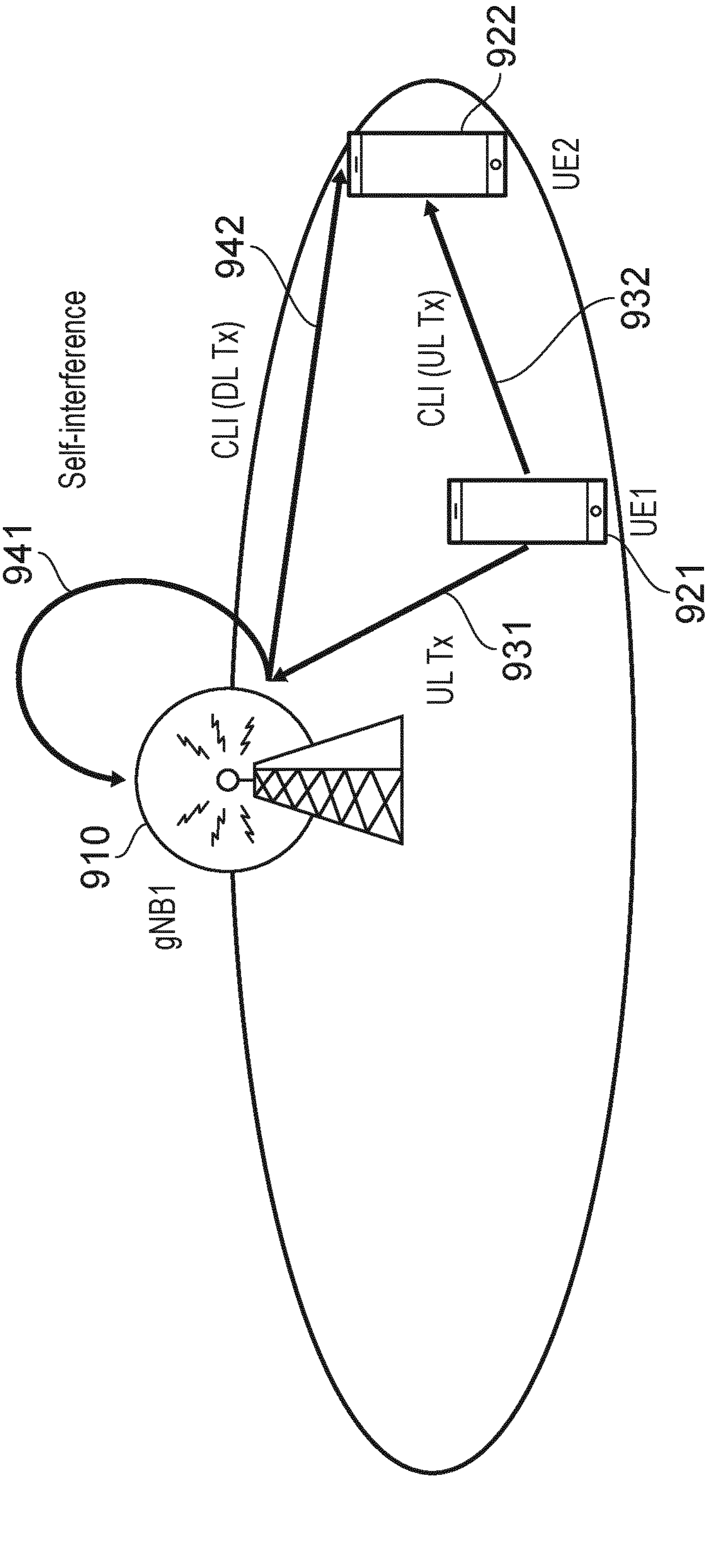

922
UE2
942
CLI (DL Tx)
Self-interference
932
CLI (UL Tx)
UE1
921
941
931
UL Tx
910
gNB1

FIG. 9

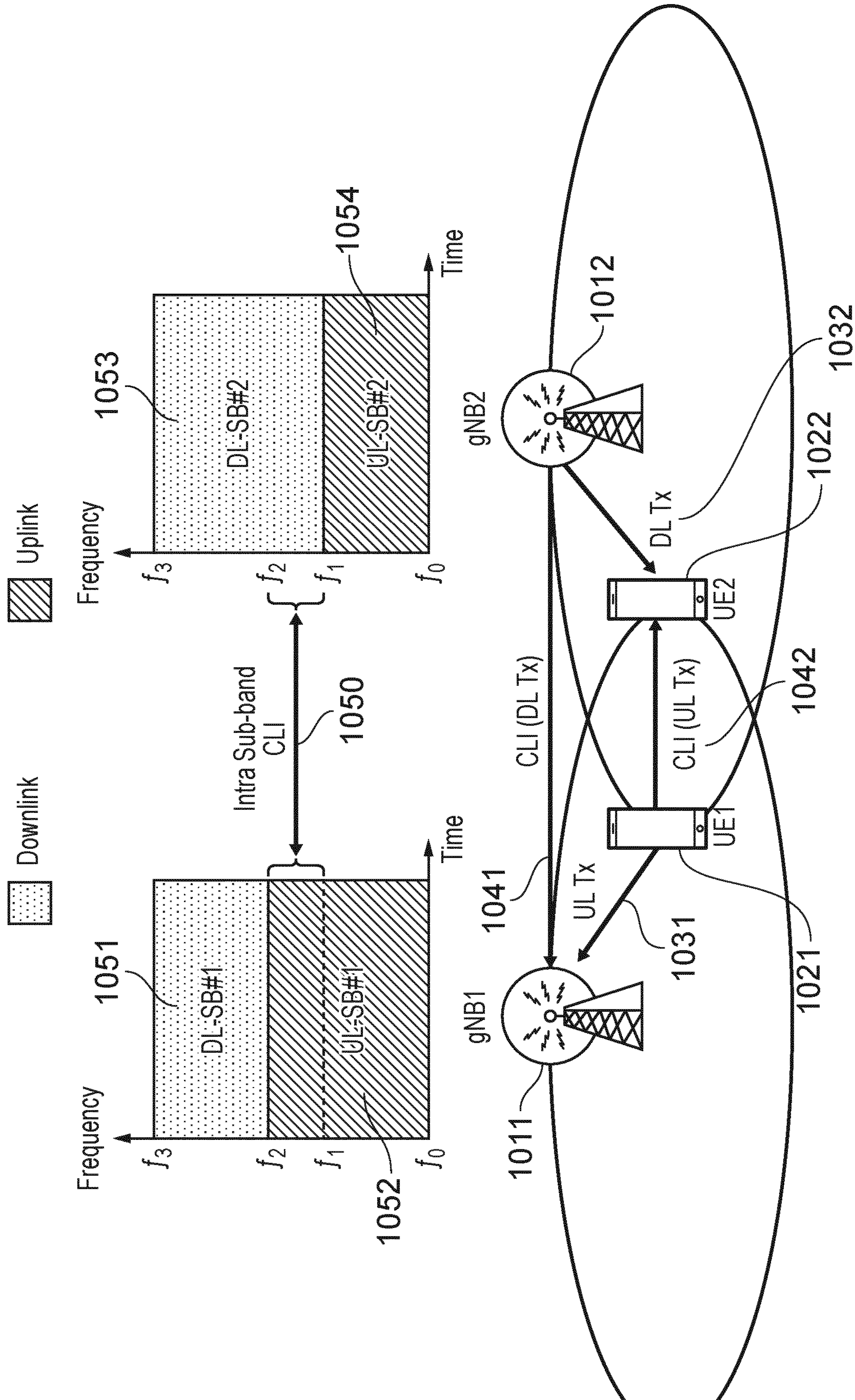
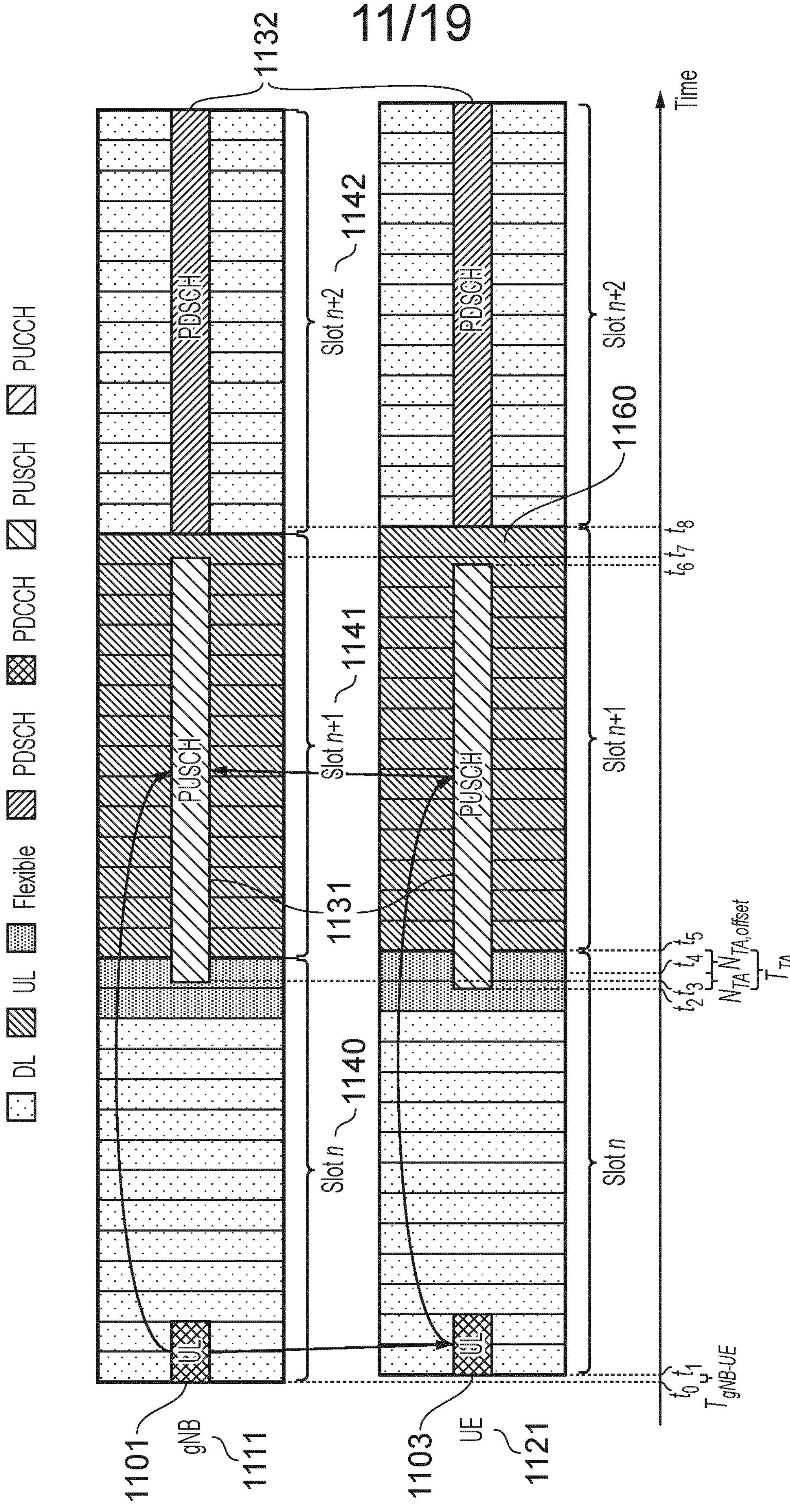

Downlink
Uplink
Frequency
Time
f_3
f_2
f_1
f_0
DL-SB#1
UL-SB#1
DL-SB#2
UL-SB#2
1051
1052
1053
1054
Intra Sub-band CLI
1050
gNB1
gNB2
UE1
UE2
UL Tx
DL Tx
CLI (DL Tx)
CLI (UL Tx)
1011
1012
1021
1022
1031
1032
1041
1042

FIG. 10



DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1132
1142
1160
1141
1131
1140
Slot n
Slot n+1
Slot n+2
PDSCH
PUSCH
UL
1101
gNB
1111
1103
UE
1121
Time
t_0 t_1
$T_{gNB\text{-}UE}$
t_2 t_3 t_4 t_5
N_{TA} $N_{TA,offset}$
T_{TA}
t_6 t_7 t_8

FIG. 11

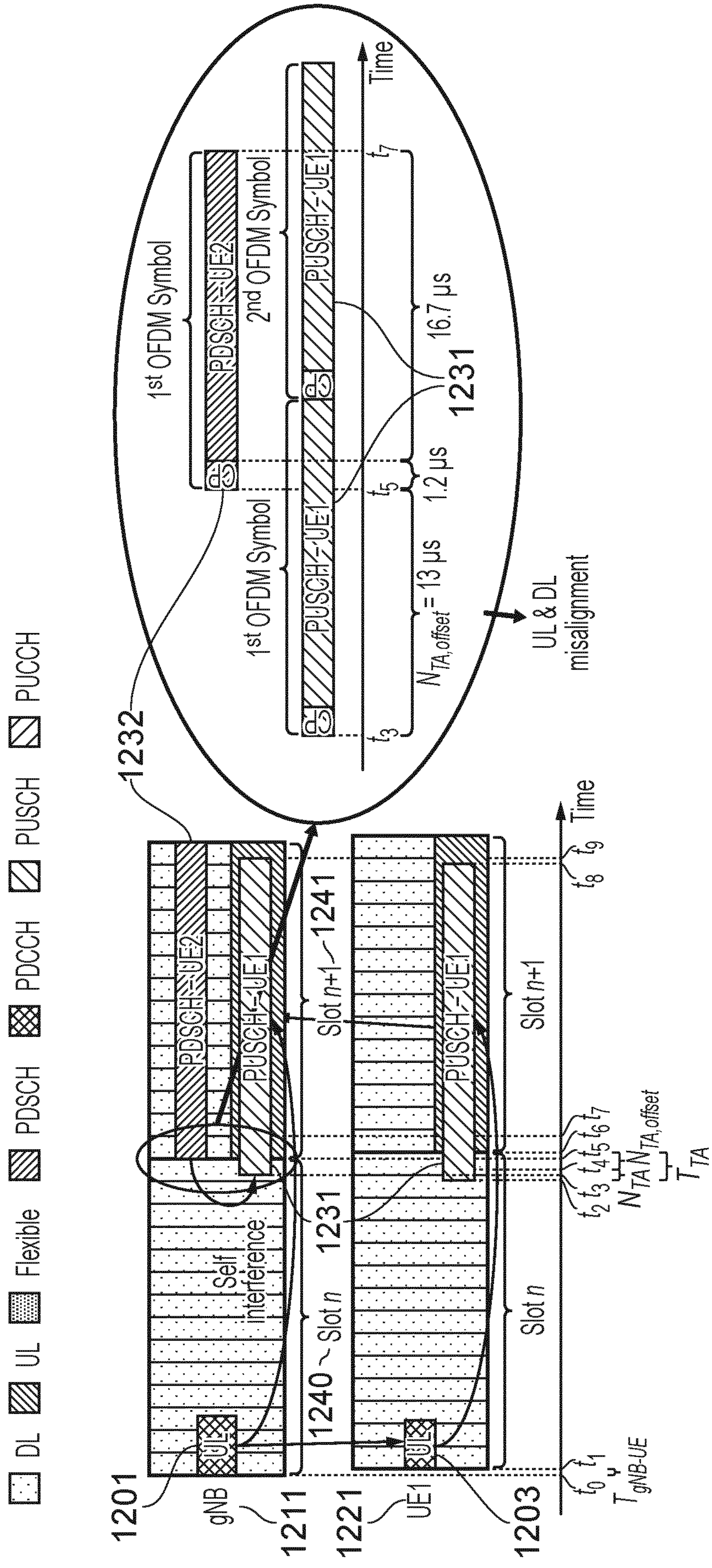

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1201
gNB
1211
1221
UE1
1203
UL
Self interference
1231
1240
Slot n
Slot n+1
1241
PDSCH - UE2
PUSCH - UE1
1232
Time
1st OFDM Symbol
2nd OFDM Symbol
N_TA,offset = 13 µs
1.2 µs
16.7 µs
UL & DL misalignment
t0 t1 t2 t3 t4 t5 t6 t7 t8 t9
T_gNB-UE
N_TA N_TA,offset
T_TA

FIG. 12

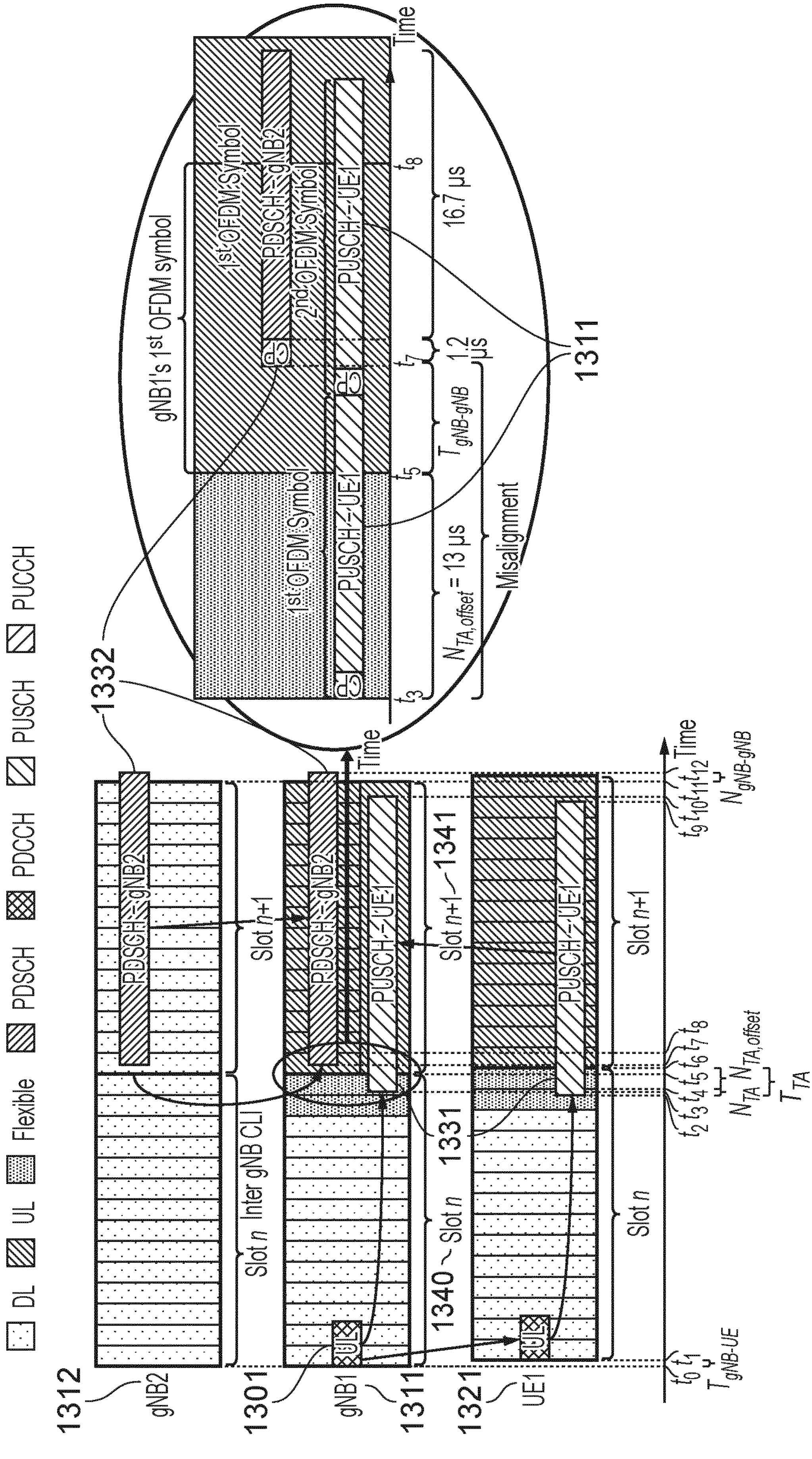

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1312
gNB2
PDSCH - gNB2
Slot n
Inter gNB CLI
Slot n+1
1301
gNB1
UL
PDSCH - gNB2
PUSCH - UE1
1340
Slot n
Slot n+1
1341
1311
1331
1321
UE1
UL
PUSCH - UE1
Slot n
Slot n+1
Time
1332
gNB1's 1st OFDM symbol
1st OFDM Symbol
PDSCH - gNB2
2nd OFDM Symbol
PUSCH - UE1
CP
16.7 μs
1.2 μs
Misalignment
1311
Time

FIG. 13

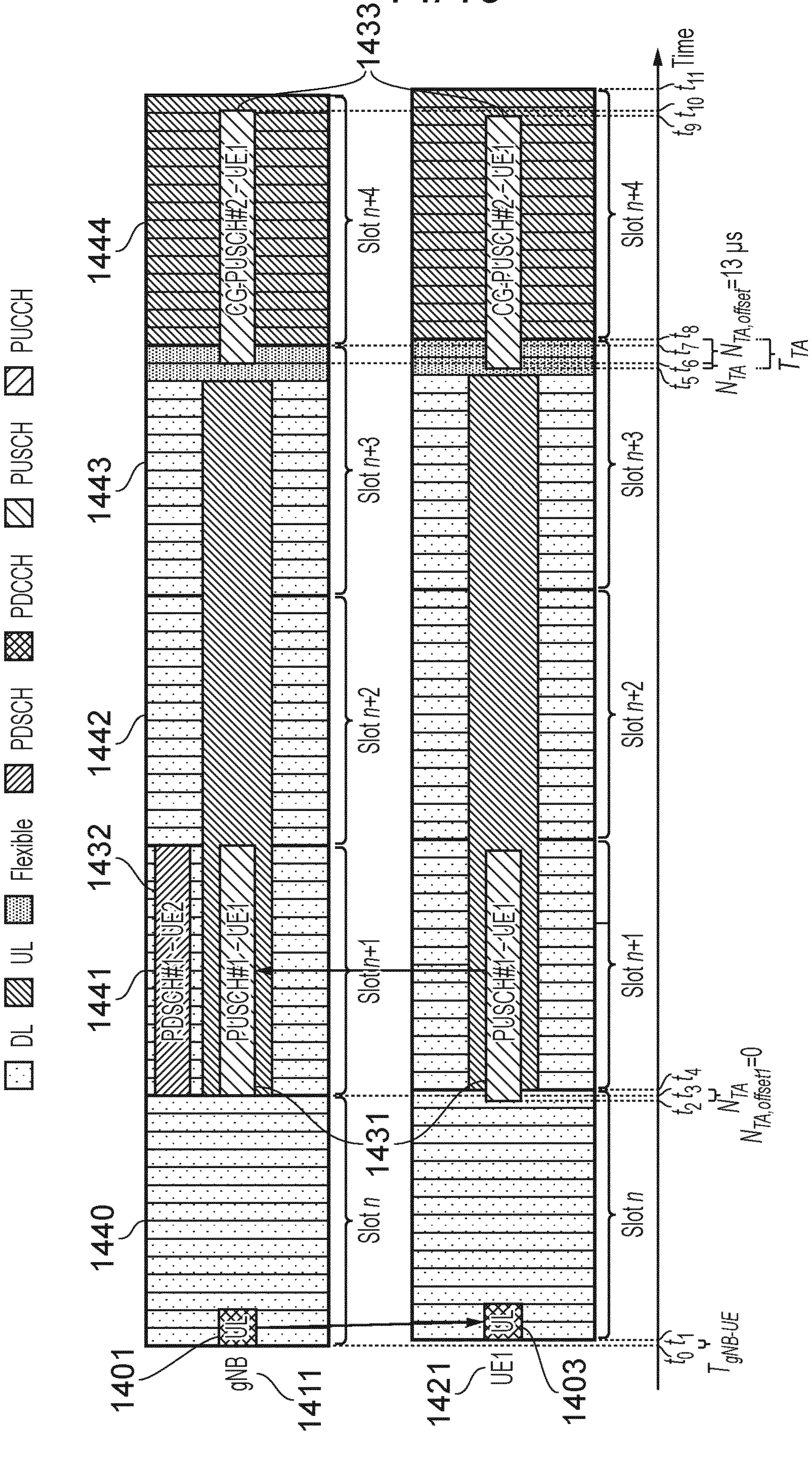

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1401
gNB
1411
1421
UE1
1403
1440
1441
1432
1442
1443
1444
1431
1433
PDSCH#1–UE2
PUSCH#1–UE1
CG-PUSCH#2–UE1
Slot n
Slot n+1
Slot n+2
Slot n+3
Slot n+4
Time
t_0 t_1
T_{gNB-UE}
t_2 t_3 t_4
N_{TA}
$N_{TA,offset1}$=0
t_5 t_6 t_7 t_8
N_{TA} $N_{TA,offset}$=13 µs
T_{TA}
t_9 t_{10} t_{11}

FIG. 14

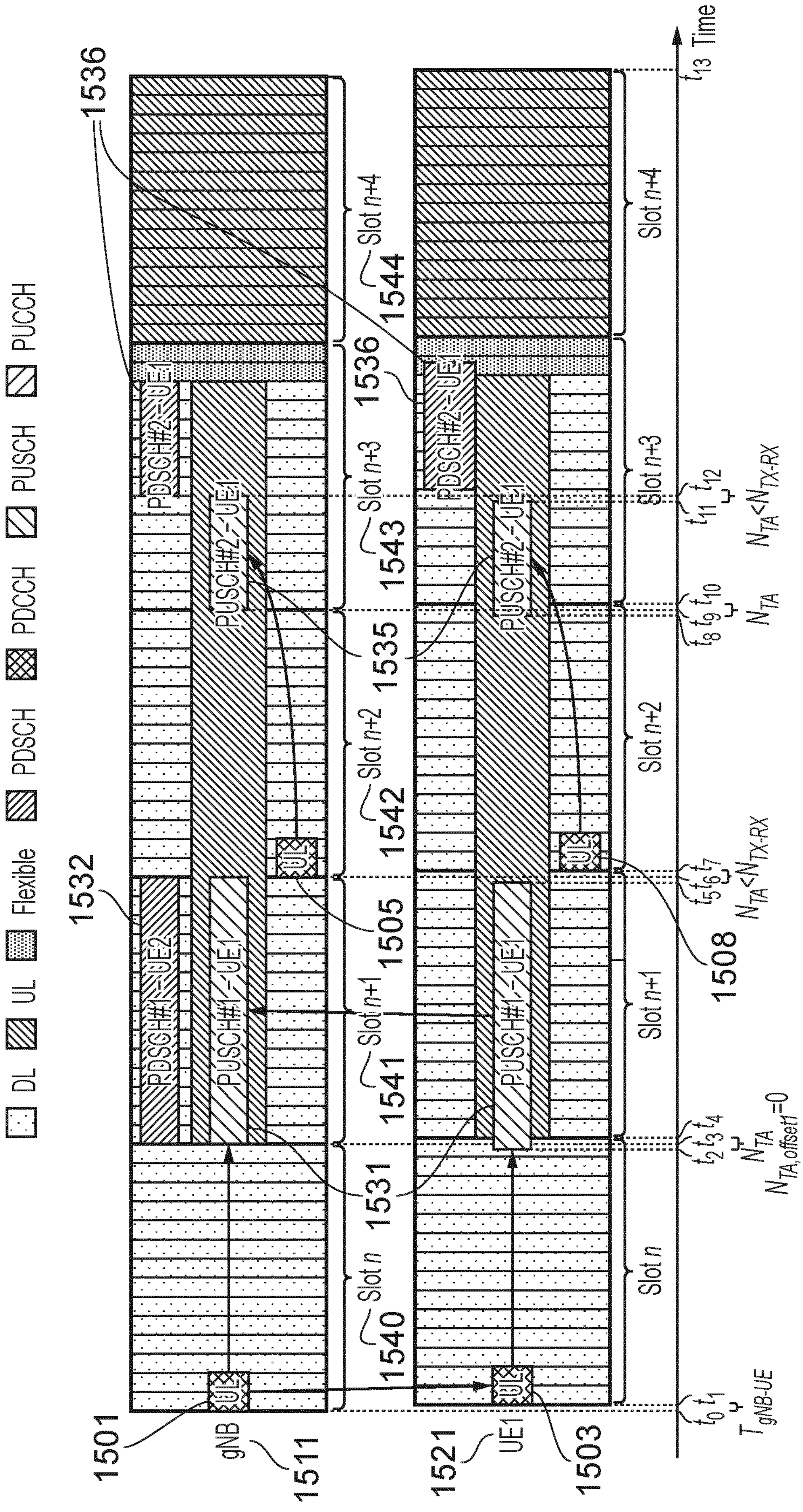

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1536
1532
1501
gNB
1511
1521
UE1
1503
UL
1540
Slot n
1531
1541
Slot n+1
1505
1508
1542
Slot n+2
1535
1543
Slot n+3
1544
Slot n+4
PDSCH#1 - UE2
PUSCH#1 - UE1
PDSCH#2 - UE1
PUSCH#2 - UE1
t0 t1
T_gNB-UE
t2 t3 t4
N_TA
N_TA,offset1=0
t5 t6 t7
N_TA<N_TX-RX
t8 t9 t10
N_TA
t11 t12
N_TA<N_TX-RX
t13 Time

FIG. 15

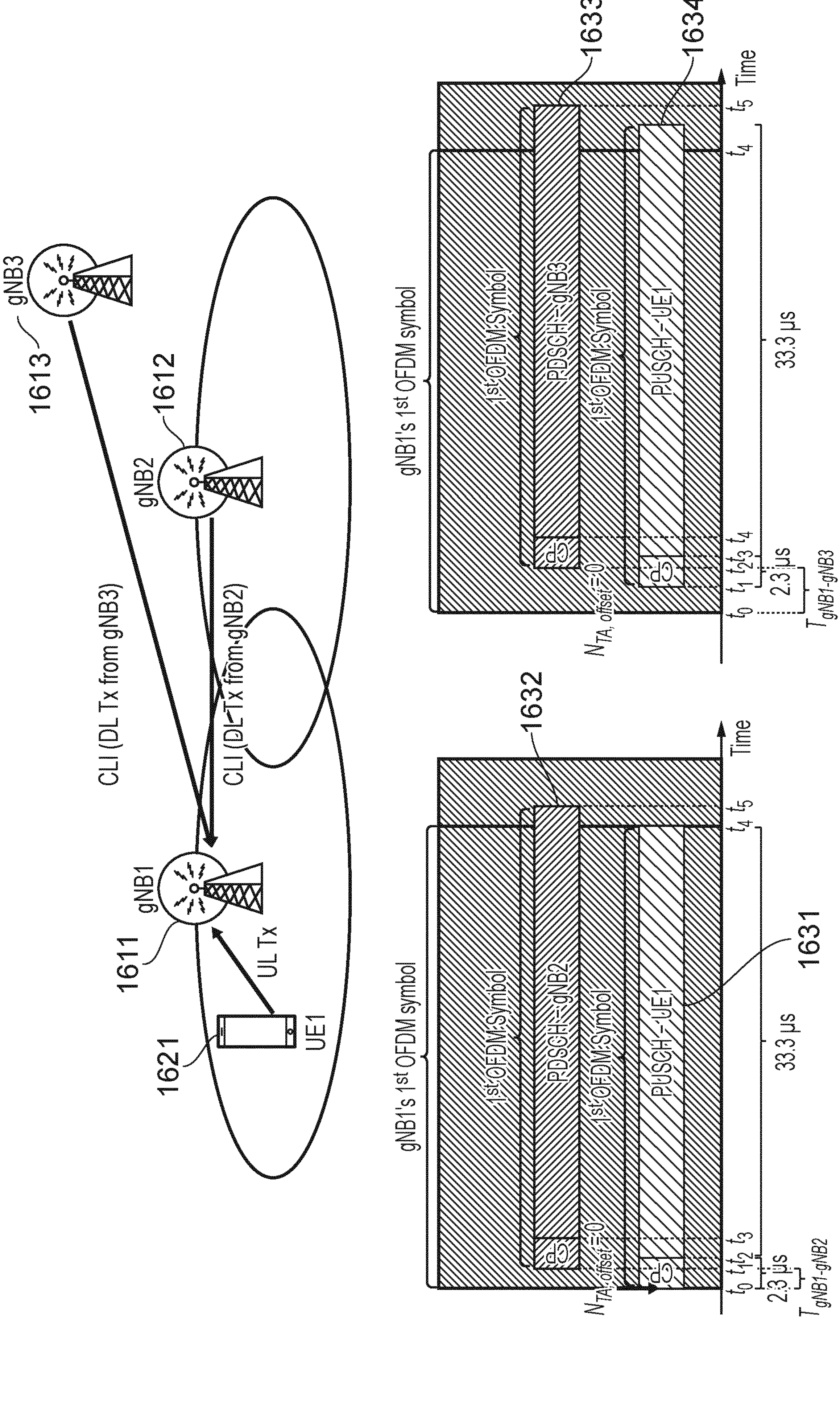

1611
1612
1613
1621
gNB1
gNB2
gNB3
UE1
UL Tx
CLI (DL Tx from gNB2)
CLI (DL Tx from gNB3)
gNB1's 1st OFDM symbol
1st OFDM Symbol
PDSCH - gNB2
PDSCH - gNB3
PUSCH - UE1
33.3 µs
2.3 µs
Time
1631
1632
1633
1634

FIG. 16

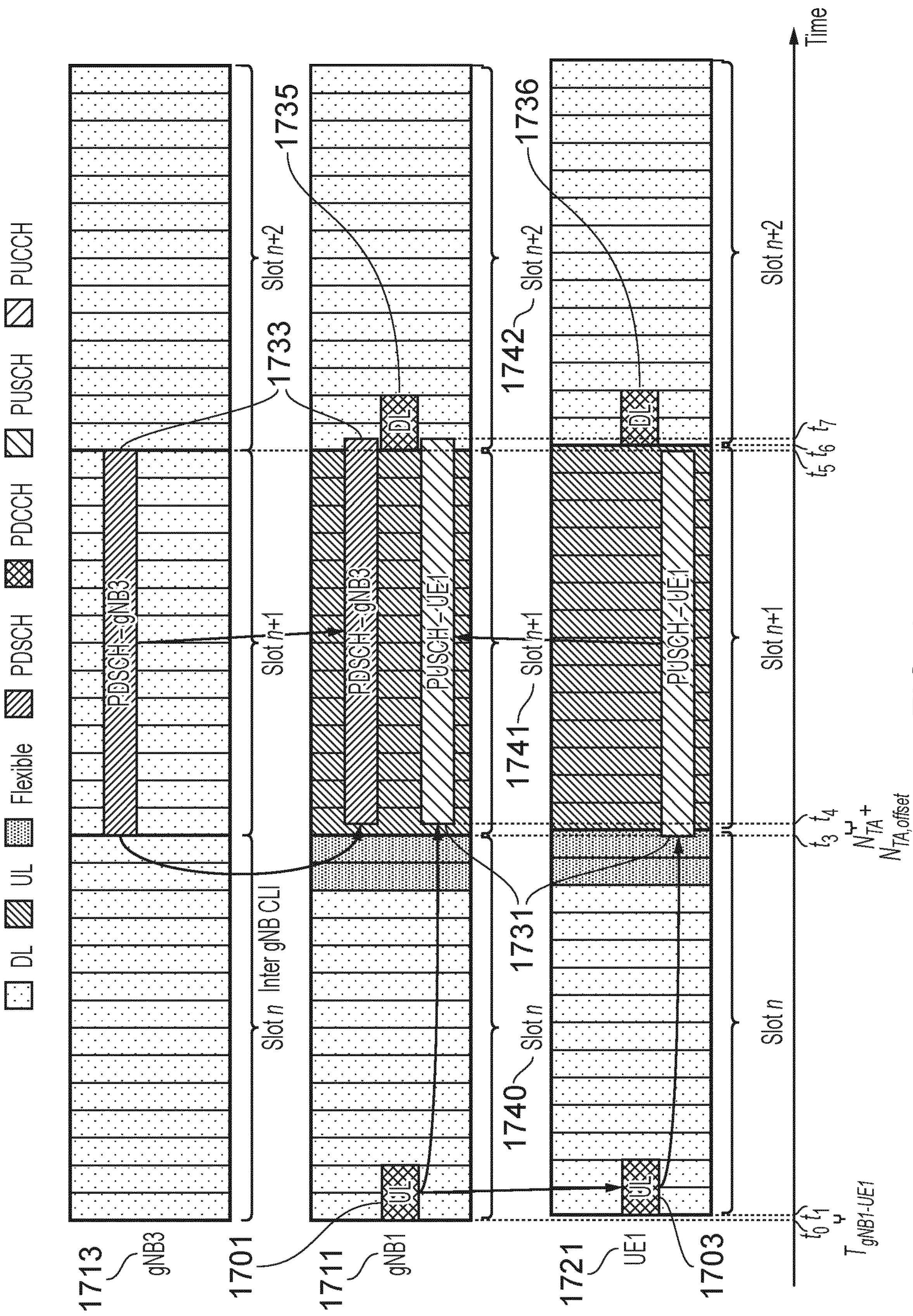

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1713
gNB3
1701
1711
gNB1
1721
UE1
1703
Slot n
Inter gNB CLI
Slot n+1
Slot n+2
PDSCH - gNB3
PUSCH - UE1
UL
DL
1731
1733
1735
1736
1740
1741
1742
Time
t_0 t_1
$T_{gNB1-UE1}$
t_3 t_4
N_{TA} +
$N_{TA,offset}$
t_5 t_6 t_7

FIG. 17

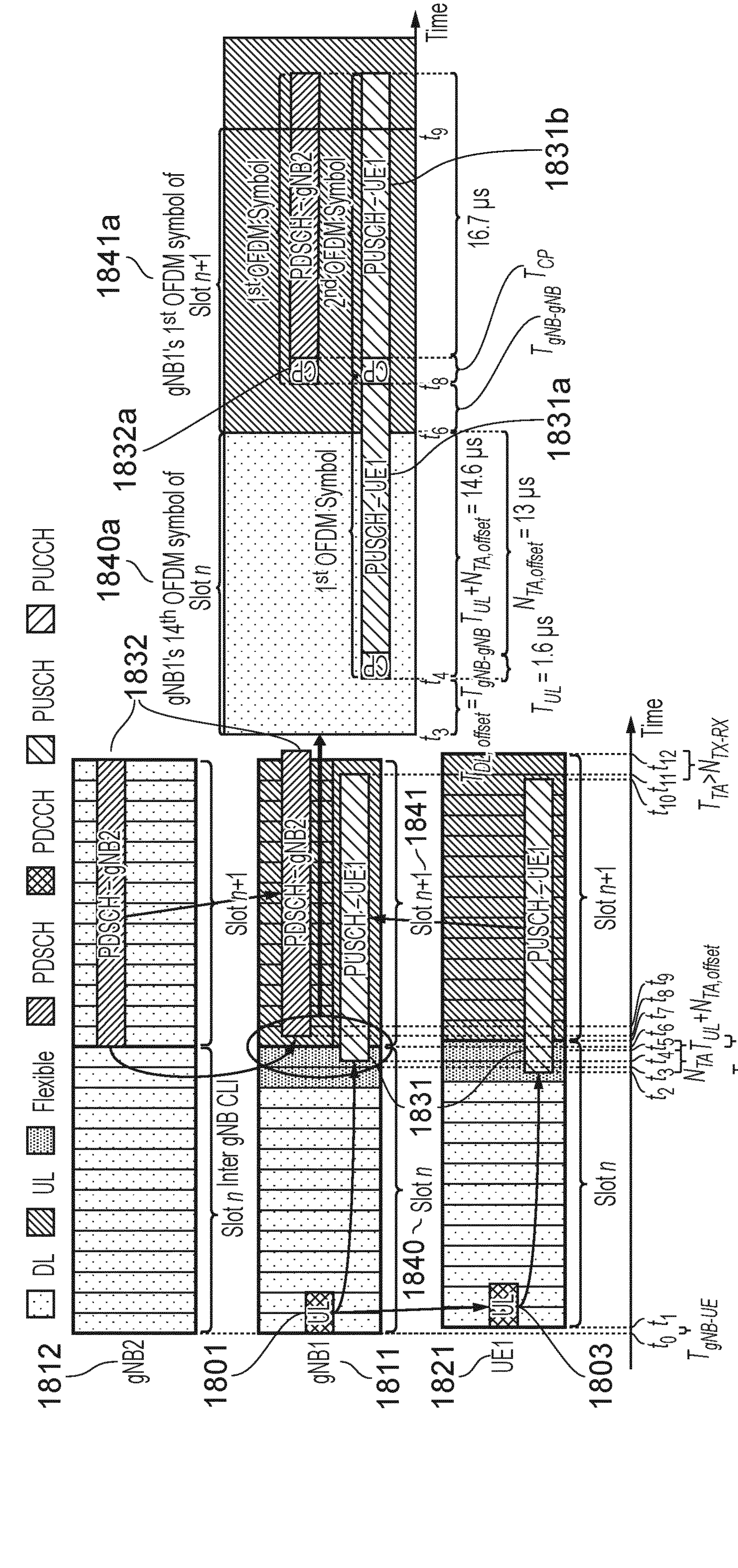

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1812
gNB2
PDSCH - gNB2
Slot n Inter gNB CLI
Slot n+1
1832
1801
gNB1
1811
1840
Slot n
1831
Slot n+1
1841
UL
PUSCH - UE1
1821
UE1
1803
Time
1840a
gNB1's 14th OFDM symbol of Slot n
1st OFDM Symbol
1832a
1841a
gNB1's 1st OFDM symbol of Slot n+1
1st OFDM Symbol
2nd OFDM Symbol
1831a
1831b
16.7 µs
$T_{gNB\text{-}gNB}$ T_{CP}
$T_{DL,offset} = T_{gNB\text{-}gNB}$ $T_{UL} + N_{TA,offset} = 14.6$ µs
$T_{UL} = 1.6$ µs $N_{TA,offset} = 13$ µs
$T_{TA} > N_{TX\text{-}RX}$
N_{TA} $T_{UL} + N_{TA,offset}$
$T_{gNB\text{-}gNB}$
$T_{gNB\text{-}UE}$

FIG. 18

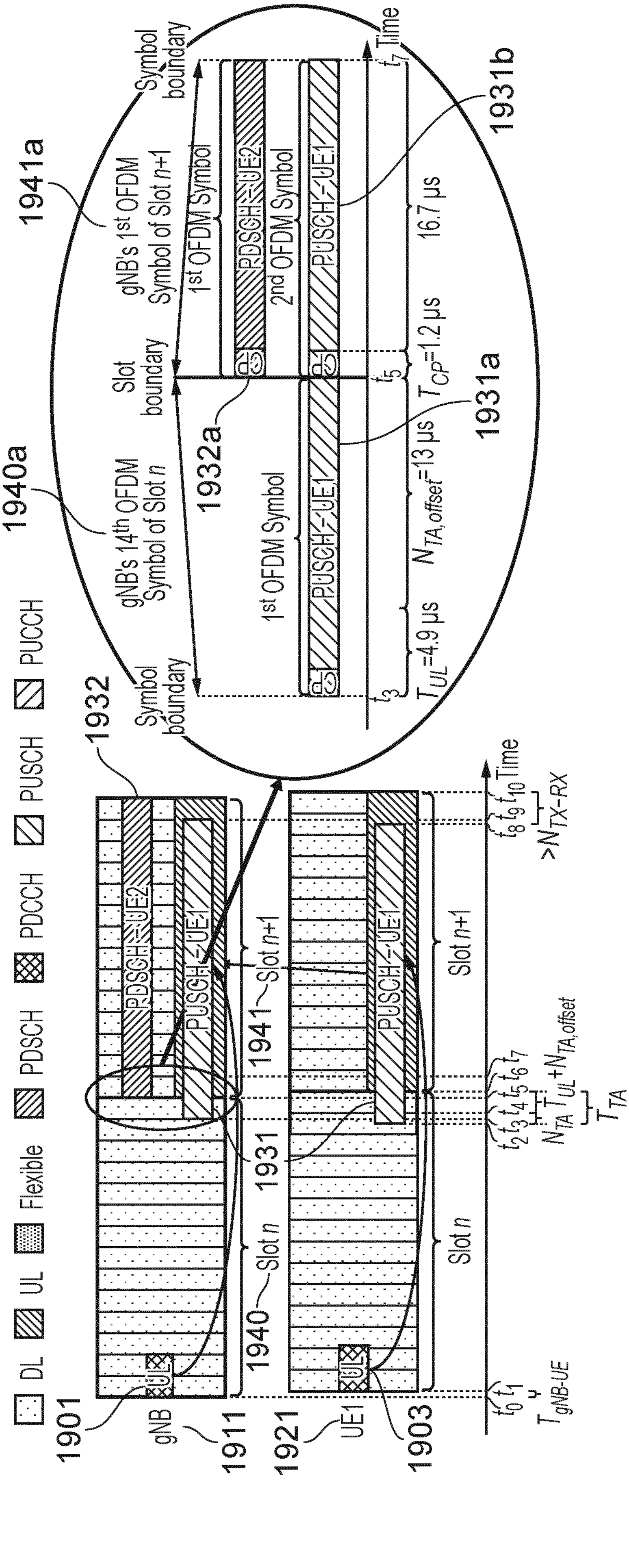

DL
UL
Flexible
PDSCH
PDCCH
PUSCH
PUCCH
1901
gNB
1911
1921
UE1
1903
UL
1940
Slot n
1931
1941
Slot n+1
1932
PDSCH - UE2
PUSCH - UE1
t_0 t_1
T_{gNB-UE}
t_2 t_3 t_4 t_5 t_6 t_7
N_{TA} T_{UL} + $N_{TA,offset}$
T_{TA}
t_8 t_9 t_{10} Time
$>N_{TX-RX}$
1940a
1941a
gNB's 14th OFDM Symbol of Slot n
gNB's 1st OFDM Symbol of Slot n+1
Symbol boundary
Slot boundary
1st OFDM Symbol
2nd OFDM Symbol
1932a
1931a
1931b
CP
T_{UL}=4.9 μs
$N_{TA,offset}$=13 μs
T_{CP}=1.2 μs
16.7 μs
t_3
t_5
t_7 Time

FIG. 19

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/053443

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W56/00 H04L5/00 H04W76/00 H04W88/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021/047769 A1 (NOKIA TECHNOLOGIES OY [FI]) 18 March 2021 (2021-03-18) pages 9-13 pages 15, 17 figures 3-8 -----	1-30
X	US 2011/171949 A1 (LIAO PEI-KAI [TW] ET AL) 14 July 2011 (2011-07-14) paragraphs [0008], [0009] paragraphs [0021] - [0041] figures 4-7 -----	1-30
	-/--	

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

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 May 2024	03/06/2024

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

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HUAWEI ET AL: "Discussion on potential enhancement on subband non-overlapping full duplex", 3GPP DRAFT; R1-2208409, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. e-Meeting; 20221010 - 20221019 30 September 2022 (2022-09-30), XP052276334, Retrieved from the Internet: URL:https://ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_110b-e/Docs/R1-2208409.zip R1-2208409.docx [retrieved on 2022-09-30] pages 1-10 -----	1-30

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/053443

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2021047769 A1	18-03-2021	NONE	
US 2011171949 A1	14-07-2011	CN 102301804 A	28-12-2011
		EP 2517510 A1	31-10-2012
		TW 201204124 A	16-01-2012
		US 2011171949 A1	14-07-2011
		WO 2011082689 A1	14-07-2011