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Beam management for frequency division duplex operation

Abstract

A method of operating a wireless communication device (**102**) configured to communicate with a communications network (**100**) using frequency duplex transmission in an uplink frequency band (**601**) and in a downlink frequency band (**602**) is provided. The method includes monitoring for first downlink reference signals (**445**, **6052**) transmitted by an access node (**101**) of the communications network (**100**) in the uplink frequency band (**601**) and using multiple first downlink transmit beams (**351-354**); and monitoring for second downlink reference signals (**411**, **446**) transmitted by the access node (**101**) of the communications network (**100**) in the downlink frequency band (**602**) and using multiple second downlink transmit beams (**361-364**).

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Background/Summary

TECHNICAL FIELD

(1) Various examples of the invention generally relate to beam management for frequency division duplex operation. Various examples of the invention specifically relate to beam management during initial access of a wireless communication device to a cellular network.

BACKGROUND

(2) Various techniques are known to enhance reliability and/or throughput of communication on a wireless link.

(3) Firstly, multiple-input multiple-output (MIMO) techniques are known. Here, the transmitter node and the receiver node both include multiple antennas that can be operated in a phase-coherent manner. Thereby, a signal can be transmitted redundantly (diversity multi-antenna operational mode) along multiple spatial data streams, or multiple signals can be transmitted on multiple spatial data streams (spatial multiplexing multi-antenna operational mode). Spatial data streams can be defined by focusing the transmission energy for transmitting (transmit beam, TX beam) and/or the receive sensitivity for receiving (receive beam, RX beam) to a particular spatial direction. Here, the process of identifying the appropriate beams is often referred to as beam establishment or beam management.

(4) Secondly, using frequency division duplex (FDD), signals can be transmitted from a first node to a second node in a first frequency band and further signals can be transmitted contemporaneously from the second node to the first node in a second frequency band that is different from the first frequency band.

(5) It has been found that accurate beam management can be challenging for FDD operation.

SUMMARY

(6) Accordingly, a need exists for advanced techniques of beam management in connection with FDD operation. This need is met by the features of the independent claims. The features of the dependent claims define embodiments.

(7) A method of operating a UE is provided. The UE is configured to communicate with a communications network using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The method includes monitoring for first downlink reference signals (RSs). The first downlink RSs are transmitted by an access node of the communications network in the uplink frequency band and using multiple first downlink transmit beams. The method also

includes monitoring for second downlink RSs transmitted by the access node of the communications network in the downlink frequency band and using multiple second downlink transmit beams.

(8) A computer program or a computer program product or a computer-readable storage medium includes program code. The program code can be loaded and executed by at least one processor. Executing the program code causes the at least one processor to perform a method of operating a UE. The UE is configured to communicate with a communications network using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The method includes monitoring for first downlink RSs. The first downlink RSs are transmitted by an access node of the communications network in the uplink frequency band and using multiple first downlink transmit beams. The method also includes monitoring for second downlink RSs transmitted by the access node of the communications network in the downlink frequency band and using multiple second downlink transmit beams.

(9) A UE is configured to communicate with a communications network using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The UE includes control circuitry configured to monitor for first downlink RSs. The first downlink RSs are transmitted by an access node of the communications network in the uplink frequency band and using multiple first downlink transmit beams. The control circuitry is also configured to monitor for second downlink RSs transmitted by the access node of the communications network in the downlink frequency band and using multiple second downlink transmit beams.

(10) A method of operating an access node of a communications network is provided. The access node is configured to communicate with a wireless communication device using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The method includes transmitting first downlink RSs in the uplink frequency band and using multiple first downlink transmit beams. The method also includes transmitting second downlink RSs in the downlink frequency band and using multiple second downlink transmit beams.

(11) A computer program or a computer program product or a computer-readable storage medium includes program code. The program code can be loaded and executed by at least one processor. Executing the program code causes the at least one processor to perform a method of operating an access node of a communications network. The access node is configured to communicate with a wireless communication device using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The method includes transmitting first downlink RSs in the uplink frequency band and using multiple first downlink transmit beams. The method also includes transmitting second downlink RSs in the downlink frequency band and using multiple second downlink transmit beams.

(12) An access node of a communications network is provided. The access node is configured to communicate with a wireless communication device using frequency duplex transmission in an uplink frequency band and in a downlink frequency band. The access node includes control circuitry configured to transmit first downlink RSs in the uplink frequency band and using multiple first downlink transmit beams; and to transmit second downlink RSs in the downlink frequency band and using multiple second downlink transmit beams.

(13) It is to be understood that the features mentioned above and those yet to be explained below may be used not only in the respective combinations indicated, but also in other combinations or in isolation without departing from the scope of the invention.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 schematically illustrates a communication system according to various examples.

- (2) FIG. 2 schematically illustrates MIMO operation of the communication system of FIG. 1 according to various examples.
- (3) FIG. 3 schematically illustrates a transmit beam sweep of a base station of the communication system according to various examples.
- (4) FIG. 4 schematically illustrates a receive beam sweep of a wireless communication device of the communication system according to various examples.
- (5) FIG. 5 schematically illustrates nonreciprocal beams used for communicating between the base station and the wireless communication device of the communication system according to various examples.
- (6) FIG. 6 schematically illustrates a cellular network according to various examples.
- (7) FIG. 7 schematically illustrates multiple connection modes in which the wireless communication device can be operated according to various examples.
- (8) FIG. 8 schematically illustrates multiple random-access occasions for initial access of the wireless communication device to the cellular network according to various examples.
- (9) FIG. 9 is a signaling diagram of communicating between the wireless communication device and the cellular network according to various examples.
- (10) FIG. 10 schematically illustrates logic for beam management at the wireless communication device according to various examples.
- (11) FIG. 11 is a flowchart of a method according to various examples.
- (12) FIG. 12 is a flowchart of a method according to various examples.

DETAILED DESCRIPTION OF EMBODIMENTS

(13) Some examples of the present disclosure generally provide for a plurality of circuits or other electrical devices. All references to the circuits and other electrical devices and the functionality provided by each are not intended to be limited to encompassing only what is illustrated and described herein. While particular labels may be assigned to the various circuits or other electrical devices disclosed, such labels are not intended to limit the scope of operation for the circuits and the other electrical devices. Such circuits and other electrical devices may be combined with each other and/or separated in any manner based on the particular type of electrical implementation that is desired. It is recognized that any circuit or other electrical device disclosed herein may include any number of microcontrollers, a graphics processor unit (GPU), integrated circuits, memory devices (e.g., FLASH, random access memory (RAM), read only memory (ROM), electrically programmable read only memory (EPROM), electrically erasable programmable read only memory (EEPROM), or other suitable variants thereof), and software which co-act with one another to perform operation(s) disclosed herein. In addition, any one or more of the electrical devices may be configured to execute a program code that is embodied in a non-transitory computer readable medium programmed to perform any number of the functions as disclosed.

(14) In the following, embodiments of the invention will be described in detail with reference to the accompanying drawings. It is to be understood that the following description of embodiments is not to be taken in a limiting sense. The scope of the invention is not intended to be limited by the embodiments described hereinafter or by the drawings, which are taken to be illustrative only.

(15) The drawings are to be regarded as being schematic representations and elements illustrated in the drawings are not necessarily shown to scale. Rather, the various elements are represented such that their function and general purpose become apparent to a person skilled in the art. Any connection or coupling between functional blocks, devices, components, or other physical or functional units shown in the drawings or described herein may also be implemented by an indirect connection or coupling. A coupling between components may also be established over a wireless connection. Functional blocks may be implemented in hardware, firmware, software, or a combination thereof.

(16) Techniques are described that facilitate FDD operation of communication on a wireless link. Techniques are described that facilitate FDD operation in combination with MIMO. In particular,

the techniques described herein facilitate beam management during the initial access of a wireless communication device (UE) to a cellular network (NW). The techniques described herein can be used to reliably determine a downlink (DL) transmit (TX) beam at a base station (BS) of the cellular NW to be used for transmitting data to the UE in the DL frequency band of the wireless link, as well as to reliably determine an uplink (UL) receive (RX) beam at the BS to be used for receiving data from the UE in the UL frequency band. Also, beam management of UE beams, i.e., an UL TX beam and/or a DL RX beam can be facilitated.

(17) DL TX beams and UL RX beams are so-called BS beams, because they are employed by the BS. UL TX beams and DL RX beams are so-called UE beams. DL RX beams can also be referred to as RX spatial filter.

(18) Once a beam has been determined, this beam can be used for subsequent communication of data, e.g., application data and/or higher-layer control data.

(19) Generally, the techniques described herein are based on the finding that for FDD operation of communication on the wireless link channel reciprocity may not be applicable. In other words, the best DL TX beam may significantly deviate from the best UL RX beam. For example, a spatial coverage associated with the best DL TX beam may differ from a spatial coverage of the best UL RX beam. Here, “best” is used as describing a beam that is superior signal-to-noise properties if compared to other beams having different spatial coverage.

(20) Above, various aspects in the general framework of FDD operation have been described. Next, various inventive concepts will be described that facilitate reliable FDD operation. According to various examples, it is possible to transmit DL RSs (sometimes also we refer to as DL pilot signals) from the BS to the UE in the UL frequency band. The DL RSs can employ precoding. It is possible that the UE acquires some knowledge on the channel transmission matrix based on the DL RSs. Generally speaking, the cellular NW can transmit first DL RSs in the UL frequency band and can transmit second DL RSs in the DL frequency band. The UE can then use the first DL RSs, as well as the second DL RSs, e.g., to make a choice of one or more random-access occasions.

(21) FIG. 1 schematically illustrates a communication system. The communication system includes two nodes **101**, **102** that are configured to communicate with each other via a wireless link **114**. In the example of FIG. 1, the node **101** is implemented by an access node, more specifically a BS, and the node **102** is implemented by a UE. The BS **101** can be part of a cellular NW (not shown in FIG. 1). As a general rule, the techniques described herein could be used for various types of communication systems, e.g., also for peer-to-peer communication, etc. For sake of simplicity, however, hereinafter, various techniques will be described in the context of a communication system that is implemented by a BS of a cellular NW and a UE.

(22) Communication on the wireless link **114** can employ time-division duplex (TDD) and/or frequency-division duplex (FDD). Using TDD, communication in the DL and in the UL takes place at different points in time using the same frequency. Using FDD, communication in the DL and in the UL takes place at the same point in time, using different frequencies. The inset of FIG. 1 (dashed lines) illustrates respective frequency bands **601**, **602** for UL and DL transmission, respectively, in an example configuration.

(23) Communication on the wireless link **114** can employ Orthogonal Frequency Division Multiplex (OFDM) modulation. Here, time-frequency resource grids including multiple time-frequency resources can be defined for each frequency band **601**, **602**. Each time-frequency resource can correspond to an OFDM symbol/subcarrier.

(24) FIG. 2 illustrates details with respect to the BS **101**. The BS **101** includes control circuitry that is implemented by a processor **1011** and a non-volatile memory **1015**. The processor **1011** can load program code that is stored in the memory **1015**. The processor **1011** can then execute the program code. Executing the program code causes the processor to perform techniques as described herein, e.g.: communicating on a wireless link using MIMO and/or FDD; performing beamsweeps; transmitting signals such as RSs; scheduling signals for transmission on the wireless link;

participating in initial access of the UE **102**; monitoring for the UE **102** accessing random-access occasions; etc.

(25) FIG. **2** also illustrates details with respect to the UE **102**. The UE **102** includes control circuitry that is implemented by a processor **1021** and a nonvolatile memory **1025**. The processor **1021** can load program code that is stored in the memory **1025**. The processor can execute the program code. Executing the program code causes the processor to perform techniques as described herein, e.g.: communicating on a wireless link using MIMO and/or FDD; performing beamsweeps; participating in an initial access of the UE **102** to the cellular NW of the BS **101**; monitoring for RSs, i.e., attempting to receive RSs; selecting one or more random-access occasions; etc.

(26) FIG. **2** also illustrates details with respect to communication between the BS **101** and the UE **102** on the wireless link **114**. The BS **101** includes an interface **1012** that can access and control multiple antennas **1014**. Likewise, the UE **102** includes an interface **1022** that can access and control multiple antennas **1024**.

(27) While the scenario of FIG. **2** illustrates the antennas **1014** being coupled to the BS **101**, as a general rule, it would be possible to employ transmit-receive points (TRPs) that are spaced apart from the base station.

(28) The interfaces **1012**, **1022** can each include one or more TX chains and one or more receiver chains. For instance, such RX chains can include low noise amplifiers, analogue to digital converters, mixers, etc. Analogue and/or digital beamforming would be possible.

(29) Thereby, phase-coherent transmitting and/or receiving (communicating) can be implemented across the multiple antennas **1014**, **1024**. Thereby, the BS **101** and the UE **102** implement a MIMO communication system.

(30) As a general rule, the receiver of the MIMO communication system receives a signal y that is obtained from an input signal x multiplied by the transmission matrix H . FIG. **2** includes two example labels for the components $h_{sub.11}$ and $h_{sub.13}$ of the transmission matrix H .

(31) The transmission matrix H defines the channel impulse response of the wireless link **114**. The rank of the transmission matrix corresponds to the number of linearly independent rows or columns and, as such, indicates how many independent data streams can be used simultaneously; this is sometimes referred to as the number of layers. The rank can be set in different multi-antenna transmission modes. For multi-antenna transmission modes, the amplitude and/or phase (antenna weights) of each one of the antennas **1014**, **1024** is appropriately controlled by the interfaces **1012**, **1022**. The antenna weights can define a certain spatial filter.

(32) For instance, a diversity multi-antenna transmission mode relies on transmitting the same data redundantly using multiple TX antennas. Thus, multiple data streams carry the same data. Thereby, the signal-to-noise ratio can be increased. The redundant signals can be generated using different encoding, e.g., Alamouti encoding.

(33) Another multi-antenna transmission mode is spatial multiplexing. Spatial multiplexing allows to increase the data rate: The data is divided into different data streams and these different data streams can be transmitted contemporaneously over the wireless link **114**.

(34) The diversity multi-antenna transmission mode and the spatial multiplexing multi-antenna transmission mode can be described as using multiple beams, the beams defining the spatial data streams. These modes are, therefore, also referred to as multibeam operation. By using a beam, the direction of the signals transmitted by a transmitter of the communication system is controlled. Energy is focused into a respective direction, by phase-coherent superposition of the individual signals originating from each antenna **1014**, **1024**. Thereby, the spatial data stream can be directed. The spatial data streams transmitted on multiple beams can be independent, resulting in spatial multiplexing MIMO transmission; or dependent on each other, e.g., redundant, resulting in diversity MIMO transmission.

(35) As a general rule, alternatively or additionally to such TX beams, it is possible to employ RX beams.

(36) The concept of beams can be used in so-called beamsweeps. Details with respect to beamsweeping are explained next in connection with FIG. 3 and FIG. 4.

(37) FIG. 3 illustrates DL TX beams **301-309** used by the BS **101**. In some examples, the BS **101** can employ a beamsweep **300**. Here, the BS **101** activates the beams **301-309** on different resources (e.g., different time-frequency resources, and/or using orthogonal codes) such that the UE **102** can monitor for respective signals transmitted on the DL TX beams **301-309**. As a general rule, monitoring for signals can pertain to attempting to receive signals. The UE **102** may then select the best DL TX beam **301-309**—e.g., based on a RX property of the received signal, such as amplitude and/or phase and/or angle-of-arrival, etc.—and provide a respective indication to the BS **101**. As a general rule, the best DL TX beam **301-309** could be the strongest beam. Also, other quality metrics may be taken into account, e.g., signal-to-noise. Then, subsequent data can be communicated on the selected DL TX beam **301-309**. Such beam management can, in particular, be facilitated by using RSs, i.e., signals having a well-defined transmit property such as sequence, amplitude, phase, and/or precoding, etc. RSs are sometimes also referred to as pilot signals.

(38) It would be possible that such DL TX beamsweep **300** implemented by the BS **101** is coordinated with a DL RX beamsweep **310** implemented by the UE **102**. A DL RX beamsweep **310** is illustrated in FIG. 4. The DL RX beamsweep **310** includes multiple DL RX beams **311*-313*** (for sake of simplicity, throughout this text, RX beams are denoted with “*”). The DL RX beamsweep **310** does not necessarily have to be coordinated with a DL TX beamsweep **300**.

(39) FIG. 5 schematically illustrates aspects with respect to beam management at the BS **101** according to various examples. FIG. 5 illustrates that the BS **101** transmits DL signals in the DL frequency band **602** using the DL TX beam **301**.

(40) Notably, the BS **101** does not use the UL RX beam **301*** (dotted line in FIG. 5) that corresponds to the DL TX beam **301** for receiving UL signals in the UL frequency band **601**. Rather, the BS uses an UL RX beam **303*** that corresponds to a different DL TX beam **303** for receiving UL signals in the UL frequency band **601**: Typically, channel reciprocity is not applicable for FDD operation and this is why the BS **101** uses non-corresponding beams **301**, **303*** for transmitting and receiving, respectively.

(41) The DL TX beam **301** corresponds to the UL RX beam **301***, because the beams **301**, **301*** have similar spatial filter characteristics and/or use the same antenna weights.

(42) To facilitate beam management, the BS **101** transmits DL reference signals **445**, **446** in, both, the UL frequency band **601**, as well as in the DL frequency band **602**. The UE **102** can monitor for the DL RSs **445**, **446** in both frequency bands. The BS **101** can, e.g., transmit the DL RSs **445** using multiple DL TX beams, e.g., using a beamsweep; likewise, the BS **101** may transmit the DL RSs **446** using multiple DL TX beams, e.g., using a beamsweep. In particular, beam management during initial access can be facilitated by such means.

(43) FIG. 6 schematically illustrates a cellular NW **100**. The example of FIG. 6 illustrates the cellular NW **100** according to the 3GPP NR/5G architecture. Details of the 3GPP 5G architecture are described in 3GPP TS 23.501, version 16.3.0 (2019-12). While FIG. 1 and further parts of the following description illustrate techniques in the 3GPP 5G framework of a cellular NW, similar techniques may be readily applied to other communication protocols. Examples include 3GPP LTE 4G—e.g., in the MTC or NB-IOT framework—and even non-cellular wireless systems, e.g., an IEEE Wi-Fi technology.

(44) In the scenario of FIG. 1, a UE **102** is connectable to the cellular NW **100** via a data connection. For example, the UE **102** may be one of the following: a cellular phone; a smart phone; an IOT device; a MTC device; a sensor; an actuator; etc.

(45) The UE **102** is connectable to a core NW (CN) **115** of the cellular NW **100** via a RAN **111**, typically formed by one or more BSs **101** (only a single BS **101** is illustrated in FIG. 1 for sake of simplicity). A wireless link **114** is established between the RAN **111**—specifically between one or more of the BSs **101** of the RAN **111**—and the UE **102**.

(46) The wireless link **114** implements a time-frequency resource grid. Typically, OFDM is used: here, a carrier includes multiple subcarriers. The subcarriers (in frequency domain) and the symbols (in time domain) then define time-frequency resource elements of the time-frequency resource grid. Thereby, a protocol time base is defined, e.g., by the duration of frames and subframes including multiple symbols and the start and stop positions of the frames and subframes. Different time-frequency resource elements can be allocated to different logical channels or RSs of the wireless link **114**. Examples include: Physical DL Shared Channel (PDSCH); Physical DL Control Channel (PDCCH); Physical UL Shared Channel (PUSCH); Physical UL Control Channel (PUCCH); channels for random access; etc. For FDD, the PUCCH and PUSCH are communicated on the wireless link **114** in the UL frequency band **601** and the PDCCH and the PDSCH are in the DL frequency band **602** (hence, the names “UL frequency band” and “DL frequency band”).

(47) The CN **115** includes a user plane (UP) **191** and a control plane (CP) **192**. Application data—e.g., of a data service—is typically routed via the UP **191**. For this, there is provided a UP function (UPF) **121**. The UPF **121** may implement router functionality. Application data may pass through one or more UPFs **121**. In the scenario of FIG. **1**, the UPF **121** acts as a gateway towards a data NW (DN) **180**, e.g., the Internet or a Local Area NW. Application data can be communicated between the UE **102** and one or more servers **181** of the data NW **180**. The server **181** can execute an application that provides a service associated with the application data.

(48) The cellular NW **100** also includes a mobility-control node, here implemented by an Access and Mobility Management Function (AMF) **131**. The cellular NW **100** also includes a session-control node, here implemented by a Session Management Function (SMF) **132**. The cellular NW **100** further includes a Policy Control Function (PCF) **133**; a NW Slice Selection Function (NSSF) **135**; an Authentication Server Function (AUSF) **136**; and a Unified Data Management (UDM) **137**.

(49) FIG. **6** also illustrates the protocol reference points N1-N22 between these nodes.

(50) The AMF **131** provides one or more of the following functionalities: connection management sometimes also referred to as registration management; NAS termination for communication between the CN **115** and the UE **102**; connection management; reachability management; mobility management; connection authentication; and connection authorization. After UE registration to the NW, the AMF **131** creates a UE context **459** and keeps this UE context, at least as long as the UE **102** is registered to the cellular NW **100**. The UE context **459** can hold one or more identities of the UE **102** (UE ID), e.g., temporary identities.

(51) The SMF **132** supports a data connection **189**. The data connection **189** is established by the SMF **132** if the respective UE **102** operates in a connected connection mode. The data connection **189** is established on the wireless link **114**. The wireless link **114** can pertain to the underlying physical medium and the data connection **189** can include a set of logical channels, scheduling rules, etc. The data connection **189** may include one or more data flows or bearers such as a dedicated data flow/bearer or a default data flow/bearer. The state of the data connection is also defined on the RRC layer, e.g., generally Layer 3 of the OSI model. The SMF **132** provides one or more of the following functionalities: session management including session establishment, modify and release, including data flow/bearer set up of UP data flows/bearers between the RAN **111** and the UPF **121**; selection and control of UPFs; configuring of traffic steering; etc.

(52) FIG. **7** illustrates aspects with respect to different connection modes **401-402** in which the UE **102** can operate according to various examples. When operating in the connected connection mode **401**, the data connection **189** between the UE **102** and the cellular NW **100** is established. Application data can be communicated to and from the UE **102**. A transition into the connected connection mode **401** is referred to as initial access.

(53) When operating the UE **102** in the idle connection mode **402**, the data connection **189** is released. It would be possible that the AMF **131** maintains the UE context **459**. The UE **102** can use a discontinuous reception cycle (DRX) cycle that alternately switches the interface **1022** between an inactive state and an active state. The interface **1022**—when operating in the inactive state—

may not be able to RX any signals. E.g., an amplifier or an analogue to digital converter or parts of the digital front end may be switched off. On the other hand, the interface **1022**—when operating in the active state—may be able to RX signals, e.g., paging signals.

(54) To transition from the idle connection mode **402** to the connected connection mode **401**, a random-access (RA) procedure may be performed. The RA procedure includes transmitting a RA preamble at a RA occasion (RO). Details with respect to the ROs are illustrated in FIG. **8**.

(55) FIG. **8** schematically illustrates aspects with respect to synchronization signal blocks (SSBs). FIG. **8** illustrates that the BS **101** transmits multiple SSBs **411** at different resources, e.g., time-frequency and/or code resources. The SSBs are transmitted in the DL frequency band **602**.

(56) The SSBs **411** can facilitate a cell search for the UE **102** during initial access. An SSB **411** can, e.g., include a primary synchronization signal (SS) and a secondary SS. The primary SS and the secondary SS implement RSs. The SSBs **411** can include a physical broadcast channel (PBCH). The PBCH carries a master information block and uses a specific modulation, typically quadrature phase shift keying, for reliable reception.

(57) Within an SSB **411**, the primary SS and the secondary SS are for the UE **102** to lock into the correct frequency and time. There is also some identity of the transmitting BS **101** encoded into the combined SS. When in sync, the UE **102** can extract information about the associated RA channel allocation from the PBCH.

(58) The SSBs **411** can be repeatedly or periodically transmitted by the BS **101**, e.g., on predefined time-frequency resources of the time-frequency resource grid.

(59) It is possible that a burst **410** of SSBs **411** is transmitted, employing a beamsweep **360** including the DL TX beams **361-364**. Thereby, spatial coverage can be increased. Typically, the burst may have a duration of, e.g., up to 5 ms. The periodicity with which the bursts are transmitted may be 20 ms to 160 ms.

(60) The SSBs **411** transmitted on different DL TX beams **361-364** can have a different SSB time index. Thus, different SSBs **411**—i.e., having different SSB time indices—are associated with different ROs **415-418**.

(61) FIG. **8** also illustrates aspects with respect to the ROs **415-418**. As illustrated in FIG. **8**, there is an association **419** between SSBs **411** of the burst **410** having different SSB time indices, and multiple ROs **415-418**. The different ROs **415-418** are arranged at different times, frequencies or employ different—e.g., orthogonal—codes for the RA preamble.

(62) The association **419** is typically implemented by pre-defining a number of SSB time indices per RO. This number can be larger than one which corresponds to multiple SSBs being associated with a single RO. The number can also be smaller than one which corresponds to a single SSB corresponding to multiple ROs. The SSBs (e.g., in ascending order of the time index) are then associated with the ROs, firstly, in frequency domain; secondly, in time domain within a slot; and thirdly in time domain between RA slots.

(63) By selecting the appropriate ROs **415-418**, the UE **102** can indicate—according to reference implementations—which DL TX beam **361-364** was best. This enables to establish an appropriate beam pair during initial access.

(64) Typically, the BS **101** monitors the ROs **415-418** using UL RX beams **351*-354***. These UL RX beams **351*-354*** can correspond to the DL TX beams **361-364** used for transmitting the SSBs **411**, as illustrated in FIG. **8**. For example, the same spatial filter may be used. It would be possible to use the same antenna weights or a scaled version of these antenna weights.

(65) Various techniques are based on the finding that the UE **102** accesses a particular RRO **415-418** by transmitting in the UL frequency band **601**. Here, the corresponding UL RX beams **351*-354*** used by the BS **101** to monitor the RO **415-418**—due to nonreciprocity—may not be ideal for receiving the signal transmitted by the UE **102**.

(66) This can impair the signal-to-noise ratio. According to various techniques described herein, such drawbacks can be mitigated.

(67) FIG. 9 is a signaling diagram of communication between the UE 102 and the BS 101.

(68) In the example of FIG. 9, the communication between the BS 101 and the UE 102 on the wireless link 114 uses FDD in the frequency bands 601, 602.

(69) Prior to initiating the RA procedure 600, the UE 102 monitors for SSBs 411 transmitted by the BS 101. This transmission is implemented using a beamsweep, e.g., the beamsweep 360 (cf. FIG. 8). The SSBs 411 transmitted at 6501 thus form a burst 410. The SSBs 411 are transmitted in the DL frequency band 602.

(70) Next, at 6502, DL RSs—here implemented by channel state information RSs (CSI-RSs) 6052—are transmitted. The CSI-RS 6052 are transmitted in the UL frequency band 601. The CSI-RSs 6052 can be transmitted in a burst, using a DL TX beamsweep. It would be possible that scheduling information for the CSI-RS 6052 is included in an information block broadcasted by the BS 101, e.g., in the SSBs 411. More generally, the scheduling information indicative of time-frequency resources that include the CSI-RSs 6052 may be transmitted using control signaling on the DL frequency band 602. Alternatively or additionally to such scheduling information, it would also be possible that configuration information is broadcasted by the BS 101, the configuration information being indicative of whether the transmission of the CSI-RS 6052 is activated or deactivated. For example, some cells of the cellular NW 100 may use the CSI-RSs 6052 being transmitted in the UL frequency band 601, while other cells may not transmit the CSI-RSs 6052 in the UL frequency band 601.

(71) As a general rule, the same or different DL TX beams may be used for transmitting the SSB 411 and the CSI-RS 6052; i.e., the same or different spatial filters may be used.

(72) The UE 102 monitors for the SSBs at 6501 and for the CSI-RSs 6052 at 6502.

(73) Based on the SSBs 411, the UE 102 can synchronize with the BS 101.

(74) The UE 102 can then—optionally—monitor for paging indicators and paging messages (paging signals) 6000. Blind decoding of the PDCCH for receiving the paging indicator can be implemented. Upon receiving the paging signal 6000 at 6503 (in the DL frequency band 602), initial access is then triggered using the RA procedure 600.

(75) Paging signals are one possible trigger criterion for the initial access. Other trigger criteria may be considered alternatively or additionally. For example, power-up or UE-originating data may be other trigger criteria for the initial access.

(76) At 6504, based on the SSBs 411 and the CSI-RSs 6052, the UE 102 transmits a RA preamble to the BS 101, in a respective RAmSg1 6001. This RAmSg1 6001 may be indicative of a temporary identity of the UE 102.

(77) In response to transmitting the RAmSg1 6001, the UE 102 receives, at 6505, a RA response message, the RAmSg2 6002. The RAmSg2 includes a new temporary identity for the UE 102, timing adjustment information, and an UL scheduling grant for time-frequency resources. The UL scheduling grant may be addressed to the UEs 102 RA Radio NW Temporary Identity (RA-RNTI). Using these UL resources indicated by the UL scheduling grant included in the RAmSg2 6002, the UE 102 sends, at 6506, a RRC connection request RAmSg3 6003. In response to the RRC connection request 6003, the UE 102 receives, at 6507, a contention resolution message RAmSg4 6004 to ensure the right UE is addressed. This finalizes or aborts establishment of the data connection 189. The UE 102 is then transitioned into operation into the connected connection mode 402.

(78) Early data 6011—e.g., application data or RRC control data—can be included in the RAmSg3 6003 and/or the RAmSg4 6004.

(79) By transmitting the CSI-RS 6052 in the UL frequency band 601, improved beam management becomes possible. This is explained in connection with FIG. 10.

(80) FIG. 10 illustrates aspects with respect to the logic at the UE 102 for selecting the appropriate RO 415-418. FIG. 10 illustrates details of FIG. 9.

(81) At 6501, transmission of the SSBs 411 in the DL band 602 using the DL TX beams 361-364 is

illustrated (also cf. FIG. 8). As illustrated by the arrow, the UE **102** receives only the SSB **411** transmitted using the TX beam **363**.

(82) At **6502**, the CSI-RS **6052** are transmitted in a burst, using the DL TX beams **351-354**. As a general rule, the DL TX beams **351-354** may be the same or different as the DL TX beams **361-364**. I.e., the same or different spatial filters may be used.

(83) As illustrated by the arrow, the UE **102** only receives the CSI-RS **6052** transmitted using the TX beam **352**. The CSI-RS **6052** transmitted on the remaining beams **351, 353-354** are not received.

(84) As is apparent from a comparison of the DL TX beams **361-364** and the DL TX beams **351-354**, due to the different transmission frequencies, the best spatial characteristic differs between the frequencies in the UL frequency band **601** and the DL frequency band **602**.

(85) The DL TX beams **351-354** in the UL frequency band **601** can be mapped to the ROs **415-418**. For example, such mapping can be in accordance with one or more mappings and/or the association **419** (cf. FIG. 8); such one or more mappings can be predefined in the standard. The one or more predefined mappings can be fixed, or can depend on certain configuration parameters provided by the cellular NW **100**, e.g., in the system information of the BS **101**. A few options for such direct or indirect mapping of the DL TX beams **351-354** in the UL frequency band **601** to the ROs **415-418** are illustrated in the TAB. 1 below.

(86) TABLE-US-00001 TABLE 1 Various options for mapping from DL TX beams 351-354 in UL frequency band 601 to ROs 415-418 A Mapping: DL TX beams 351-354 in UL frequency band 601 >> DL TX beams 361-364 in DL frequency band 602 DL TX beams 361-364 are associated with SSBs 411 and thus with ROs 415-418 (cf. FIG. 8) B (Direct) Mapping DL TX beams 351-354 in UL frequency band 601 >> ROs 415-418

(87) FIG. 10 also illustrates a mapping **359** between the DL TX beams **351-354** in the UL frequency band **601** and the DL TX beams **361-364** in the DL frequency band **602**. FIG. 10 generally corresponds to example A of TAB. 1.

(88) In a simple scenario, the DL TX beams **351-354** are the same as the DL TX beams **361-364**. Then, the mapping can reflect this.

(89) Sometimes, different DL TX beams **351-354, 361-364** in the UL frequency band **601** and in the DL frequency band **602**. Then, the mapping **359** may be set in accordance with a spatial coverage characteristic of the various DL TX beams **351-354, 361-364**: for example, the DL TX beam **351** covers a corresponding spatial surrounding of the BS **101** as the DL TX beam **361** and, accordingly, the DL TX beam **351** is mapped by the mapping **359** to the DL TX beam **361**.

(90) As illustrated in FIG. 10, the UE **102** selects—at **6504**—the RO **416** for transmitting the RA preamble, i.e., the RA message **1 6001**. This selection is based on the monitoring of the CSI-RS **6052** at **6502** (rather than based on the monitoring of the SSBs **411** at **6501**). Specifically, the RO **416** is selected, because the CSI-RS **6052** transmitted using the DL TX beam **352** is received (while the CSI-RS **6052** transmitted using the TX beams **351, 353-354** are not received or received at a lower amplitude or lower signal-to-noise ratio).

(91) In detail, the DL TX beam **352** is “seen” at a strong amplitude and/or large signal-to-noise ratio at the UE **102**. Because the DL TX beam **352** is in the UL frequency band **601**, the assumption is that reception by the BS **101** using the UL RX beam **352*** corresponding to the DL TX beam **352** (cf. FIG. 8) also exhibits a large signal-to-noise ratio, i.e., under the assumption of channel reciprocity. The UL RX beam **352*** is used by the BS **101** at the RO **416**. The RO **416**, in turn, is associated with the SSB **411** transmitted using the DL TX beam **362** in the DL frequency band **602**. The DL TX beam **362** is mapped to DL TX beam **352**. Thus, in other words, based on the monitoring of the CSI-RS **6052** at **6502**, the UE **102** can determine the DL TX beam **352**. Based on the DL TX beam **362** mapped to the DL TX beam **352** (using the predefined mapping **359**), it is then possible to select the RO **416**.

(92) As a general rule, the mapping **359** may be indicated in broadcasted information, e.g., an

information block included in the PBCH. The mapping **359** could also be fixedly set. The UE **102** can identify the DL TX beam **352**, because the CSI-RS **6052** is indicative of the DL TX beam **352**. The CSI-RS **6052** may be indicative of the DL TX beam **352**, e.g., explicitly—e.g., by using a beam identity in the sequence generation of the CSI-RS **6052**—or implicitly—e.g., by using a predefined association between CSI-RSs **6052** and DL TX beams **351-354**.

(93) Accordingly, the UE **102** accesses the RO **416**. In detail, the UE **102** may transmit the RAm_{sg}**1 6001** using the UL TX beam **382**; the determining of the UL TX beam **382** is not germane for the functioning of the techniques described herein and is therefore not discussed in detail.

(94) The BS **101** can receive the RAm_{sg}**1 6001** transmitted at **6504** using the UL RX beam **352***, during the RO **416**.

(95) The UE **102** also provides an indication of the DL TX beam **363** to the BS **101**. The DL TX beam **363** has been determined by the UE **102** as the strongest one of the DL TX beams **361-364**, based on the monitoring for the SSBs **411**. The DL TX beam **363** is determined to be the best beam in the DL frequency band **602**. According to reference techniques, this indication would be provided by selecting the RO **417** (cf. FIG. **8**). However, as explained above, the RO **416** is selected. Accordingly, the indication of the DL TX beam **363** is provided differently. In the illustrated example, the RAm_{sg}**1 6001** is indicative—e.g., by means of preamble partitioning—of the DL TX beam **363**. Another option would be to indicate the DL TX beam **363** as part of the EDT **6011** in the RAm_{sg}**3 6003**.

(96) Accordingly, at **6505**, the BS **101** transmits the RAm_{sg}**2 6002** using the DL TX beam **363**.

(97) In the example of FIG. **10**, the DL TX beam **363** used for transmitting in the DL frequency band **602** differs from the UL RX beam **352** used for receiving in the UL frequency band **601**. The RO **416** thus is not associated with the DL TX beam **363** (rather, it is associated with the DL TX beam **362**, cf. FIG. **8**). For this reason, the UE **102** provides the explicit indication of the DL TX beam **363**. It would be possible that the explicit indication of the DL TX beam **361-364** seen strongest by the UE **102** is only provided if there is a discrepancy between the access RO **415-418** and the DL TX beam **361-364** selected. In other words, it would be possible that the RAm_{sg}**1** includes an explicit indicator indicative of the selected DL TX beam **361-364** only if the selected DL TX beam **361-364** is not associated by the association **419** with the accessed RO **415-418**.

(98) FIG. **11** is a flowchart of a method according to various examples. The method of FIG. **11** may be executed by a UE of a communication system. For example, the method of FIG. **11** may be executed by the UE **102**. More specifically, it would be possible that the method of FIG. **11** is executed by the processor **1021** of the UE **102**, upon loading program code from the memory **1025**.

(99) At box **8001**, the UE monitors for second RSs in a DL frequency band defined in accordance with FDD operation. For instance, the UE can monitor for the second RSs included in SSBs, e.g., PSS or SSS. The second RSs are transmitted using second DL TX beams in the DL frequency band. See FIG. **9**: **6501**.

(100) At box **8002**, the UE can then select the strongest/best one of the second DL TX beams, e.g., by comparing a receive amplitude among the received second RSs.

(101) At box **8011**, the UE monitors for first RSs in an UL frequency band defined in accordance with the FDD operation. For instance, the UE can monitor for CSI-RSs. The first RSs are transmitted using first DL TX beams in the UL frequency band.

(102) At box **8012**, the strongest/best first DL TX beam is selected, e.g., based on comparing the receive amplitude among the received first RSs.

(103) Then, at box **8013**, a second DL TX beam in the DL frequency band is determined, based on the strongest first DL TX beam that is selected at box **8012**. This can be done in accordance with a predefined mapping. For example, details with respect to a possible mapping **359** have been explained in connection with FIG. **10**. The second DL TX beam determined at box **8013** may sometimes be different from the selected second DL TX beam of box **8002**.

(104) Next, at box **8014**, the appropriate RO is selected from multiple ROs, based on the

determined second DL TX beam in the DL frequency band of box **8013**.

(105) At box **8015**, the RAm_{sg1} is transmitted at the selected RO of box **8014**. Preamble partitioning can be used in order to indicate the strongest second DL TX beam, selected at box **8002**. Preamble partitioning means that different sets of candidate preambles are available and the selection of a preamble from the given set is indicative of the respective strongest DL TX beam. Box **8115** corresponds to box **8015** (cf. FIG. **11**).

(106) Then, at box **8016**, the RAm_{sg2} is received; the RAm_{sg2} is transmitted using the strongest second DL TX beam selected at box **8002**.

(107) At box **8017**, the RAm_{sg3} is transmitted.

(108) FIG. **12** is a flowchart of a method according to various examples. The method of FIG. **12** may be executed by an access node of a communication system. For instance, the method of FIG. **12** may be executed by a BS of a cellular network, e.g., by the BS **101**. More specifically, it would be possible that the method of FIG. **12** is executed by the processor **1011** of the BS **101**, upon loading program code from the memory **1015**.

(109) At box **8101**, second DL RSs are transmitted in the DL frequency band. Box **8101** corresponds to box **8001** (cf. FIG. **11**).

(110) At box **8111**, first DL RSs are transmitted in the UL frequency band. Box **8111** corresponds to box **8011** (cf. FIG. **11**).

(111) At box **8115**, RAm_{sg1} is received in an RO. The RAm_{sg1} is indicative of a strongest DL TX beam. For instance, the RAm_{sg1} can include a respective explicit indicator or preamble partitioning may be employed; if the RAm_{sg1} does not explicitly indicate the strongest DL TX beam, the strongest DL TX beam is the one that is associated with the RO in which the RAm_{sg1} is received (cf. FIG. **8**: association **419**).

(112) At box **8116**, the BS then transmits the RAm_{sg2} using the strongest DL TX beam as explicitly or implicitly indicated at box **8115**.

(113) At box **8117**, the RAm_{sg3} is received. The BS uses the UL RX beam that is associated with the RO in which the RAm_{sg1} is received at box **8115**. In detail, the UL RX beam may be obtained from using the same spatial filter as the DL RX beam used for transmitting the SSB that is associated with the RO in which the RAm_{sg1} is received at box **8115**.

(114) Although the invention has been shown and described with respect to certain preferred embodiments, equivalents and modifications will occur to others skilled in the art upon the reading and understanding of the specification. The present invention includes all such equivalents and modifications and is limited only by the scope of the appended claims.

(115) For illustration, various examples have been described in connection with DL RSs that are implemented as CSI-RS. However, it is possible to use other kinds and types of DL RSs in connection with the techniques described herein.

(116) For further illustration, various examples have been described in connection with the management for initial access. However, the techniques described herein are not limited to initial access. For example, it would be possible to use DL RSs transmitted in the UL band while the UE operates in the connected connection mode.

(117) For still further illustration, above, various techniques have been described in which a 4-step RA procedure is used. Similar techniques may also be applied for a 2-step RA procedure. As a general rule, the 2-step RA procedure relies on a combination of RAm_{sg1} and RAm_{sg3} into RAm_{sgA}, and on a combination of RAm_{sg2} and RAm_{sg4} into RAm_{sgB}.

Claims

1. A method of operating a wireless communication device configured to communicate with a communications network using frequency duplex transmission in an uplink frequency band and in a downlink frequency band, the method comprising: monitoring for first downlink reference signals

transmitted by an access node of the communications network in the uplink frequency band and using multiple first downlink transmit beams, and monitoring for second downlink reference signals transmitted by the access node of the communications network in the downlink frequency band and using multiple second downlink transmit beams, wherein the second downlink reference signals are transmitted using the multiple second downlink transmit beams being associated with multiple random-access occasions, and wherein the method further comprising: selecting a random-access occasion from the multiple random-access occasions based on said monitoring of the first downlink reference signals, and transmitting, in the uplink frequency band, a random-access message to the communications network in the selected random-access occasion.

2. The method of claim 1, further comprising: based on said monitoring of the first downlink reference signals: determining a first downlink transmit beam of the multiple first downlink transmit beams, wherein the random-access occasion is mapped to the determined first downlink transmit beam.

3. The method of claim 2, wherein the random-access occasion is selected from the multiple random-access occasions based on a second downlink transmit beam of the multiple second downlink transmit beams that is determined based on a predefined mapping between the multiple first downlink transmit beams and the multiple second downlink transmit beams, or wherein the random-access occasion is selected from the multiple random-access occasions based on a predefined mapping between the multiple first downlink transmit beams and the multiple random-access occasions.

4. The method of claim 1, further comprising: based on said monitoring of the second downlink reference signals: selecting a second downlink transmit beam from the multiple second downlink transmit beams, and providing an indication of the selected second downlink transmit beam to the communications network.

5. The method of claim 4, wherein the random-access message is indicative of the selected second downlink transmit beam.

6. The method of claim 5, wherein the random-access message comprises an explicit indicator indicative of the selected second downlink transmit beam if the selected second downlink transmit beam is not associated with the selected random-access occasion.

7. The method of claim 1, further comprising: receiving scheduling information for the first downlink reference signals in the downlink frequency band.

8. The method of claim 1, further comprising: receiving a configuration information indicative of transmission of the first downlink reference signals in the uplink frequency band.

9. A method of operating an access node of a communications network, the access node configured to communicate with a wireless communication device using frequency duplex transmission in an uplink frequency band and in a downlink frequency band, the method comprising: transmitting first downlink reference signals in the uplink frequency band and using multiple first downlink transmit beams, and transmitting second downlink reference signals in the downlink frequency band and using multiple second downlink transmit beams, wherein the second downlink reference signals are transmitted using the multiple second downlink transmit beams being associated with multiple random-access occasions, and wherein the method further comprising: monitoring, in the multiple random-access occasions, and using multiple uplink receive beams for a random-access message transmitted by the wireless communication device in the uplink frequency band; and selecting an uplink receive beam from the multiple uplink receive beams based on said monitoring.

10. The method of claim 9, further comprising: obtaining an indication of a second downlink transmit beam of the multiple second downlink transmit beams from the wireless communication device, selecting the second downlink transmit beam from the multiple second downlink transmit beams in accordance with the indication.

11. The method of claim 10, wherein the random-access message provides the indication of the second downlink transmit beam.

12. A wireless communication device configured to communicate with a communications network using frequency duplex transmission in an uplink frequency band and in a downlink frequency band, the wireless communication device comprising control circuitry configured to: monitor for first downlink reference signals transmitted by an access node of the communications network in the uplink frequency band and using multiple first downlink transmit beams, and monitor for second downlink reference signals transmitted by the access node of the communications network in the downlink frequency band and using multiple second downlink transmit beams, wherein the second downlink reference signals are transmitted using the multiple second downlink transmit beams being associated with multiple random-access occasions, and wherein the control circuitry is further configured to: select a random-access occasion from the multiple random-access occasions based on said monitoring of the first downlink reference signals, and transmit, in the uplink frequency band, a random-access message to the communications network in the selected random-access occasion.
