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Receive timing difference for inter-band asynchronous NR-DC operation

Abstract

An apparatus and system of establishing receive timing difference (RTD) for high subcarrier spacing (SCS) are described. The RTD is dependent on whether carrier aggregation (CA) or dual connectivity (DC) is used. For CA, RTD reflects the entire time difference between carriers caused by a Timing Alignment Error (TAE) and propagation delay difference between slots aligned at transmission. For DC, RTD is between the closest slot boundaries and reflects only slot boundary misalignment without considering the slot index.

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Background/Summary

PRIORITY CLAIM (1) This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 63/298,080, filed Jan. 10, 2022, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD
(1) Embodiments pertain to timing in wireless communications. In particular, some embodiments relate to timing in transmissions using high subcarrier spacings (SCSs).
BACKGROUND
(2) The use and complexity of wireless systems has increased due to both an increase in the types of electronic devices using network resources as well as the amount of data and bandwidth being used by various applications, such as video streaming, operating on the electronic devices. As expected, a number of issues abound with the advent of any new technology, including complexities related to use of high frequency (FR2-2) bands for communication.

Description

BRIEF DESCRIPTION OF THE FIGURES
(1) In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The figures illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

(2) FIG. **1**A illustrates an architecture of a network, in accordance with some aspects.

(3) FIG. **1**B illustrates a non-roaming 5G system architecture in accordance with some aspects.

(4) FIG. **1**C illustrates a non-roaming 5G system architecture in accordance with some aspects.

(5) FIG. **2** illustrates a block diagram of a communication device in accordance with some embodiments.

(6) FIG. **3** illustrates a Rel-15/Rel-16 receive timing difference (RTD) definition in accordance with some embodiments.

(7) FIG. **4** illustrates a small slot length RTD in accordance with some embodiments.

DETAILED DESCRIPTION

(8) The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

(9) FIG. **1**A illustrates an architecture of a network in accordance with some aspects. The network **140**A includes 3GPP LTE/4G and NG network functions that may be extended to 6G and later generation functions. Accordingly, although 5G will be referred to, it is to be understood that this is to extend as able to 6G (and later) structures, systems, and functions. A network function can be implemented as a discrete network element on a dedicated hardware, as a software instance running on dedicated hardware, and/or as a virtualized function instantiated on an appropriate platform, e.g., dedicated hardware or a cloud infrastructure.

(10) The network **140**A is shown to include user equipment (UE) **101** and UE **102**. The UEs **101** and **102** are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks) but may also include any mobile or non-mobile computing device, such as portable (laptop) or desktop computers, wireless handsets, drones, or any other computing device including a wired and/or wireless communications interface. The UEs **101** and **102** can be collectively referred to herein as UE **101**, and UE **101** can be used to perform one or more of the techniques disclosed herein.

(11) Any of the radio links described herein (e.g., as used in the network **140**A or any other illustrated network) may operate according to any exemplary radio communication technology and/or standard. Any spectrum management scheme including, for example, dedicated licensed spectrum, unlicensed spectrum, (licensed) shared spectrum (such as Licensed Shared Access (LSA) in 2.3-2.4 GHz, 3.4-3.6 GHZ, 3.6-3.8 GHZ, and other frequencies and Spectrum Access System (SAS) in 3.55-3.7 GHZ and other frequencies). Different Single Carrier or Orthogonal Frequency Domain Multiplexing (OFDM) modes (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.), and in particular 3GPP NR, may be used by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

(12) In some aspects, any of the UEs **101** and **102** can comprise an Internet-of-Things (IoT) UE or a Cellular IoT (CIoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. In some aspects, any of the UEs **101** and **102** can include a narrowband (NB) IoT UE (e.g., such as an enhanced NB-IoT (eNB-IoT) UE and Further Enhanced (FeNB-IoT) UE). An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network includes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network. In some aspects, any of the UEs **101** and **102** can include enhanced MTC (eMTC) UEs or further

enhanced MTC (FeMTC) UEs.

(13) The UEs **101** and **102** may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) **110**. The RAN **110** may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The RAN **110** may contain one or more gNBs, one or more of which may be implemented by multiple units. Note that although gNBs may be referred to herein, the same aspects may apply to other generation NodeBs, such as 6.sup.th generation NodeBs—and thus may be alternately referred to as next generation NodeB (xNB).

(14) Each of the gNBs may implement protocol entities in the 3GPP protocol stack, in which the layers are considered to be ordered, from lowest to highest, in the order Physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Control (PDCP), and Radio Resource Control (RRC)/Service Data Adaptation Protocol (SDAP) (for the control plane/user plane). The protocol layers in each gNB may be distributed in different units—a Central Unit (CU), at least one Distributed Unit (DU), and a Remote Radio Head (RRH). The CU may provide functionalities such as the control the transfer of user data, and effect mobility control, radio access network sharing, positioning, and session management, except those functions allocated exclusively to the DU.

(15) The higher protocol layers (PDCP and RRC for the control plane/PDCP and SDAP for the user plane) may be implemented in the CU, and the RLC and MAC layers may be implemented in the DU. The PHY layer may be split, with the higher PHY layer also implemented in the DU, while the lower PHY layer is implemented in the RRH. The CU, DU and RRH may be implemented by different manufacturers, but may nevertheless be connected by the appropriate interfaces therebetween. The CU may be connected with multiple DUs.

(16) The interfaces within the gNB include the E1 and front-haul (F) F1 interface. The E1 interface may be between a CU control plane (gNB-CU-CP) and the CU user plane (gNB-CU-UP) and thus may support the exchange of signalling information between the control plane and the user plane through ELAP service. The E1 interface may separate Radio Network Layer and Transport Network Layer and enable exchange of UE associated information and non-UE associated information. The E1AP services may be non UE-associated services that are related to the entire E1 interface instance between the gNB-CU-CP and gNB-CU-UP using a non UE-associated signalling connection and UE-associated services that are related to a single UE and are associated with a UE-associated signalling connection that is maintained for the UE.

(17) The F1 interface may be disposed between the CU and the DU. The CU may control the operation of the DU over the F1 interface. As the signalling in the gNB is split into control plane and user plane signalling, the F1 interface may be split into the F1-C interface for control plane signalling between the gNB-DU and the gNB-CU-CP, and the F1-U interface for user plane signalling between the gNB-DU and the gNB-CU-UP, which support control plane and user plane separation. The F1 interface may separate the Radio Network and Transport Network Layers and enable exchange of UE associated information and non-UE associated information. In addition, an F2 interface may be between the lower and upper parts of the NR PHY layer. The F2 interface may also be separated into F2-C and F2-U interfaces based on control plane and user plane functionalities.

(18) The UEs **101** and **102** utilize connections **103** and **104**, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections **103** and **104** are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a 5G protocol, a 6G protocol, and the like.

(19) In an aspect, the UEs **101** and **102** may further directly exchange communication data via a ProSe interface **105**. The ProSe interface **105** may alternatively be referred to as a sidelink (SL) interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), a Physical Sidelink Broadcast Channel (PSBCH), and a Physical Sidelink Feedback Channel (PSFCH).

(20) The UE **102** is shown to be configured to access an access point (AP) **106** via connection **107**. The connection **107** can comprise a local wireless connection, such as, for example, a connection consistent with any IEEE 802.11 protocol, according to which the AP **106** can comprise a wireless fidelity (WiFi®) router. In this example, the AP **106** is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

(21) The RAN **110** can include one or more access nodes that enable the connections **103** and **104**. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), Next Generation NodeBs (gNBs), RAN nodes, and the like, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). In some aspects, the communication nodes **111** and **112** can be transmission-reception points (TRPs). In instances when the communication nodes **111** and **112** are NodeBs (e.g., eNBs or gNBs), one or more TRPs can function within the communication cell of the NodeBs. The RAN **110** may include one or more RAN nodes for providing macrocells, e.g., macro RAN node **111**, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node **112**.

(22) Any of the RAN nodes **111** and **112** can terminate the air interface protocol and can be the first point of contact for the UEs **101** and **102**. In some aspects, any of the RAN nodes **111** and **112** can fulfill various logical functions for the RAN **110** including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In an example, any of the nodes **111** and/or **112** can be a gNB, an eNB, or another type of RAN node.

(23) The RAN **110** is shown to be communicatively coupled to a core network (CN) **120** via an S1 interface **113**. In aspects, the CN **120** may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN (e.g., as illustrated in reference to FIGS. **1**B-**1**C). In this aspect, the S1 interface **113** is split into two parts: the S1-U interface **114**, which carries traffic data between the RAN nodes **111** and **112** and the serving gateway (S-GW) **122**, and the S1-mobility management entity (MME) interface **115**, which is a signalling interface between the RAN nodes **111** and **112** and MMEs **121**.

(24) In this aspect, the CN **120** comprises the MMEs **121**, the S-GW **122**, the Packet Data Network (PDN) Gateway (P-GW) **123**, and a home subscriber server (HSS) **124**. The MMEs **121** may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs **121** may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS **124** may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The CN **120** may comprise one or several HSSs **124**, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS **124** can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

(25) The S-GW **122** may terminate the S1 interface **113** towards the RAN **110**, and routes data packets between the RAN **110** and the CN **120**. In addition, the S-GW **122** may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities of the S-GW **122** may include a lawful intercept, charging, and some policy enforcement.

(26) The P-GW **123** may terminate an SGi interface toward a PDN. The P-GW **123** may route data packets between the CN **120** and external networks such as a network including the application server **184** (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface **125**. The P-GW **123** can also communicate data to other external networks **131**A, which can include the Internet, IP multimedia subsystem (IPS) network, and other networks. Generally, the application server **184** may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this aspect, the P-GW **123** is shown to be communicatively coupled to an application server **184** via an IP interface **125**. The application server **184** can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VOIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs **101** and **102** via the CN **120**.

(27) The P-GW **123** may further be a node for policy enforcement and charging data collection. Policy and Charging Rules Function (PCRF) **126** is the policy and charging control element of the CN **120**. In a non-roaming scenario, in some aspects, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with a local breakout of traffic, there may be two PCRFs associated with a UE's IP-CAN session: a Home PCRF (H-PCRF) within an HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF **126** may be communicatively coupled to the application server **184** via the P-GW **123**.

(28) In some aspects, the communication network **140**A can be an IoT network or a 5G or 6G network, including 5G new radio network using communications in the licensed (5G NR) and the unlicensed (5G NR-U) spectrum. One of the current enablers of IoT is the narrowband-IoT (NB-IoT). Operation in the unlicensed spectrum may include dual connectivity (DC) operation and the standalone LTE system in the unlicensed spectrum, according to which LTE-based technology solely operates in unlicensed spectrum without the use of an "anchor" in the licensed spectrum, called MulteFire. Further enhanced operation of LTE systems in the licensed as well as unlicensed spectrum is expected in future releases and 5G systems. Such enhanced operations can include techniques for sidelink resource allocation and UE processing behaviors for NR sidelink V2X communications.

(29) An NG system architecture (or 6G system architecture) can include the RAN **110** and a core network (CN) **120**. The NG-RAN **110** can include a plurality of nodes, such as gNBs and NG-eNBs. The CN **120** (e.g., a 5G core network (5GC)) can include an access and mobility function (AMF) and/or a user plane function (UPF). The AMF and the UPF can be communicatively coupled to the gNBs and the NG-eNBs via NG interfaces. More specifically, in some aspects, the gNBs and the NG-eNBs can be connected to the AMF by NG-C interfaces, and to the UPF by NG-U interfaces. The gNBs and the NG-eNBs can be coupled to each other via Xn interfaces.

(30) In some aspects, the NG system architecture can use reference points between various nodes. In some aspects, each of the gNBs and the NG-eNBs can be implemented as a base station, a mobile edge server, a small cell, a home eNB, and so forth. In some aspects, a gNB can be a master node (MN) and NG-eNB can be a secondary node (SN) in a 5G architecture.

(31) FIG. **1**B illustrates a non-roaming 5G system architecture in accordance with some aspects. In particular, FIG. **1**B illustrates a 5G system architecture **140**B in a reference point representation, which may be extended to a 6G system architecture. More specifically, UE **102** can be in communication with RAN **110** as well as one or more other CN network entities. The 5G system architecture **140**B includes a plurality of network functions (NFs), such as an AMF **132**, session management function (SMF) **136**, policy control function (PCF) **148**, application function (AF) **150**, UPF **134**, network slice selection function (NSSF) **142**, authentication server function (AUSF) **144**, and unified data management (UDM)/home subscriber server (HSS) **146**.

(32) The UPF **134** can provide a connection to a data network (DN) **152**, which can include, for example, operator services, Internet access, or third-party services. The AMF **132** can be used to

manage access control and mobility and can also include network slice selection functionality. The AMF **132** may provide UE-based authentication, authorization, mobility management, etc., and may be independent of the access technologies. The SMF **136** can be configured to set up and manage various sessions according to network policy. The SMF **136** may thus be responsible for session management and allocation of IP addresses to UEs. The SMF **136** may also select and control the UPF **134** for data transfer. The SMF **136** may be associated with a single session of a UE **101** or multiple sessions of the UE **101**. This is to say that the UE **101** may have multiple 5G sessions. Different SMFs may be allocated to each session. The use of different SMFs may permit each session to be individually managed. As a consequence, the functionalities of each session may be independent of each other.

(33) The UPF **134** can be deployed in one or more configurations according to the desired service type and may be connected with a data network. The PCF **148** can be configured to provide a policy framework using network slicing, mobility management, and roaming (similar to PCRF in a 4G communication system). The UDM can be configured to store subscriber profiles and data (similar to an HSS in a 4G communication system).

(34) The AF **150** may provide information on the packet flow to the PCF **148** responsible for policy control to support a desired QoS. The PCF **148** may set mobility and session management policies for the UE **101**. To this end, the PCF **148** may use the packet flow information to determine the appropriate policies for proper operation of the AMF **132** and SMF **136**. The AUSF **144** may store data for UE authentication.

(35) In some aspects, the 5G system architecture **140**B includes an IP multimedia subsystem (IMS) **168**B as well as a plurality of IP multimedia core network subsystem entities, such as call session control functions (CSCFs). More specifically, the IMS **168**B includes a CSCF, which can act as a proxy CSCF (P-CSCF) **162**BE, a serving CSCF (S-CSCF) **164**B, an emergency CSCF (E-CSCF) (not illustrated in FIG. **1**B), or interrogating CSCF (I-CSCF) **166**B. The P-CSCF **162**B can be configured to be the first contact point for the UE **102** within the IM subsystem (IMS) **168**B. The S-CSCF **164**B can be configured to handle the session states in the network, and the E-CSCF can be configured to handle certain aspects of emergency sessions such as routing an emergency request to the correct emergency center or PSAP. The I-CSCF **166**B can be configured to function as the contact point within an operator's network for all IMS connections destined to a subscriber of that network operator, or a roaming subscriber currently located within that network operator's service area. In some aspects, the I-CSCF **166**B can be connected to another IP multimedia network **170**B, e.g. an IMS operated by a different network operator.

(36) In some aspects, the UDM/HSS **146** can be coupled to an application server (AS) **160**B, which can include a telephony application server (TAS) or another application server. The AS **160**B can be coupled to the IMS **168**B via the S-CSCF **164**B or the I-CSCF **166**B.

(37) A reference point representation shows that interaction can exist between corresponding NF services. For example, FIG. **1**B illustrates the following reference points: N1 (between the UE **102** and the AMF **132**), N2 (between the RAN **110** and the AMF **132**), N3 (between the RAN **110** and the UPF **134**), N4 (between the SMF **136** and the UPF **134**), N5 (between the PCF **148** and the AF **150**, not shown), N6 (between the UPF **134** and the DN **152**), N7 (between the SMF **136** and the PCF **148**, not shown), N8 (between the UDM **146** and the AMF **132**, not shown), N9 (between two UPFs **134**, not shown), N10 (between the UDM **146** and the SMF **136**, not shown), N11 (between the AMF **132** and the SMF **136**, not shown), N12 (between the AUSF **144** and the AMF **132**, not shown), N13 (between the AUSF **144** and the UDM **146**, not shown), N14 (between two AMFs **132**, not shown), N15 (between the PCF **148** and the AMF **132** in case of a non-roaming scenario, or between the PCF **148** and a visited network and AMF **132** in case of a roaming scenario, not shown), N16 (between two SMFs, not shown), and N22 (between AMF **132** and NSSF **142**, not shown). Other reference point representations not shown in FIG. **1**B can also be used.

(38) FIG. **1**C illustrates a 5G system architecture **140**C and a service-based representation. In

addition to the network entities illustrated in FIG. **1**B, system architecture **140**C can also include a network exposure function (NEF) **154** and a network repository function (NRF) **156**. In some aspects, 5G system architectures can be service-based and interaction between network functions can be represented by corresponding point-to-point reference points Ni or as service-based interfaces.

(39) In some aspects, as illustrated in FIG. **1**C, service-based representations can be used to represent network functions within the control plane that enable other authorized network functions to access their services. In this regard, 5G system architecture **140**C can include the following service-based interfaces: Namf **158**H (a service-based interface exhibited by the AMF **132**), Nsmf **158**I (a service-based interface exhibited by the SMF **136**), Nnef **158**B (a service-based interface exhibited by the NEF **154**), Npcf **158**D (a service-based interface exhibited by the PCF **148**), a Nudm **158**E (a service-based interface exhibited by the UDM **146**), Naf **158**F (a service-based interface exhibited by the AF **150**), Nnrf **158**C (a service-based interface exhibited by the NRF **156**), Nnssf **158**A (a service-based interface exhibited by the NSSF **142**), Nausf 158G (a service-based interface exhibited by the AUSF **144**). Other service-based interfaces (e.g., Nudr, N5g-eir, and Nudsf) not shown in FIG. **1**C can also be used.

(40) NR-V2X architectures may support high-reliability low latency sidelink communications with a variety of traffic patterns, including periodic and aperiodic communications with random packet arrival time and size. Techniques disclosed herein can be used for supporting high reliability in distributed communication systems with dynamic topologies, including sidelink NR V2X communication systems.

(41) FIG. **2** illustrates a block diagram of a communication device in accordance with some embodiments. The communication device **200** may be a UE such as a specialized computer, a personal or laptop computer (PC), a tablet PC, or a smart phone, dedicated network equipment such as an eNB, a server running software to configure the server to operate as a network device, a virtual device, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. For example, the communication device **200** may be implemented as one or more of the devices shown in FIGS. **1**A-**1**C. Note that communications described herein may be encoded before transmission by the transmitting entity (e.g., UE, gNB) for reception by the receiving entity (e.g., gNB, UE) and decoded after reception by the receiving entity.

(42) Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules and components are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

(43) Accordingly, the term "module" (and "component") is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example,

to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

(44) The communication device **200** may include a hardware processor (or equivalently processing circuitry) **202** (e.g., a central processing unit (CPU), a GPU, a hardware processor core, or any combination thereof), a main memory **204** and a static memory **206**, some or all of which may communicate with each other via an interlink (e.g., bus) **208**. The main memory **204** may contain any or all of removable storage and non-removable storage, volatile memory or non-volatile memory. The communication device **200** may further include a display unit **210** such as a video display, an alphanumeric input device **212** (e.g., a keyboard), and a user interface (UI) navigation device **214** (e.g., a mouse). In an example, the display unit **210**, input device **212** and UI navigation device **214** may be a touch screen display. The communication device **200** may additionally include a storage device (e.g., drive unit) **216**, a signal generation device **218** (e.g., a speaker), a network interface device **220**, and one or more sensors, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device **200** may further include an output controller, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

(45) The storage device **216** may include a non-transitory machine readable medium **222** (hereinafter simply referred to as machine readable medium) on which is stored one or more sets of data structures or instructions **224** (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions **224** may also reside, completely or at least partially, within the main memory **204**, within static memory **206**, and/or within the hardware processor **202** during execution thereof by the communication device **200**. While the machine readable medium **222** is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions **224**.

(46) The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the communication device **200** and that cause the communication device **200** to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks.

(47) The instructions **224** may further be transmitted or received over a communications network using a transmission medium **226** via the network interface device **220** utilizing any one of a number of wireless local area network (WLAN) transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks. Communications over the networks may include one or more different protocols, such as Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi, IEEE 802.16 family of standards known as WiMax, IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, a next generation (NG)/5th generation (5G) standards among others. In an example, the network interface device **220** may include one or

more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the transmission medium **226**.

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

(49) The term "processor circuitry" or "processor" as used herein thus refers to, is part of, or includes circuitry capable of sequentially and automatically carrying out a sequence of arithmetic or logical operations, or recording, storing, and/or transferring digital data. The term "processor circuitry" or "processor" may refer to one or more application processors, one or more baseband processors, a physical central processing unit (CPU), a single- or multi-core processor, and/or any other device capable of executing or otherwise operating computer-executable instructions, such as program code, software modules, and/or functional processes.

(50) Any of the radio links described herein may operate according to any one or more of the following radio communication technologies and/or standards including but not limited to: a Global System for Mobile Communications (GSM) radio communication technology, a General Packet Radio Service (GPRS) radio communication technology, an Enhanced Data Rates for GSM Evolution (EDGE) radio communication technology, and/or a Third Generation Partnership Project (3GPP) radio communication technology, for example Universal Mobile Telecommunications System (UMTS), Freedom of Multimedia Access (FOMA), 3GPP Long Term Evolution (LTE), 3GPP Long Term Evolution Advanced (LTE Advanced), Code division multiple access 2000 (CDMA2000), Cellular Digital Packet Data (CDPD), Mobitex, Third Generation (3G), Circuit Switched Data (CSD), High-Speed Circuit-Switched Data (HSCSD), Universal Mobile Telecommunications System (Third Generation) (UMTS (3G)), Wideband Code Division Multiple Access (Universal Mobile Telecommunications System) (W-CDMA (UMTS)), High Speed Packet Access (HSPA), High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA), High Speed Packet Access Plus (HSPA+), Universal Mobile Telecommunications System-Time-Division Duplex (UMTS-TDD), Time Division-Code Division Multiple Access (TD-CDMA), Time Division-Synchronous Code Division Multiple Access (TD-CDMA), 3rd Generation Partnership Project Release 8 (Pre-4th Generation) (3GPP Rel. 8 (Pre-4G)), 3GPP Rel. 9 (3rd Generation Partnership Project Release 9), 3GPP Rel. 10 (3rd Generation Partnership Project Release 10), 3GPP Rel. 11 (3rd Generation Partnership Project Release 11), 3GPP Rel. 12 (3rd Generation Partnership Project Release 12), 3GPP Rel. 13 (3rd Generation Partnership Project Release 13), 3GPP Rel. 14 (3rd Generation Partnership Project Release 14), 3GPP Rel. 15 (3rd Generation Partnership Project Release 15), 3GPP Rel. 16 (3rd Generation Partnership Project Release 16), 3GPP Rel. 17 (3rd Generation Partnership Project Release 17) and subsequent Releases (such as Rel. 18, Rel. 19, etc.), 3GPP 5G, 5G, 5G New Radio (5G NR), 3GPP 5G New Radio, 3GPP LTE Extra, LTE-Advanced Pro, LTE Licensed-Assisted Access (LAA), MuLTEfire, UMTS Terrestrial Radio Access (UTRA), Evolved UMTS Terrestrial Radio Access (E-UTRA), Long Term Evolution Advanced (4th Generation) (LTE Advanced (4G)), cdmaOne (2G), Code division multiple access 2000 (Third generation) (CDMA2000 (3G)), Evolution-Data Optimized or Evolution-Data Only (EV-DO), Advanced Mobile Phone System (1st Generation)

(AMPS (1G)), Total Access Communication System/Extended Total Access Communication System (TACS/ETACS), Digital AMPS (2nd Generation) (D-AMPS (2G)), Push-to-talk (PTT), Mobile Telephone System (MTS), Improved Mobile Telephone System (IMTS), Advanced Mobile Telephone System (AMTS), OLT (Norwegian for Offentlig Landmobil Telefoni, Public Land Mobile Telephony), MTD (Swedish abbreviation for Mobiltelefonisystem D, or Mobile telephony system D), Public Automated Land Mobile (Autotel/PALM), ARP (Finnish for Autoradiopuhelin, "car radio phone"), NMT (Nordic Mobile Telephony), High capacity version of NTT (Nippon Telegraph and Telephone) (Hicap), Cellular Digital Packet Data (CDPD), Mobitex, DataTAC, Integrated Digital Enhanced Network (iDEN), Personal Digital Cellular (PDC), Circuit Switched Data (CSD), Personal Handy-phone System (PHS), Wideband Integrated Digital Enhanced Network (WiDEN), iBurst, Unlicensed Mobile Access (UMA), also referred to as also referred to as 3GPP Generic Access Network, or GAN standard), Zigbee, Bluetooth®, Wireless Gigabit Alliance (WiGig) standard, mmWave standards in general (wireless systems operating at 10-300 GHz and above such as WiGig, IEEE 802.11ad, IEEE 802.11ay, etc.), technologies operating above 300 GHz and THz bands, (3GPP/LTE based or IEEE 802.11p or IEEE 802.11bd and other) Vehicle-to-Vehicle (V2V) and Vehicle-to-X (V2X) and Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Vehicle (12V) communication technologies, 3GPP cellular V2X, DSRC (Dedicated Short Range Communications) communication systems such as Intelligent-Transport-Systems and others (typically operating in 5850 MHz to 5925 MHz or above (typically up to 5935 MHz following change proposals in CEPT Report 71)), the European ITS-G5 system (i.e. the European flavor of IEEE 802.11p based DSRC, including ITS-G5A (i.e., Operation of ITS-G5 in European ITS frequency bands dedicated to ITS for safety re-lated applications in the frequency range 5,875 GHz to 5,905 GHZ), ITS-G5B (i.e., Operation in European ITS frequency bands dedicated to ITS non-safety applications in the frequency range 5,855 GHz to 5,875 GHZ), ITS-G5C (i.e., Operation of ITS applications in the frequency range 5,470 GHz to 5,725 GHZ)), DSRC in Japan in the 700 MHz band (including 715 MHz to 725 MHz), IEEE 802.11bd based systems, etc.

(51) Aspects described herein can be used in the context of any spectrum management scheme including dedicated licensed spectrum, unlicensed spectrum, license exempt spectrum, (licensed) shared spectrum (such as LSA=Licensed Shared Access in 2.3-2.4 GHz, 3.4-3.6 GHZ, 3.6-3.8 GHz and further frequencies and SAS=Spectrum Access System/CBRS=Citizen Broadband Radio System in 3.55-3.7 GHZ and further frequencies). Applicable spectrum bands include IMT (International Mobile Telecommunications) spectrum as well as other types of spectrum/bands, such as bands with national allocation (including 450-470 MHz, 902-928 MHz (note: allocated for example in US (FCC Part 15)), 863-868.6 MHz (note: allocated for example in European Union (ETSI EN 300 220)), 915.9-929.7 MHz (note: allocated for example in Japan), 917-923.5 MHz (note: allocated for example in South Korea), 755-779 MHz and 779-787 MHz (note: allocated for example in China), 790-960 MHz, 1710-2025 MHz, 2110-2200 MHz, 2300-2400 MHz, 2.4-2.4835 GHz (note: it is an ISM band with global availability and it is used by Wi-Fi technology family (11b/g/n/ax) and also by Bluetooth), 2500-2690 MHz, 698-790 MHz, 610-790 MHz, 3400-3600 MHz, 3400-3800 MHz, 3800-4200 MHz, 3.55-3.7 GHZ (note: allocated for example in the US for Citizen Broadband Radio Service), 5.15-5.25 GHz and 5.25-5.35 GHz and 5.47-5.725 GHz and 5.725-5.85 GHz bands (note: allocated for example in the US (FCC part 15), consists four U-NII bands in total 500 MHz spectrum), 5.725-5.875 GHz (note: allocated for example in EU (ETSI EN 301 893)), 5.47-5.65 GHz (note: allocated for example in South Korea, 5925-7125 MHz and 5925-6425 MHz band (note: under consideration in US and EU, respectively. Next generation Wi-Fi system is expected to include the 6 GHz spectrum as operating band but it is noted that, as of December 2017, Wi-Fi system is not yet allowed in this band. Regulation is expected to be finished in 2019-2020 time frame), IMT-advanced spectrum, IMT-2020 spectrum (expected to include 3600-3800 MHz, 3800-4200 MHz, 3.5 GHz bands, 700 MHz bands, bands within the 24.25-86

GHz range, etc.), spectrum made available under FCC's "Spectrum Frontier" 5G initiative (including 27.5-28.35 GHZ, 29.1-29.25 GHZ, 31-31.3 GHZ, 37-38.6 GHZ, 38.6-40 GHz, 42-42.5 GHZ, 57-64 GHz, 71-76 GHZ, 81-86 GHz and 92-94 GHZ, etc), the ITS (Intelligent Transport Systems) band of 5.9 GHZ (typically 5.85-5.925 GHZ) and 63-64 GHz, bands currently allocated to WiGig such as WiGig Band 1 (57.24-59.40 GHz), WiGig Band 2 (59.40-61.56 GHz) and WiGig Band 3 (61.56-63.72 GHZ) and WiGig Band 4 (63.72-65.88 GHz), 57-64/66 GHz (note: this band has near-global designation for Multi-Gigabit Wireless Systems (MGWS)/WiGig. In US (FCC part 15) allocates total 14 GHz spectrum, while EU (ETSI EN 302 567 and ETSI EN 301 217-2 for fixed P2P) allocates total 9 GHz spectrum), the 70.2 GHz-71 GHz band, any band between 65.88 GHz and 71 GHz, bands currently allocated to automotive radar applications such as 76-81 GHZ, and future bands including 94-300 GHz and above. Furthermore, the scheme can be used on a secondary basis on bands such as the TV White Space bands (typically below 790 MHz) where in particular the 400 MHz and 700 MHz bands are promising candidates. Besides cellular applications, specific applications for vertical markets may be addressed such as PMSE (Program Making and Special Events), medical, health, surgery, automotive, low-latency, drones, etc. applications.

(52) Aspects described herein can also implement a hierarchical application of the scheme is possible, e.g., by introducing a hierarchical prioritization of usage for different types of users (e.g., lowithmedium/high priority, etc.), based on a prioritized access to the spectrum e.g., with highest priority to tier-1 users, followed by tier-2, then tier-3, etc. users, etc.

(53) Aspects described herein can also be applied to different Single Carrier or OFDM flavors (CP-OFDM, SC-FDMA, SC-OFDM, filter bank-based multicarrier (FBMC), OFDMA, etc.) and in particular 3GPP NR (New Radio) by allocating the OFDM carrier data bit vectors to the corresponding symbol resources.

(54) 5G networks extend beyond the traditional mobile broadband services to provide various new services such as internet of things (IoT), industrial control, autonomous driving, mission critical communications, etc. that may have ultra-low latency, ultra-high reliability, and high data capacity requirements due to safety and performance concerns. Some of the features in this document are defined for the network side, such as APs, eNBs, NR or gNBs—note that this term is typically used in the context of 3GPP 5G and 6G communication systems, etc. Still, a UE may take this role as well and act as an AP, eNB, or gNB; that is some or all features defined for network equipment may be implemented by a UE.

(55) As above, new radio (NR) operations extend into the frequency range 2 (FR2) band. In particular, NR operation in has been approved to extend to 71 GHz (high frequency (FR2-2)). Operation in the FR2-2 band using high subcarrier spacings (SCSs) including two new SCSs-480 kHz and 960 kHz. These SCSs have short slot/symbol/cyclic prefix (CP) lengths which are 31.250 ns/2.23 ns/146 ns and 15.625 ns/1.12 ns/73 ns for 480 kHz and 960 kHz respectively.

(56) Some timing requirements can be very sensitive to such short slot lengths. For instance, now propagation delay difference between carriers in carrier aggregation (CA)/dual connectivity (DC), which determines the maximum receive timing difference (MRTD) requirement, can be larger than one slot. In TS 38.133, v.17.3.0, 2021 Oct. 4, the receive timing difference requirements are introduced as follows: a UE shall be capable of handling a relative receive timing difference between slot timing boundary of a cell belonging to MCG and the closest slot timing boundary of a cell belonging to the SCG to be aggregated for NR DC operation. A UE shall be capable of handling a relative receive timing difference among the closest slot timing boundaries of different carriers to be aggregated in NR carrier aggregation.

(57) As can be seen the receive timing difference (RTD) between carriers is considered as the timing difference between the closest slot boundaries. In Rel-15/Rel-16 the slot length is always larger than Timing Alignment Error (TAE)+propagation delay difference for any CA scenario, so misalignment between carriers is always within one slot. Thus, the above-mentioned definition of

RTD is reasonable.

(58) However, the slot length for 480 kHz and 960 kHz SCS is short and TAE+propagation delay difference between slot timing boundary of different carriers may be longer than 1 slot. In this case using the existing definition there will be an ambiguity at the network side in case of cross-carrier operation. Thus, with the existing definition the network cannot assume that the UE can handle the receive a timing difference of the slots that were sent simultaneously (i.e., slots whose boundaries are aligned at signal transmission) larger than half slot.

(59) Embodiments herein address these and other issues by introducing a new definition for RTD requirements. RTD reflects the whole time difference between carriers caused by time alignment error (TAE) and propagation delay difference. RTD is considered between the boundaries of the slots that were sent simultaneously. Among other things, embodiments herein help resolve issues of inadequate definition of receive timing difference in case of high SCSs.

(60) In TS38.133 requirements on the receive timing difference are introduced as follows: a UE shall be capable of handling a relative receive timing difference between slot timing boundary of a cell belonging to a master cell group (MCG) and the closest slot timing boundary of a cell belonging to the secondary cell group (SCG) to be aggregated for NR DC operation. A UE shall be capable of handling a relative receive timing difference among the closest slot timing boundaries of different carriers to be aggregated in NR carrier aggregation.

(61) FIG. **3** illustrates a Rel-15/Rel-16 RTD definition in accordance with some embodiments. As shown in FIG. **3**, the slot length in Rel-15/Rel-16 is always larger than TAE+propagation delay difference for any CA scenario, so misalignment between carriers is always within one slot and the above-mentioned definition of RTD considering the closest slot boundary makes sense. But for high SCSs introduced in Rel-17 TAE+propagation delay difference can be larger than 1 slot.

(62) FIG. **4** illustrates a small slot length RTD in accordance with some embodiments. In this case, various options may be used to account for RTD as shown in FIG. **4**. Option 1: RTD reflects the entire time difference between carriers caused by the TAE and propagation delay difference. RTD in option 1 is considered between the boundaries of the slots that were sent simultaneously. Option 2: RTD reflects only slot boundary misalignment without considering the slot index. RTD in option 2 is considered between the closest slot boundaries.

(63) Option 1 may be more appropriate at least for a CA case in which the slot index correspondence is important for cross-carrier operations. For a DC case, there is no cross-carrier interaction and the slot index correspondence may be of less importance, so the legacy definition (Option 2) can be kept even for high SCSs.

(64) Example #1: For NR carrier aggregation, the receive timing difference between carriers to be handled by the UE is the timing difference between the slot boundaries of the slots that were sent simultaneously. The definition is applied at least for high SCSs.

(65) Example #2: For NR DC, the receive timing difference between carriers to be handled by the UE is the timing difference between the closest slot boundaries. For high SCSs TAE+propagation delay difference can be larger than 1 slot, so the MRTD between the closest slot boundaries is equal to half slot length. Thus, in the case of NR DC with high SCS, the UE is in asynchronous conditions with MRTD. This is shown in Table 1, below.

(66) Example #3: For NR DC with high SCS, the UE is always in asynchronous conditions with MRTD, as shown in Table 1.

(67) TABLE-US-00001 TABLE 1 MRTD for NR DC Max {Sub-carrier spacing in PCell (kHz), Maximum receive Sub-carrier spacing in PSCell (kHz)} timing difference (µs) 480 16.625 960 7.8125

Examples

(68) Example 1 is an apparatus for a user equipment (UE), the apparatus comprising: memory; and processing circuitry, to configure the UE to: receive, a first downlink signal on a first carrier and a second downlink signal on a second carrier, each of the first downlink signal and the second

downlink signal having a subcarrier spacing (SCS) of at least one of 480 kHz or 960 kHz; determine whether new radio (NR) carrier aggregation (CA) or dual connectivity (DC) is used for the first downlink signal and the second downlink signal; and determine a receive timing difference (RTD) between slots of the first downlink signal and the second downlink signal based on which of NR CA or DC is used; and wherein the memory is configured to store the first downlink signal and the second downlink signal.

(69) In Example 2, the subject matter of Example 1 includes, wherein the processing circuitry configures the UE to receive the first downlink signal from a first cell that belongs to a master cell group (MCG) and the second downlink signal from a second cell that belongs to a secondary cell group (SCG).

(70) In Example 3, the subject matter of Examples 1-2 includes, wherein the processing circuitry configures the UE to determine that a slot length of the slots for each of the first downlink signal and the second downlink signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first carrier and the second carrier.

(71) In Example 4, the subject matter of Examples 1-3 includes, wherein the processing circuitry configures the UE to determine that the RTD reflects an entire time difference between the first carrier and the second carrier caused by a combination of a Timing Alignment Error (TAE) and propagation delay difference, the RTD being between slot boundaries of the slots aligned at transmission of the first downlink signal and the second downlink signal.

(72) In Example 5, the subject matter of Example 4 includes, wherein the processing circuitry configures the UE to determine the RTD in response to a determination that NR CA is used.

(73) In Example 6, the subject matter of Examples 3-5 includes, wherein the processing circuitry configures the UE to determine that the RTD reflects only slot boundary misalignment between the first carrier and the second carrier without consideration of a slot index of the first carrier and the second carrier.

(74) In Example 7, the subject matter of Example 6 includes, wherein the processing circuitry configures the UE to determine the RTD based on closest slot boundaries between the first carrier and the second carrier.

(75) In Example 8, the subject matter of Example 7 includes, wherein the processing circuitry configures the UE to determine the RTD in response to a determination that NR DC is used.

(76) In Example 9, the subject matter of Example 8 includes, wherein the processing circuitry configures the UE to determine a maximum timing difference (MRTD) between the closest slot boundaries is equal to half of the slot length.

(77) In Example 10, the subject matter of Example 9 includes, wherein the processing circuitry configures the UE to determine that the UE is in asynchronous conditions with the MRTD.

(78) In Example 11, the subject matter of Example 10 includes the MRTD is 16.625 us for an SCS of 480 kHz and 7.8125 us for an SCS of 960 kHz.

(79) Example 12 is a non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE), the one or more processors to configure the UE to, when the instructions are executed: receive, a first downlink signal on a first carrier and a second downlink signal on a second carrier, each of the first downlink signal and the second downlink signal having a subcarrier spacing (SCS) of at least one of 480 kHz or 960 kHz; determine whether new radio (NR) carrier aggregation (CA) or dual connectivity (DC) is used for reception of the first downlink signal and the second downlink signal; and determine a receive timing difference (RTD) between slots for the first downlink signal and the second downlink signal based on which of NR CA or DC is used.

(80) In Example 13, the subject matter of Example 12 includes, wherein the instructions, when executed by the one or more processors, configure the UE to determine for NR CA that: a slot length of the slots for each of the first downlink signal and the second downlink signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first

carrier and the second carrier, and the RTD reflects an entire time difference between the first carrier and the second carrier caused by the combination of the TAE and propagation delay difference, the RTD being between slot boundaries of the slots aligned at transmission of the first downlink signal and the second downlink signal.

(81) In Example 14, the subject matter of Examples 12-13 includes, wherein the instructions, when executed by the one or more processors, configure the UE to determine for NR DC that: a slot length of the slots for each of the first downlink signal and the second downlink signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first carrier and the second carrier, and the RTD reflects only slot boundary misalignment between the first carrier and the second carrier without consideration of a slot index of the first carrier and the second carrier.

(82) In Example 15, the subject matter of Examples 12-14 includes, wherein the instructions, when executed by the one or more processors, configure the UE to determine for NR DC that: a slot length of the slots for each of the first downlink signal and the second downlink signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first downlink signal and the second downlink signal, the RTD is based on closest slot boundaries between the first carrier and the second carrier, and a maximum timing difference (MRTD) between the closest slot boundaries is equal to half of the slot length.

(83) In Example 16, the subject matter of Example 15 includes, wherein: the instructions, when executed by the one or more processors, configure the UE to determine that the UE is in asynchronous conditions with the MRTD, and the MRTD is 16.625 us for an SCS of 480 kHz and 7.8125 us for an SCS of 960 kHz.

(84) Example 17 is an apparatus for a user equipment (UE), the apparatus comprising: memory; and processing circuitry, to configure the UE to: determine whether new radio (NR) carrier aggregation (CA) or dual connectivity (DC) is to be used for transmission of a first signal on a first carrier and a second signal on a second carrier, each of the first signal and the second signal having a subcarrier spacing (SCS) of at least one of 480 kHz or 960 kHz; determine a receive timing difference (RTD) between slots for the first signal and the second signal based on which of NR CA or DC is to be used; and transmit, to at least one next generation radio access network (NG-RAN) node, a first signal on a first carrier and a second signal on a second carrier based on the RTD; and wherein the memory is configured to store the first signal and the second signal.

(85) In Example 18, the subject matter of Example 17 includes, wherein: a slot length of the slots for each of the first signal and the second signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first signal and the second signal, and for NR CA the RTD reflects an entire time difference between the first carrier and the second carrier caused by the combination of the TAE and propagation delay difference, the RTD being between slot boundaries of slots aligned at transmission of the first signal and the second signal.

(86) In Example 19, the subject matter of Examples 17-18 includes, wherein: a slot length of the slots for each of the first signal and the second signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first signal and the second signal, and for NR DC the RTD reflects only slot boundary misalignment between the first carrier and the second carrier without consideration of a slot index of the first carrier and the second carrier.

(87) In Example 20, the subject matter of Examples 17-19 includes, wherein: a slot length of the slots for each of the first signal and the second signal is less than a combination of a Timing Alignment Error (TAE) and propagation delay difference between the first signal and the second signal, for NR DC the RTD is based on closest slot boundaries between the first carrier and the second carrier, a maximum timing difference (MRTD) between the closest slot boundaries is equal to half of the slot length, and the MRTD is 16.625 us for an SCS of 480 kHz and 7.8125 us for an SCS of 960 kHz.

(88) Example 21 is at least one machine-readable medium including instructions that, when executed by processing circuitry, cause the processing circuitry to perform operations to implement of any of Examples 1-20.

(89) Example 22 is an apparatus comprising means to implement of any of Examples 1-20.

(90) Example 23 is a system to implement of any of Examples 1-20.

(91) Example 24 is a method to implement of any of Examples 1-20.

(92) Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader scope of the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

(93) The subject matter may be referred to herein, individually and/or collectively, by the term "embodiment" merely for convenience and without intending to voluntarily limit the scope of this application to any single inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

(94) In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, UE, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

(95) The Abstract of the Disclosure is provided to comply with 37 C.F.R. § 1.72(b), requiring an abstract that will allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it may be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

Claims

1. An apparatus for a user equipment (UE) configured for operating in a fifth-generation new radio (5G NR) network, the apparatus comprising: memory; and processing circuitry, the processing circuitry configured to: decode signalling received from a gNodeB (gNB) to configure the UE with a master cell group (MCG) in frequency-range 1 (FR1) and a secondary cell group (SCG) in frequency-range 2-2 (FR2-2) for inter-band asynchronous NR dual-connectivity (NR-DC) operation; receive a downlink channel from a cell belonging to the MCG in FR1 and a downlink channel from a cell belonging to the SCG in FR2-2 to be aggregated for the inter-band asynchronous NR-DC operation, wherein for the inter-band asynchronous NR-DC operation, the UE is configured to handle a maximum receive timing difference between a subframe timing boundary of the cell belonging to MCG in FR1 and a closest subframe timing boundary of the cell belonging to the SCG in FR2-2; and aggregate a carrier of the downlink channel from the cell belonging to the MCG in FR1 and a carrier of the downlink channel from the cell belonging to the SCG in FR2-2 for the inter-band asynchronous NR-DC operation, wherein the maximum receive timing difference is based on a subcarrier spacing (SCS).
2. The apparatus of claim 1, wherein when the SCS is 480 kHz, the maximum receive timing difference is less than 16.625 µs, and wherein when the SCS is 960 kHz, the maximum receive timing difference is 7.8125 µs.
3. The apparatus of claim 2, wherein subframe timing boundaries of the cell belonging to the MCG in FR1 and cell belonging to the SCG in FR2-2 are unaligned.
4. The apparatus of claim 2, wherein the carrier of the downlink channel from the cell belonging to the MCG in FR1 and the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 are unsynchronized.
5. The apparatus of claim 2, wherein the carrier of the downlink channel from the cell belonging to the MCG in FR1 is within a frequency range of 410 MHz-7125 MHz, and wherein the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 is within a frequency range of 52600 MHz-71000 MHz.
6. The apparatus of claim 5, wherein for the inter-band asynchronous NR-DC operation when the UE is configured with an MCG and SCG both in FR1 with an SCS less than 480 KHz, the UE is capable of handling a maximum receive timing difference between a subframe timing boundary of a cell belonging to MCG in FR1 and a closest subframe timing boundary of a cell belonging to the SCG in FR1 that is greater than the maximum receive timing difference when the SCS is 480 kHz.
7. The apparatus of claim 2, wherein when the maximum receive timing difference between a subframe timing boundary of the cell belonging to MCG in FR1 and a closest subframe timing boundary of the cell belonging to the SCG in FR2-2 is greater than a predetermined value for the SCS, the processing circuitry is configured to refrain from: receiving the downlink channel from the cell belonging to the MCG in FR1 and the downlink channel from the cell belonging to the SCG in FR2-2; and aggregating the carrier of the downlink channel from the cell belonging to the MCG in FR1 and the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 or the inter-band asynchronous NR-DC operation.
8. The apparatus of claim 2, wherein the signalling to configure the UE with the MCG in FR1 and the SCG in FR2-2 for the inter-band asynchronous NR-DC operation comprises radio-resource control (RRC) signalling.
9. The apparatus of claim 8, wherein the processing circuitry comprises a baseband processor and wherein the memory is configured to store configuration information for the inter-band asynchronous NR-DC operation.
10. A non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a user equipment (UE) configured for operating in a fifth-generation new

radio (5G NR) network, the processing circuitry configured to: decode signalling received from a gNodeB (gNB) to configure the UE with a master cell group (MCG) in frequency-range 1 (FR1) and a secondary cell group (SCG) in frequency-range 2-2 (FR2-2) for inter-band asynchronous NR dual-connectivity (NR-DC) operation; receive a downlink channel from a cell belonging to the MCG in FR1 and a downlink channel from a cell belonging to the SCG in FR2-2 to be aggregated for the inter-band asynchronous NR-DC operation, wherein for the inter-band asynchronous NR-DC operation, the UE is configured to handle a maximum receive timing difference between a subframe timing boundary of the cell belonging to MCG in FR1 and a closest subframe timing boundary of the cell belonging to the SCG in FR2-2; and aggregate a carrier of the downlink channel from the cell belonging to the MCG in FR1 and a carrier of the downlink channel from the cell belonging to the SCG in FR2-2 for the inter-band asynchronous NR-DC operation, wherein the maximum receive timing difference is based on a subcarrier spacing (SCS).

11. The non-transitory computer-readable storage medium of claim 10, wherein when the SCS is 480 kHz, the maximum receive timing difference is less than 16.625 μs, and wherein when the SCS is 960 kHz, the maximum receive timing difference is 7.8 125 μs.

12. The non-transitory computer-readable storage medium of claim 11, wherein subframe timing boundaries of the cell belonging to the MCG in FR1 and cell belonging to the SCG in FR2-2 are unaligned.

13. The non-transitory computer-readable storage medium of claim 11, wherein the carrier of the downlink channel from the cell belonging to the MCG in FR1 and the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 are unsynchronized.

14. The non-transitory computer-readable storage medium of claim 11, wherein the carrier of the downlink channel from the cell belonging to the MCG in FR1 is within a frequency range of 410 MHz-7125 MHz, and wherein the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 is within a frequency range of 52600 MHz-71000 MHz.

15. The non-transitory computer-readable storage medium of claim 14, wherein for the inter-band asynchronous NR-DC operation when the UE is configured with an MCG and SCG both in FR1 with an SCS less than 480 KHz, the UE is capable of handling a maximum receive timing difference between a subframe timing boundary of a cell belonging to MCG in FR1 and a closest subframe timing boundary of a cell belonging to the SCG in FR1 that is greater than the maximum receive timing difference when the SCS is 480 kHz.

16. The non-transitory computer-readable storage medium of claim 11, wherein when the maximum receive timing difference between a subframe timing boundary of the cell belonging to MCG in FR1 and a closest subframe timing boundary of the cell belonging to the SCG in FR2-2 is greater than a predetermined value for the SCS, the processing circuitry is configured to refrain from: receiving the downlink channel from the cell belonging to the MCG in FR1 and the downlink channel from the cell belonging to the SCG in FR2-2; and aggregating the carrier of the downlink channel from the cell belonging to the MCG in FR1 and the carrier of the downlink channel from the cell belonging to the SCG in FR2-2 or the inter-band asynchronous NR-DC operation.

17. An apparatus for gNode B (gNB) configured for operating in a fifth-generation new radio (5G NR) network, the apparatus comprising: memory; and processing circuitry, the processing circuitry configured to: encode signalling for transmission to a user equipment (UE) to configure the UE with a master cell group (MCG) in frequency-range 1 (FR1) and a secondary cell group (SCG) in frequency-range 2-2 (FR2-2) for inter-band asynchronous NR dual-connectivity (NR-DC) operation; encode a downlink channel for transmission from a cell belonging to the MCG in FR1 and a downlink channel for transmission from a cell belonging to the SCG in FR2-2 to be aggregated by the UE for the inter-band asynchronous NR-DC operation, wherein for the inter-band asynchronous NR-DC operation, the gNB is to configure a subframe timing boundary of the cell belonging to MCG in FR1 and a closest subframe timing boundary of the cell belonging to the SCG in FR2-2 to be less than a maximum receive timing difference; and receive, from the UE, a

carrier of the downlink channel from the cell belonging to the MCG in FR1 aggregated with a carrier of the downlink channel from the cell belonging to the SCG in FR2-2 for the inter-band asynchronous NR-DC operation, wherein the maximum receive timing difference is based on a subcarrier spacing (SCS).

18. The apparatus of claim 17, wherein when the SCS is 480 kHz, the maximum receive timing difference is configured to be less than 16.625 µs, and wherein when the SCS is 960 kHz, the maximum receive timing difference is configured to be 7.8125 µs.