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User equipment uplink beam sweeping based on a trigger rule

Abstract

A user equipment (UE) of a wireless communication network receives conditions for sweeping beams between a base station of the network and the UE. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. The UR measures at least one characteristic of each of the beams in accordance with the measurement configuration. After the measuring, the UE detects a trigger in accordance with the trigger rule. In response to detecting the trigger, the UE sweeps the beams on uplink based on the measuring.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS

(1) This application is a National Phase entry of PCT Application No. PCT/US2021/026023, entitled “BEAM SWEEPING” and filed on Apr. 6, 2021, which claims priority of Greek application Ser. No. 20200100178, entitled “BEAM SWEEPING” and filed on Apr. 7, 2020, both of which are expressly incorporated by reference herein in their entirety.

BACKGROUND

Technical Field

(2) The present disclosure relates generally to communication systems, and more particularly in some examples, to control of beam sweeping across beams of a channel between user equipment (UE) of a wireless communication network and a base station of the network.

Introduction

(3) Wireless communication systems are widely deployed to provide various telecommunication services such as telephony, video, data, messaging, and broadcasts. Typical wireless communication systems may employ multiple-access technologies capable of supporting communication with multiple users by sharing available system resources. Examples of such multiple-access technologies include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems, single-carrier frequency division multiple access (SC-FDMA) systems, and time division synchronous code division multiple access (TD-SCDMA) systems. These multiple access technologies have been adopted in various telecommunication standards to provide a common protocol that enables different wireless devices to communicate on a municipal, national, regional, and even global level. An example telecommunication standard is 5G New Radio (NR). 5G NR is part of a continuous mobile broadband evolution promulgated by Third Generation Partnership Project (3GPP) to meet new requirements associated with latency, reliability, security, scalability (e.g., with Internet of Things (IoT)), and other requirements. 5G NR includes services associated with enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable low latency communications (URLLC). Some aspects of 5G NR may be based on the 4G Long Term Evolution (LTE) standard. There exists a need for further improvements in 5G NR technology. These improvements may also be applicable to other multi-access technologies and the telecommunication standards that employ these technologies.

SUMMARY

(4) The following presents a simplified summary of one or more aspects in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated aspects, and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present some concepts of one or more aspects in a simplified form as a prelude to the more detailed description that is presented later.

(5) The technology disclosed herein includes method, apparatus, and computer-readable media including instructions for wireless communication. In such technology, a UE receives conditions for sweeping beams between a base station of the network and the UE. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. The UE measures at least one characteristic of each of the beams in accordance with the measurement configuration. After the measuring, the UE detects a trigger in accordance with the trigger rule. In response to detecting the trigger, the UE

sweeps the beams on uplink based on the measuring.

(6) In some examples, the base station first transmits, to a UE, conditions for sweeping beams between the UE and the base station. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. The base station second transmits, by the base station after the first transmitting, a reference signal over the beams on downlink. The base station receives, in response to the first and second transmitting and from the UE, downlink beam measurements in accordance with the beam measurement configuration. The base station prepares, in response to the receiving, at least one beam not currently used in downlink. The base station also receives, on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule. The base station then transmits at least one physical channel on at least one prepared beam to the UE.

(7) In some examples, the base station transmits, to a UE of the network, a beam sweeping configuration specifying a reference signal. The base station measures at least one characteristic of each of a plurality of beams of a physical channel, each of the beams comprising the specified reference signal, from the UE to the base station on uplink. The measured beams include each beam currently in use for communication between the base station and the UE and a plurality of beams not currently in use for downlink data transfer to the UE. The base station detects, after the measuring, a beam sweeping trigger condition. The base station sweeps, in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration.

(8) In some examples, the UE receives, from a base station, a beam sweeping configuration specifying a reference signal. The UE transmits, on each of a plurality of beams of a physical channel, the specified reference signal to the base station. The beams include each beam currently in use for data transfer between the base station and the UE and a plurality of beams not currently in use for data transfer to the UE from the base station. The UE receives a plurality of the transmitted beams swept on downlink to the UE, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE.

(9) To the accomplishment of the foregoing and related ends, the one or more aspects comprise the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative features of the one or more aspects. These features are indicative, however, of but a few of the various ways in which the principles of various aspects may be employed, and this description is intended to include all such aspects and their equivalents.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a diagram illustrating an example of a wireless communications system and an access network.

(2) FIGS. **2**A, **2**B, **2**C, and **2**D are diagrams illustrating examples of a first 5G/NR frame, DL channels within a 5G/NR subframe, a second 5G/NR frame, and UL channels within a 5G/NR subframe, respectively.

(3) FIG. **3** is a diagram illustrating a base station and user equipment (UE) in an access network, in accordance with examples of the technology disclosed herein.

(4) FIG. **4** is a diagram illustrating relationships between a UE and a base station for wireless communication, in accordance with examples of the technology disclosed herein.

(5) FIG. **5** is a message flow diagram of methods of wireless communication in accordance with examples of the technology disclosed herein.

(6) FIG. **6** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(7) FIG. **7** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(8) FIG. **8** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(9) FIG. **9** is a block diagram of a UE, in accordance with examples of the technology disclosed herein.
(10) FIG. **10** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(11) FIG. **11** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(12) FIG. **12** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(13) FIG. **13** is a block diagram of a base station, in accordance with examples of the technology disclosed herein.
(14) FIG. **14** is a diagram illustrating relationships between a UE and a base station for wireless communication, in accordance with examples of the technology disclosed herein.
(15) FIG. **15** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(16) FIG. **16** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(17) FIG. **17** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(18) FIG. **18** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(19) FIG. **19** is a block diagram of a base station, in accordance with examples of the technology disclosed herein.
(20) FIG. **20** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(21) FIG. **21** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(22) FIG. **22** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(23) FIG. **23** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(24) FIG. **24** is a flowchart of methods of wireless communication in accordance with examples of the technology disclosed herein.
(25) FIG. **25** is a block diagram of a UE, in accordance with examples of the technology disclosed herein.

DETAILED DESCRIPTION

(26) The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

(27) In some frequency ranges, for example the “millimeter wave” (mmW) range of 5G, radio waves are more susceptible to blockage and interference compared to the low frequency waves that

operate in earlier wireless communication systems. That means mmWs may easily be disrupted/blocked—for instance, by the hand or head of someone using a UE. Use cases for 5G NR such as mMTC and URLLC may use beam diversity/redundancy in the physical channels between base stations and UEs to address the possibility of blocking while maintaining the quality of service expected of those use cases.

(28) This approach, while generally effective, can still be less effective than desired under certain circumstances. For example, where a mmW downlink transmission between a 5G base station and a 5G UE is blocked, the UE can eventually declare beam failure or radio link failure and issue a new random-access request to the network. However, the random-access process may require dozens of one millisecond cycles to complete—a delay much too long for 5G usage scenarios such as mMTC and URLLC.

(29) In aspects of the present disclosure, methods, non-transitory computer readable media, and apparatuses are provided. In some examples of the technology disclosed herein, a UE receives conditions for sweeping beams between a base station of the network and the UE. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. The UE measures at least one characteristic of each of the beams in accordance with the measurement configuration. After the measuring, the UE detects a trigger in accordance with the trigger rule. In response to detecting the trigger, the UE sweeps the beams on uplink based on the measuring.

(30) In some aspects, the base station first transmits, to a UE, conditions for sweeping beams between the UE and the base station. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. The base station second transmits, by the base station after the first transmitting, a reference signal over the beams on downlink. The base station receives, in response to the first and second transmitting and from the UE, downlink beam measurements in accordance with the beam measurement configuration. The base station prepares, in response to the receiving, at least one beam not currently used in downlink. The base station also receives, on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule. The base station then transmits at least one physical channel on at least one prepared beam to the UE.

(31) In some aspects, the base station transmits, to a UE of the network, a beam sweeping configuration specifying a reference signal. The base station measures at least one characteristic of each of a plurality of beams of a physical channel, each of the beams comprising the specified reference signal, from the UE to the base station on uplink. The beams measured beams including each beam currently in use for communication between the base station and the UE and a plurality of beams not currently in use for downlink data transfer to the UE. The base station detects, after the measuring, a beam sweeping trigger condition. The base station sweeps, in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration.

(32) In some aspects, the UE receives, from a base station, a beam sweeping configuration specifying a reference signal. The UE transmits, on each of a plurality of beams of a physical channel, the specified reference signal to the base station. The beams include each beam currently in use for data transfer between the base station and the UE and a plurality of beams not currently in use for data transfer to the UE from the base station. The UE receives a plurality of the transmitted beams swept on downlink to the UE, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE.

(33) To the accomplishment of the foregoing and related ends, the one or more aspects comprise the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative features of the one or more aspects. These features are indicative, however, of but a few of the various ways in which the

principles of various aspects may be employed, and this description is intended to include all such aspects and their equivalents

(34) Several aspects of telecommunication systems will now be presented with reference to various apparatus and methods. These apparatus and methods will be described in the following detailed description and illustrated in the accompanying drawings by various blocks, components, circuits, processes, algorithms, etc. (collectively referred to as “elements”). These elements may be implemented using electronic hardware, computer software, or any combination thereof. Whether such elements are implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. By way of example, an element, or any portion of an element, or any combination of elements may be implemented as a “processing system” that includes one or more processors. Examples of processors include microprocessors, microcontrollers, graphics processing units (GPUs), central processing units (CPUs), application processors, digital signal processors (DSPs), reduced instruction set computing (RISC) processors, systems on a chip (SoC), baseband processors, field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. One or more processors in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software components, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise.

(35) Accordingly, in one or more example embodiments, the functions described may be implemented in hardware, software, or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise a random-access memory (RAM), a read-only memory (ROM), an electrically erasable programmable ROM (EEPROM), optical disk storage, magnetic disk storage, other magnetic storage devices, combinations of the aforementioned types of computer-readable media, or any other medium that can be used to store computer executable code in the form of instructions or data structures that can be accessed by a computer.

(36) FIG. **1** is a diagram illustrating an example of a wireless communications system and an access network **100**. The wireless communications system (also referred to as a wireless wide area network (WWAN)) includes base stations **102**, UEs **104**, an Evolved Packet Core (EPC) **160**, and another core network **190** (e.g., a 5G Core (5GC)). The base stations **102** may include macrocells (high power cellular base station) and/or small cells (low power cellular base station). The macrocells include base stations. The small cells include femtocells, picocells, and microcells. The base stations **102** configured for 4G LTE (collectively referred to as Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN)) may interface with the EPC **160** through first backhaul links **132** (e.g., S1 interface). The base stations **102** configured for 5G NR (collectively referred to as Next Generation RAN (NG-RAN)) may interface with core network **190** through second backhaul links **186**. In addition to other functions, the base stations **102** may perform one or more of the following functions: transfer of user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (e.g., handover, dual connectivity), inter-cell interference coordination, connection setup and release, load balancing, distribution for non-access stratum (NAS) messages, NAS node selection, synchronization, radio access network (RAN) sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations **102** may communicate directly or

indirectly (e.g., through the EPC **160** or core network **190**) with each other over third backhaul links **134** (e.g., X2 interface). The first, second and third backhaul links **132**, **186** and **134** may be wired or wireless.

(37) The base stations **102** may wirelessly communicate with the UEs **104**. Each of the base stations **102** may provide communication coverage for a respective geographic coverage area **110**. There may be overlapping geographic coverage areas **110**. For example, the small cell **102′** may have a coverage area **110′** that overlaps the coverage area **110** of one or more macro base stations **102**. A network that includes both small cell and macrocells may be known as a heterogeneous network. A heterogeneous network may also include Home Evolved Node Bs (eNBs) (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG). The communication links **120** between the base stations **102** and the UEs **104** may include uplink (UL) (also referred to as reverse link) transmissions from a UE **104** to a base station **102** and/or downlink (DL) (also referred to as forward link) transmissions from a base station **102** to a UE **104**. The communication links **120** may use multiple-input and multiple-output (MIMO) antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. In some examples of the technology disclosed herein, both the DL and the UL between the base station and a UE use the same set of multiple beams to transmit/receive physical channels. For example, a given set of beams can carry the multiple copies of a Physical Downlink Shared Channel (PDSCH), described further infra, on the DL and can carry multiple copies of a Physical Uplink Control Channel (PUCCH), also described further infra, on the UL.

(38) The communication links may be through one or more carriers. The base stations **102**/UEs **104** may use spectrum up to Y MHz (e.g., 5, 10, 15, 20, 100, 400, etc. MHz) bandwidth per carrier allocated in a carrier aggregation of up to a total of Yx MHz (x component carriers) used for transmission in each direction. The carriers may or may not be adjacent to each other. Allocation of carriers may be asymmetric with respect to DL and UL (e.g., more or fewer carriers may be allocated for DL than for UL). The component carriers may include a primary component carrier and one or more secondary component carriers. A primary component carrier may be referred to as a primary cell (PCell) and a secondary component carrier may be referred to as a secondary cell (SCell).

(39) Certain UEs **104** may communicate with each other using device-to-device (D2D) communication link **158**. The D2D communication link **158** may use the DL/UL WWAN spectrum. The D2D communication link **158** may use one or more sidelink channels, such as a physical sidelink broadcast channel (PSBCH), a physical sidelink discovery channel (PSDCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH). D2D communication may be through a variety of wireless D2D communications systems, such as for example, FlashLinQ, WiMedia, Bluetooth, ZigBee, Wi-Fi based on the IEEE 802.11 standard, LTE, or NR. The wireless communications system may further include a Wi-Fi access point (AP) **150** in communication with Wi-Fi stations (STAs) **152** via communication links **154** in a 5 GHz unlicensed frequency spectrum. When communicating in an unlicensed frequency spectrum, the STAs **152**/AP **150** may perform a clear channel assessment (CCA) prior to communicating in order to determine whether the channel is available. The small cell **102′** may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell **102′** may employ NR and use the same 5 GHz unlicensed frequency spectrum as used by the Wi-Fi AP **150**. The small cell **102′**, employing NR in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network.

(40) A base station **102**, whether a small cell **102′** or a large cell (e.g., macro base station), may include and/or be referred to as an eNB, gNodeB (gNB), or another type of base station. Some base stations, such as gNB **180** may operate in a traditional sub 6 GHz spectrum, in millimeter wave (mmW) frequencies, and/or near mmW frequencies in communication with the UE **104**. When the gNB **180** operates in mmW or near mmW frequencies, the gNB **180** may be referred to as an mmW

base station. Extremely high frequency (EHF) is part of the RF in the electromagnetic spectrum. EHF has a range of 30 GHz to 300 GHz and a wavelength between 1 millimeter and 10 millimeters. Radio waves in the band may be referred to as a millimeter wave. Near mmW may extend down to a frequency of 3 GHz with a wavelength of 100 millimeters. The super high frequency (SHF) band extends between 3 GHz and 30 GHz, also referred to as centimeter wave. Communications using the mmW/near mmW radio frequency band (e.g., 3 GHz-300 GHz) has extremely high path loss and a short range—making mmW transmissions susceptible to blocking and attenuation resulting in, e.g., unsuccessfully decoded data. The mmW base station **180** may utilize beamforming **182** with the UE **104**/**184** to compensate for the extremely high path loss and short range. The base station **180** and the UE **104** may each include a plurality of antennas, such as antenna elements, antenna panels, and/or antenna arrays to facilitate the beamforming.

(41) The base station **180** may transmit a beamformed signal to the UE **104**/**184** in one or more transmit directions **182′**. The UE **104**/**184** may receive the beamformed signal from the base station **180** in one or more receive directions **182″**. The UE **104**/**184** may also transmit a beamformed signal to the base station **180** in one or more transmit directions. The base station **180** may receive the beamformed signal from the UE **104** in one or more receive directions. The base station **180**/UE **104**/**184** may perform beam training to determine the best receive and transmit directions for each of the base station **180**/UE **104**/**184**. The transmit and receive directions for the base station **180** may or may not be the same. The transmit and receive directions for the UE **104**/**184** may or may not be the same.

(42) The EPC **160** may include a Mobility Management Entity (MME) **162**, other MMEs **164**, a Serving Gateway **166**, a Multimedia Broadcast Multicast Service (MBMS) Gateway **168**, a Broadcast Multicast Service Center (BM-SC) **170**, and a Packet Data Network (PDN) Gateway **172**. The MME **162** may be in communication with a Home Subscriber Server (HSS) **174**. The MME **162** is the control node that processes the signaling between the UEs **104** and the EPC **160**. Generally, the MME **162** provides bearer and connection management. All user Internet protocol (IP) packets are transferred through the Serving Gateway **166**, which itself is connected to the PDN Gateway **172**. The PDN Gateway **172** provides UE IP address allocation as well as other functions. The PDN Gateway **172** and the BM-SC **170** are connected to the IP Services **176**. The IP Services **176** may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, and/or other IP services. The BM-SC **170** may provide functions for MBMS user service provisioning and delivery. The BM-SC **170** may serve as an entry point for content provider MBMS transmission, may be used to authorize and initiate MBMS Bearer Services within a public land mobile network (PLMN), and may be used to schedule MBMS transmissions. The MBMS Gateway **168** may be used to distribute MBMS traffic to the base stations **102** belonging to a Multicast Broadcast Single Frequency Network (MBSFN) area broadcasting a particular service, and may be responsible for session management (start/stop) and for collecting eMBMS related charging information.

(43) The core network **190** may include an Access and Mobility Management Function (AMF) **192**, other AMFs **193**, a Session Management Function (SMF) **194**, and a User Plane Function (UPF) **195**. The AMF **192** may be in communication with a Unified Data Management (UDM) **196**. The AMF **192** is the control node that processes the signaling between the UEs **104** and the core network **190**. Generally, the AMF **192** provides QoS flow and session management. All user Internet protocol (IP) packets are transferred through the UPF **195**. The UPF **195** provides UE IP address allocation as well as other functions. The UPF **195** is connected to the IP Services **197**. The IP Services **197** may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, and/or other IP services.

(44) The base station may include and/or be referred to as a gNB, Node B, eNB, an access point, a base transceiver station, a radio base station, a radio transceiver, a transceiver function, a basic service set (BSS), an extended service set (ESS), a transmit reception point (TRP), or some other

suitable terminology. The base station **102** provides an access point to the EPC **160** or core network **190** for a UE **104**. Examples of UEs **104** include a cellular phone, a smart phone, a session initiation protocol (SIP) phone, a laptop, a personal digital assistant (PDA), a satellite radio, a global positioning system, a multimedia device, a video device, a digital audio player (e.g., MP3 player), a camera, a game console, a tablet, a smart device, a wearable device, a vehicle, an electric meter, a gas pump, a large or small kitchen appliance, a healthcare device, an implant, a sensor/actuator, a display, or any other similar functioning device. Some of the UEs **104** may be referred to as IoT devices (e.g., parking meter, gas pump, toaster, vehicles, heart monitor, etc.). The UE **104** may also be referred to as a station, a mobile station, a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal, a mobile terminal, a wireless terminal, a remote terminal, a handset, a user agent, a mobile client, a client, or some other suitable terminology.

(45) Continuing to refer to FIG. **1**, in certain aspects, the UE **104** is configured, e.g., through information elements (IEs) from the base station **102**, to sweep UL beams **182″** between the UE **104** and the base station **102** in response to detecting a trigger. Such configuration includes configuring the UE **104** with a rule specifying the trigger conditions and configuring the UE **104** to measure DL beams **182′** from the base station **102** and to report the measurement to the base station **102** prior to the detecting. Also prior to the detecting, the UE **104** begins to receive prepared beams from the base station **102** (based on the measuring) on DL beams **182′** not currently used for DL data transfer. After sweeping, the UE **104** begins to receive DL transmissions on one or more DL beams **182′** based on the swept UL beams **182″** that were successfully received by the base station **102**. The UE **104** can use UE Sweeping Component **142** for performing this configuration, measurement, and sweeping.

(46) In similar aspects, the base station **102** transmits IEs to the UE **104** on active DL beams **182′** for the configuration described above. The base station **102** then transmits a reference signal, e.g., channel state information reference signals (CSI-RS), over each of the DL beams **182′** to be measured by the UE **104**. Upon receiving measurements of each DL beam **182′** from the UE **104** over one or more uplink beams **182″**, the base station **102** may prepare certain of the beams **182′** for use, based at least in part on the measurements—for example, by transmitting a phase tracking reference signal (PTRS) on one or more DL beams **182′** including DL beams **182′** not currently used for DL transmission. Upon receiving an indication that a DL transmission was unsuccessful, for example by receiving a NACK from the UE **104** on one or more of the prepared beams in uplink **182″**, the base station **102** will switch DL transmissions to one or more of the prepared beams **182′**. The base station **102** can use Base Station Sweeping Component **144** for performing this the functions described in this paragraph.

(47) In other similar aspects, the role of sweeping entity can be switched between the base station **102** and the UE **104**. In such aspects, the base station **102** transmits configuration IEs (including a measurement configuration) and instructions to the UE **104**, e.g., a Sounding Reference Signal (SRS) configuration and instructions for the UE **104** to transmit the SRS across a plurality of UL beams **182″**. The base station **102** measures each uplink beam **182″** carrying the SRS and prepares additional DL beams **182′** as described above. Then, when the base station **102** detects a beam sweeping trigger condition, the base station sweeps across the prepared DL beams **182′**. The base station **102** can use Base Station Sweeping Component **144** for performing this the functions described in this paragraph.

(48) In this switched role aspect, the UE **104** receives the configuration IEs (including a measurement configuration) and instructions for the UE **104** as described above. The UE **104** then transmits the signal to be measured to the base station **102** over UL beams **182″**. Upon detection of a trigger condition by the base station **102** the UE **104** receives a sweep across DL beams DL beams **182′**. The UE **104** then acknowledges successful reception, to the base station **102**, on UL

beams **182″** where the UE **104** successfully received the sweep. After sweeping, the UE **104** begins to receive DL transmissions on one or more DL beams **182′** based on the swept DL beams **182′** that were successfully acknowledged to the base station **102**.

(49) Although the following description may be focused on 5G NR, the concepts described herein may be applicable to other similar areas, such as LTE, LTE-A, CDMA, GSM, and other wireless technologies.

(50) FIG. **2**A is a diagram **200** illustrating an example of a first subframe within a 5G/NR frame structure. FIG. **2**B is a diagram **230** illustrating an example of DL channels within a 5G/NR subframe. FIG. **2**C is a diagram **250** illustrating an example of a second subframe within a 5G/NR frame structure. FIG. **2**D is a diagram **280** illustrating an example of UL channels within a 5G/NR subframe. The 5G/NR frame structure may be FDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for either DL or UL, or may be TDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for both DL and UL. In the examples provided by FIGS. **2**A, **2**C, the 5G/NR frame structure is assumed to be TDD, with subframe 4 being configured with slot format 28 (with mostly DL), where D is DL, U is UL, and X is flexible for use between DL/UL, and subframe 3 being configured with slot format 34 (with mostly UL). While subframes 3, 4 are shown with slot formats 34, 28, respectively, any particular subframe may be configured with any of the various available slot formats 0-61. Slot formats 0, 1 are all DL, UL, respectively. Other slot formats 2-61 include a mix of DL, UL, and flexible symbols. UEs are configured with the slot format (dynamically through DL control information (DCI), or semi-statically/statically through radio resource control (RRC) signaling) through a received slot format indicator (SFI). Note that the description infra applies also to a 5G/NR frame structure that is TDD.

(51) Other wireless communication technologies may have a different frame structure and/or different channels. A frame (10 ms) may be divided into 10 equally sized subframes (1 ms). Each subframe may include one or more time slots. Subframes may also include mini-slots, which may include 7, 4, or 2 symbols. Each slot may include 7 or 14 symbols, depending on the slot configuration. For slot configuration 0, each slot may include 14 symbols, and for slot configuration 1, each slot may include 7 symbols. The symbols on DL may be cyclic prefix (CP) OFDM (CP-OFDM) symbols. The symbols on UL may be CP-OFDM symbols (for high throughput scenarios) or discrete Fourier transform (DFT) spread OFDM (DFT-s-OFDM) symbols (also referred to as single carrier frequency-division multiple access (SC-FDMA) symbols) (for power limited scenarios; limited to a single stream transmission). The number of slots within a subframe is based on the slot configuration and the numerology. For slot configuration 0, different numerologies μ 0 to 5 allow for 1, 2, 4, 8, 16, and 32 slots, respectively, per subframe. For slot configuration 1, different numerologies 0 to 2 allow for 2, 4, and 8 slots, respectively, per subframe. Accordingly, for slot configuration 0 and numerology μ, there are 14 symbols/slot and 2.sup.μ slots/subframe. The subcarrier spacing and symbol length/duration are a function of the numerology. The subcarrier spacing may be equal to 2.sup.μ*15 kHz, where μ is the numerology 0 to 5. As such, the numerology μ=0 has a subcarrier spacing of 15 kHz and the numerology μ=5 has a subcarrier spacing of 480 kHz. The symbol length/duration is inversely related to the subcarrier spacing. FIGS. **2**A-**2**D provide an example of slot configuration 0 with 14 symbols per slot and numerology μ=2 with 4 slots per subframe. The slot duration is 0.25 ms, the subcarrier spacing is 60 kHz, and the symbol duration is approximately 16.67 μs.

(52) A resource grid may be used to represent the frame structure. Each time slot includes a resource block (RB) (also referred to as physical RBs (PRBs)) that extends 12 consecutive subcarriers. The resource grid is divided into multiple resource elements (REs). The number of bits carried by each RE depends on the modulation scheme.

(53) As illustrated in FIG. **2**A, some of the REs carry reference (pilot) signals (RS) for the UE. The RS may include demodulation RS (DM-RS) (indicated as R.sub.x for one particular configuration,

where 100x is the port number, but other DM-RS configurations are possible) and channel state information reference signals (CSI-RS) for channel estimation at the UE. The RS may also include beam measurement RS (BRS), beam refinement RS (BRRS), and phase tracking RS (PT-RS). Some examples of the technology disclosed herein use the DM-RS of the physical downlink control channel (PDCCH) to aid in channel estimation (and eventual demodulation of the user data portions) of the physical downlink shared channel (PDSCH).

(54) FIG. **2**B illustrates an example of various DL channels within a subframe of a frame. The physical downlink control channel (PDCCH) carries DCI within one or more control channel elements (CCEs), each CCE including nine RE groups (REGs), each REG including four consecutive REs in an OFDM symbol. A primary synchronization signal (PSS) may be within symbol 2 of particular subframes of a frame. The PSS is used by a UE **104** to determine subframe/symbol timing and a physical layer identity. A secondary synchronization signal (SSS) may be within symbol 4 of particular subframes of a frame. The SSS is used by a UE to determine a physical layer cell identity group number and radio frame timing. Based on the physical layer identity and the physical layer cell identity group number, the UE can determine a physical cell identifier (PCI). Based on the PCI, the UE can determine the locations of the aforementioned DM-RS. The physical broadcast channel (PBCH), which carries a master information block (MIB), may be logically grouped with the PSS and SSS to form a synchronization signal (SS)/PBCH block. The MIB provides a number of RBs in the system bandwidth and a system frame number (SFN). The physical downlink shared channel (PDSCH) carries user data, broadcast system information not transmitted through the PBCH such as system information blocks (SIBs), and paging messages.

(55) As illustrated in FIG. **2**C, some of the REs carry DM-RS (indicated as R for one particular configuration, but other DM-RS configurations are possible) for channel estimation at the base station. The UE may transmit DM-RS for the physical uplink control channel (PUCCH) and DM-RS for the physical uplink shared channel (PUSCH). The PUSCH DM-RS may be transmitted in the first one or two symbols of the PUSCH. The PUCCH DM-RS may be transmitted in different configurations depending on whether short or long PUCCHs are transmitted and depending on the particular PUCCH format used. The UE may transmit sounding reference signals (SRS). The SRS may be transmitted in the last symbol of a subframe. The SRS may have a comb structure, and a UE may transmit SRS on one of the combs. The SRS may be used by a base station for channel quality estimation to enable frequency-dependent scheduling on the UL.

(56) FIG. **2**D illustrates an example of various UL channels within a subframe of a frame. The PUCCH may be located as indicated in one configuration. The PUCCH carries uplink control information (UCI), such as scheduling requests, a channel quality indicator (CQI), a precoding matrix indicator (PMI), a rank indicator (RI), and HARQ ACK/NACK feedback. The PUSCH carries data, and may additionally be used to carry a buffer status report (BSR), a power headroom report (PHR), and/or UCI.

(57) FIG. **3** is a block diagram of a base station **310** in communication with a UE **350** in an access network. In the DL, IP packets from the EPC **160** may be provided to a controller/processor **375**. The controller/processor **375** implements layer 3 and layer 2 functionality. Layer 3 includes a radio resource control (RRC) layer, and layer 2 includes a service data adaptation protocol (SDAP) layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The controller/processor **375** provides RRC layer functionality associated with broadcasting of system information (e.g., MIB, SIBs), RRC connection control (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer packet data units (PDUs), error correction through ARQ, concatenation,

segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TB s, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

(58) The transmit (TX) processor **316** and the receive (RX) processor **370** implement layer 1 functionality associated with various signal processing functions. Layer 1, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The TX processor **316** handles mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may then be split into parallel streams. Each stream may then be mapped to an OFDM subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an Inverse Fast Fourier Transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator **374** may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE **350**. Each spatial stream may then be provided to a different antenna **320** via a separate transmitter **318**TX. Each transmitter **318**TX may modulate an RF carrier with a respective spatial stream for transmission.

(59) At the UE **350**, each receiver **354**RX receives a signal through its respective antenna **352**. Each receiver **354**RX recovers information modulated onto an RF carrier and provides the information to the receive (RX) processor **356**. The TX processor **368** and the RX processor **356** implement layer 1 functionality associated with various signal processing functions. The RX processor **356** may perform spatial processing on the information to recover any spatial streams destined for the UE **350**. If multiple spatial streams are destined for the UE **350**, they may be combined by the RX processor **356** into a single OFDM symbol stream. The RX processor **356** then converts the OFDM symbol stream from the time-domain to the frequency domain using a Fast Fourier Transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station **310**. These soft decisions may be based on channel estimates computed by the channel estimator **358**. The soft decisions are then decoded and de-interleaved to recover the data and control signals that were originally transmitted by the base station **310** on the physical channel. The data and control signals are then provided to the controller/processor **359**, which implements layer 3 and layer 2 functionality.

(60) The controller/processor **359** can be associated with a memory **360** that stores program codes and data. The memory **360** may be referred to as a computer-readable medium. In the UL, the controller/processor **359** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the EPC **160**. The controller/processor **359** is also responsible for error detection using an ACK and/or NACK protocol to support HARQ operations.

(61) Similar to the functionality described in connection with the DL transmission by the base station **310**, the controller/processor **359** provides RRC layer functionality associated with system information (e.g., MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the

transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto TBs, demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

(62) Channel estimates derived by a channel estimator **358** from a reference signal or feedback transmitted by the base station **310** may be used by the TX processor **368** to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the TX processor **368** may be provided to different antenna **352** via separate transmitters **354**TX. Each transmitter **354**TX may modulate an RF carrier with a respective spatial stream for transmission.

(63) The UL transmission is processed at the base station **310** in a manner similar to that described in connection with the receiver function at the UE **350**. Each receiver **318**RX receives a signal through its respective antenna **320**. Each receiver **318**RX recovers information modulated onto an RF carrier and provides the information to a RX processor **370**.

(64) The controller/processor **375** can be associated with a memory **376** that stores program codes and data. The memory **376** may be referred to as a computer-readable medium. In the UL, the controller/processor **375** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE **350**. IP packets from the controller/processor **375** may be provided to the EPC **160**. The controller/processor **375** is also responsible for error detection using an ACK and/or NACK protocol to support HARQ operations.

(65) Continuing to refer to FIG. **3**, and continuing to refer to prior figures for context, in certain aspects, the UE **350** is configured, e.g., through information elements (IEs) from the base station **310** using controller processor **359**, to sweep UL beams **182**″ (e.g., using TX**354***s* under control of TX processor **368**) between the UE **350** and the base station **310** in response to detecting a trigger (e.g., using controller/processor **359**). Such configuration includes configuring the UE **350** (e.g., using RX processor **356** and/or controller processor **359**) with a rule specifying the trigger conditions and configuring the UE to measure DL beams **182**′ from the base station **310** (e.g., using **350** channel estimator **358**) and to report (e.g., using TX**354***s* and TX processor **368**) the measurement to the base station **310** prior to the detecting. Also prior to the detecting, the UE **350** begins to receive prepared beams (e.g., using one or more RX**354** and RX processor **356**) from the base station **310** (based on the measuring) on DL beams **182**′ not currently used for DL data transfer. After sweeping, the UE **350** begins to receive DL transmissions on one or more DL beams **182**′ (e.g., using one or more RX**354** and RX processor **356**) based on the swept UL beams **182**″ that were successfully received by the base station **310**.

(66) In similar aspects, the base station **310** transmits (e.g., using TX**318***s* under control of TX processor **316**) IEs to the UE **350** on active DL beams **182**′ for the configuration described above. The base station **310** then transmits (e.g., using TX**318***s* under control of TX processor **316**) a reference signal, e.g., channel state information reference signals (CSI-RS), over each of the DL beams **182**′ to be measured by the UE **350**. Upon receiving (e.g., using RX**318***s* under control of RX processor **370**) measurements of each DL beam **182**′ from the UE **104** over one or more uplink beams **182**″, the base station **310** may prepare (e.g., using TX**318***s* under control of TX processor **316**) certain of the beams **182**′ for use, based at least in part on the measurements—for example, by transmitting (e.g., using TX**318***s* under control of TX processor **316**) a phase tracking reference signal (PTRS) on one or more DL beams **182**′ including DL beams **182**′ not currently used for DL transmission. Upon receiving (e.g., using RX**318***s* under control of RX processor **370**) an indication that a DL transmission was unsuccessful, for example by receiving (e.g., using TX**318***s* under control of TX processor **316**) a NACK from the UE **104** on one or more of the prepared beams in

uplink **182**″, the base station **310** will switch (e.g., using TX**318***s* under control of TX processor **316**) DL transmissions to one or more of the prepared beams **182**′.

(67) In other similar aspects, the role of sweeping entity can be switched between the base station **310** and the UE **350**. In such aspects, the base station **310** transmits (e.g., using TX**318***s* under control of TX processor **316**) configuration IEs (including a measurement configuration) and instructions to the UE **350**, e.g., a Sounding Reference Signal (SRS) configuration and instructions for the UE **350** to transmit the SRS across a plurality of UL beams **182**″. The base station **310** measures (e.g., using channel estimator **374**) each uplink beam **182**″ carrying the SRS and prepares (e.g., using TX processor **316**) additional DL beams **182**′ as described above. Then, when the base station **310** detects (e.g., using RX**318***s* under control of RX processor **370**) a beam sweeping trigger condition, the base station sweeps (e.g., using TX**318***s* under control of TX processor **316**) across the prepared DL beams **182**′.

(68) In this switched role aspect, the UE **350** receives (e.g., using RX **354***s* and RX processor **356**) the configuration IEs (including a measurement configuration) and instructions for the UE **350** as described above. The UE **350** then transmits (using TX**354***s* under control of TX processor **368**) the signal to be measured to the base station **310** over UL beams **182**″. Upon detection of a trigger condition by the base station **102**, the UE **104** receives (using RX **354***s* and RX processor **356**) a sweep across DL beams DL beams **182**′. The UE **350** then acknowledges (using TX**354***s* under control of TX processor **368**) successful reception, to the base station **310**, on UL beams **182**″ where the UE **350** successfully received the sweep. After sweeping, the UE **104** begins to receive (using RX **354***s* and RX processor **356**) DL transmissions on one or more DL beams **182**′ based on the swept DL beams **182**′ that were successfully acknowledged to the base station **310**.

(69) Referring to FIG. **4**, and continuing to refer to prior figures for context, a notional representation of transmissions between a base station **180** (also referred to as “gNB” in the example) and a UE **184** is shown, in accordance with examples of the technology disclosed herein. In the continuing example, the UE **184** and the gNB **180** are initially connected in an URLLC usage scenario under semi-persistent scheduling (SPS) as indicated by two copies of PDSCH **422***a*. One PDSCH **422***a* is carried on beam **411***a* in downlink to the UE **184**, while the other PDSCH **422***a* is carried on beam **412***a* in downlink to the UE **184**. The UE **184** acknowledges successful reception of each copy of PDSCH **422***a* by first transmitting an ACK in each of two copies of a PUCCH **452***a* over beams **411***a* and **412***a* in uplink.

(70) Referring to FIG. **5**, and continuing to refer to prior figures for context, a flowchart of methods **500** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **500**, a UE **184** receives conditions for sweeping beams between the base station **180** and the UE **184**—Block **510**. The conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink.

(71) In the continuing example, the trigger rule and the beam measurement configuration are carried as information element (IEs) in a Radio Resource Control-level (RRC-level) message, specifically as part of RRCReconfiguration (RRCR) **432***b* via beam **411***b* on downlink. RRCR **432***b* includes a CSI-MeasConfig IE, an example of which is shown in TABLE 1. In the example of TABLE 1, the conditions include a “beamSweepingUponNack” flag for DL traffic. The flag can take on the Boolean values “true” (beam sweeping enabled) and false (beam sweeping disabled). The conditions include a trigger rule that is trigged upon detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. In the continuing example, K can take on an integer values from 1-12. The particular value of K is determined, at least in part, on the reliability level required for the connection. The conditions also include an “Origin” designator for sweeping originated by the UE **184** and sweeping originated by the gNB **180**. Note that beam sweeping by the UE takes place in the continuing example only if the “beamSweepingUponNack” flag is “true” and the “Origin”

indicates “UE Originated” “UL Beam Sweeping.” In the continuing example, both those conditions hold, and K=1.

(72) TABLE-US-00001 TABLE 1 CSI-MeasConfig information element --CSI-MeasConfig ::= SEQUENCE { nzp-CSI-RS-ResourceToAddModList SEQUENCE (SIZE (1. .maxNrofNZP-CSI-RS- Resources)) OF NZP-CSI-RS-Resource OPTIONAL, -- Need N .... OPTIONAL, -- Need N INTEGER (0 .. 6) reportTriggerSize OPTIONAL, -- Need M aperiodicTriggerStateList SetupRelease { CSI- AperiodicTriggerStateList } OPTIONAL, -- Need M semiPersistentOnPUSCH-TriggerStateList SetupRelease { CSI- SemiPersistentOnPUSCH-TriggerStateList } OPTIONAL, -- Need M . . . OPTIONAL, -- Need N beamSweepingUponNack (DL Traffic) : Boolean {true, false} (if “beamSweepingUponNack” true, Beam Sweeping After K Nacks, K (1, 2, 3, 4, . . , 12} Origin: {UL Beam Sweeping - UE Originated, DL Beam Sweeping - gNB Originated) }

(73) In some examples of the technology disclosed herein, the IEs for beam sweeping can be carried in other RRC-level messages such as RRCSetup, RRCResume, and System Information Blocks (SIBs) SIB2 or SIB 3. More generally, the IEs for beam sweeping can be carried in any RRC-level message without the IEs being part of CSI-MeasConfig used here as an example—though note that CSI-MeasConfig carried IEs for beam measurement configuration, e.g., whether the measurements are taken on zero power (“zp”) or non-zero power (“nzp”) signals from the base station **180**. Even yet more generally, the beam sweeping IEs can be carried in MAC-Control Element (MAC-CE) or DCI.

(74) In addition, the technology disclosed herein can control a time period over which a given measurement results set remains valid for use in beam sweeping, an order of the beams for sweeping, and a number of beams to sweep. In the continuing example, the order of sweeping is the order of transmission configuration indicator (TCI) state reporting—the TCI state order already used for PDSCH or PUSCH and the strongest reported TCI states in descending order. In the continuing example, the measurement results are valid for 3 msec. (three cycles), and only four beams (**411**, **412**, **413**, and **414**) of five available beams will be swept. In general, each the enable/disable flag, K, order, number of beams, measurement validity time, and order of beams can be sent as IEs or can be system parameters set in the UE **184** and gNB by other means such as back channels or as part of manufacturing.

(75) Referring to FIG. **9**, and continuing to refer to prior figures for context, a UE **350** wireless communication disclosed herein is shown, in accordance with examples of the technology disclosed herein. UE **350** includes UE sweeping component **142** as described in conjunction with FIG. **3** above. UE sweeping component **142** includes receiving component **142***a*. In some examples, the receiving component **142***a* receives conditions for sweeping beams between the base station **180** and the UE **184**. Accordingly, the receiving component **142***a* may provide means for UE **184** receiving conditions for sweeping beams between the base station **180** and the UE **184**.

(76) The UE **184**, having received the beam sweeping conditions, measures at least one characteristic of each of the beams in accordance with the measurement configuration—Block **530**. In the continuing example, the UE **184** measures CSI-RS swept across beams **411***c*, **412***c*, **413***c*, **414***c*, and **415***c* in downlink in accordance with the CSI-MeasConfig received in RRCR **432***b*, giving the results shown in TABLE 2.

(77) TABLE-US-00002 TABLE 2 TCI State Beam 411 (CQI): A dB TCI State Beam 412 (CQI): B (<A) dB TCI State Beam 413 (CQI): C (<B) dB TCI State Beam 414 (CQI): D (< C) dB TCI State Beam 415 (CQI): E (< D) dB

(78) Referring again to FIG. **9**, UE sweeping component **142** includes measuring component **142***b*. In some examples, the measuring component **142***b* measures at least one characteristic of each of the beams in accordance with the measurement configuration. Accordingly, the measuring component **142***b* may provide means for measuring at least one characteristic of each of the beams in accordance with the measurement configuration.

(79) After measuring, the UE **184** detects a beam sweeping trigger in accordance with the trigger rule—Block **570**. In the continuing example, where K=1, in the cycle after measurements are complete, the UE **184** fails to receive and decode PDSCH **422***e* on either beam **411***e* or **412***e*. In other examples, triggers such as bit error rate on decoding over a time window, PER not maintained at the target level, SRS indicating at the gNB signal strength below threshold, and gNB originated beam change due to load can be used.
(80) Referring again to FIG. **9**, UE sweeping component **142** includes detecting component **142***c*. In some examples, detecting component **142***c* detects a beam sweeping trigger in accordance with the trigger rule. Accordingly, the measuring component **142***b* may provide means for detecting a beam sweeping trigger in accordance with the trigger rule.
(81) In response to detecting the trigger, the UE **184** sweeps the beams on uplink based on the measuring—Block **580**. In the continuing example, the four beams (**411**, **412**, **413**, and **414**) of the five measured beams having the strongest CQI are swept. "Sweeping" in the continuing example includes transmitting a NACK in PUCCH on each beam **411***f*, **412***f*, **413***f*, and **414***f* in sequence in uplink. In some examples, sweeping is performed over the beams that are not blocked (in the continuing example, the beams currently used for data transmission are blocked). Excluding the blocked beams from sweeping can be useful when the system (both the UE **184** and the base station **180**) is certain that the error occurred due to blocking. Sweeping all beams is appropriate when the UE **184** or the base station **180** is not able to detect if the error occurred due to blocking.
(82) Referring again to FIG. **9**, UE sweeping component **142** includes sweeping component **142***d*. In some examples, sweeping component **142***c* sweeps the beams on uplink based on the measuring. Accordingly, the sweeping component **142***c* may provide means for sweeping the beams on uplink based on the measuring.
(83) Referring to FIG. **6**, and continuing to refer to prior figures for context, a flowchart of methods **600** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **600**, Block **510**, Block **530**, Block **570**, and Block **580** are performed as described in connection with FIG. **5**.
(84) In such methods **600**, after measuring at least one characteristic of each of the beams in accordance with the measurement configuration, and before detecting a trigger, the UE **184** transmits, to the base station, the measured at least one characteristic for each of the beams—Block **640**. In the continuing example, the UE **184** transmits the results shown in TABLE 2 to the base station **180** along with an ACK as part of PUCCH **451***d* on beam **411***d* in uplink.
(85) In some examples, the measured characteristics are transmitted in other messages, such as an RRC Measurement Report. In some cases, the UE **184** may report a set of beams with a given order, but the base station **180** can configure a beam sweeping pattern within any subset or the whole set and within any order. Consider two cases—Case 1: the UE **184** does not transmit SRS while receiving CSI-RS; and Case 2: the UE **184** transmits SRS in uplink at the same time window during which the UE **184** receives and measures CSI-RS. In Case 1, the base station **180** will select a subset of the reported CSI-RS set for the beam sweeping pattern. In Case 2, the base station **180** can select any beams among those used for CSI-RS and SRS measurements. Hence, in Case 2, the UE **184** may receive a beam sweeping pattern not including any of the beams reported via PUCCH.
(86) Referring again to FIG. **9**, in the examples of FIG. **6**, UE sweeping component **142** includes transmitting component **142***e*. In some examples, transmitting component **142***e* transmits, to the base station, the measured at least one characteristic for each of the beams. Accordingly, the transmitting component **142***e* may provide means for transmitting, to the base station, the measured at least one characteristic for each of the beams.
(87) The UE **184** second receives, from the base station **180**, an acknowledgement of successful reception of the transmitted measurements of the beam characteristics—Block **650**. In some examples, the acknowledgement operates as another enable/disable flag serial to the enable/disable flag described in conjunction with FIG. **5**. In some examples, the acknowledgment is carried on

downlink on DCI. In some examples, the base station **180** uses the acknowledgement to adjust the number, order, or identity of the beams to be swept upon the UE **184** detecting a trigger condition. In the continuing example, acknowledgement is sent by the base station **180** in message **442***d* using beam **411***d* in downlink. In some examples, message **442***d* includes IEs that reorder the assumed beam order, or omit some beams, or substitute others based on information obtained by the network/base station **180** and policy implemented din the network/base station **180**. In other examples, no acknowledgment is sent, and the UE **184** assumes, in accordance with the received beam sweeping conditions that the four strongest beams are to be swept on detecting a trigger.

(88) In some examples, another parameter of the beam sweeping pattern, in addition to the TCI state IDs, the number of TCI states, the order, is the duration per TCI state. E.g. consider a UE being close to the base station and the uplink beam sweeping takes place by the UE transmitting 1 symbol PUCCH. In another case, the UE might be far from the base station and the UE might be asked to transmit the same PUCCH format in 2 symbols. For the sake of covering all of the cases, consider the following uplink beam sweeping pattern" TCI State ID 1, duration 1 symbol; TCI State ID 2, duration 1 symbol; TCI State ID 3, duration 2 symbols; TCI State ID 4, duration 2 symbols; and TCI State ID 5, duration, 1 symbol.

(89) Referring again to FIG. **9**, in the examples of FIG. **6**, UE sweeping component **142** includes second receiving component **142***f*. In some examples, second receiving component **142***f* receives, from the base station **180**, an acknowledgement of successful reception of the transmitted measurements of the beam characteristics. Accordingly, the transmitting component **142***e* may provide means for receiving, from the base station **180**, an acknowledgement of successful reception of the transmitted measurements of the beam characteristics.

(90) The UE **184** third receives, from the base station **180** and after the second receiving, phase tracking reference signals (PTRS) on at least one of the reported beams—Block **660**. In some examples, the base station **180** uses PTRS transmitted on each of a plurality of beams as a way to prepare the UE **184** for use of currently unused beams for both sweeping and for data transfer upon detection of a trigger.

(91) In some examples, when the base station **180** transmits DL PTRS for a given TCI state, this means that the DL TCI State is "prepared" and an eventual TCI state switch from the TCI states currently used for data transmission to this new TCI state can be done relatively quickly. Similarly, in case the UE **184** is requested to transmit PTRS within a given UL TCI state, then, this UL beam is "prepared."

(92) Referring again to FIG. **9**, in the examples of FIG. **6**, UE sweeping component **142** includes third receiving component **142***g*. In some examples, third receiving component **142***g* receives, from the base station **180** and after the second receiving, phase tracking reference signals (PTRS) on at least one of the reported beams. Accordingly, the transmitting component **142***e* may provide means for receiving, from the base station **180** and after the second receiving, phase tracking reference signals (PTRS) on at least one of the reported beams.

(93) Referring to FIG. **7**, and continuing to refer to prior figures for context, a flowchart of methods **700** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **700**, Block **510**, Block **530**, Block **570**, and Block **580** are performed as described in connection with FIG. **5**. In such methods **700**, prior to receiving the conditions, the UE **184** requests conditions for sweeping beams of a physical channel between a base station of the network and the UE—Block **720**. In such methods **700**, the UE receiving conditions for sweeping beams between a base station of the network and the UE is in response to the requesting. The request can be triggered by the service type, and by how the current quality of service is meeting the service type requirements.

(94) Referring again to FIG. **9**, in the examples of FIG. **7**, UE sweeping component **142** includes requesting component **142***h*. In some examples, requesting component **142***h* requests conditions for sweeping beams of a physical channel between a base station of the network and the UE.

Accordingly, the transmitting component **142***e* may provide means for requesting conditions for sweeping beams of a physical channel between a base station of the network and the UE.

(95) Referring to FIG. **8**, and continuing to refer to prior figures for context, a flowchart of methods **800** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **800**, Block **510**, Block **530**, Block **570**, and Block **580** are performed as described in connection with FIG. **5**. In such methods **800**, each swept beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding the detected trigger. In such methods **800**, the UE fourth receives data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station—Block **890**.

(96) In the continuing example, each of beams **411***f*, **412***f*, **413***f*, and **414***f* (four of the five measured beams) carries a NACK on PUCCH **451***f* in uplink. Uplink-downlink channel symmetry applies in the continuing example, and beams **411***f* and **412***f* are not received by the base station **180**. However, the base station **180** does receive PUCCH **451***f* carrying NACK (the K=1 trigger condition) on beams **413***f* and **414***f* in uplink. As a consequence, the base station **180** transmits and the UE **184** receives both DCI **462***g* on at least beam **413***g* in downlink and SPS PDSCH **422***g* across now-active beams **413***g* and **414***g*. The UE **184** can then acknowledge successful reception and decoding of SPS PDSCH **422***g* using ACK on PUCCH **451***g* in uplink on beams **413***g* and **414***g*. Without further blocking or interference, the base station will continue to transmit subsequent SPS PDSCH, e.g., SPS PDSCH **422***h*, on beams **413** and **414** in downlink, e.g., beams **413***h* and **414***h*. In some examples, the UE **184** prepares its receiver to receive retransmission or DCI via the same beam sweeping pattern (or a subset of it). Hence, the UE **184** receiver, expects Beam 1 at time t0, beam 2 at time t1=t0+1 symbol, beam 3 at t2=t1+1 symbol, etc. The base station receives the first correct version of PUCCH with the NACK from TCI state ID (beam)—see Block **580** described above. In the continuing example, it does not make sense to perform retransmission and DCI transmission via the blocked beams, then, the base station **180** transmits at t2 the beam 3, knowing that the UE is expecting this transmission of TCI state ID 3 at this time instant.

(97) Referring again to FIG. **9**, in the examples of FIG. **8**, UE sweeping component **142** includes fourth receiving component **142***g*. In some examples, fourth receiving component **142***g* receives data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station. Accordingly, the transmitting component **142***e* may provide means for receiving data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

(98) Referring to FIG. **10**, and continuing to refer to prior figures for context, a flowchart of methods **1000** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods, the base station **180** first transmits, to a UE of the network, the conditions for sweeping beams between the UE **184** and the base station **180**—Block **1010**. Similar to the description of FIG. **5**, but from the view of the base station **180** rather than the UE **184**, the conditions include a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. In the continuing example, the trigger rule and the beam measurement configuration are carried as IEs as part of RRCR **432***b* via beam **411***b* on downlink. RRCR **432***b* includes the CSI-MeasConfig IE of TABLE 1. As noted above, the “beamSweepingUponNack” flag is “true,” the “Origin” indicates “UE Originated” “UL Beam Sweeping,” and K=1. The order of sweeping is the order of transmission configuration indicator TCI state reporting—the TCI state order already used for PDSCH or PUSCH and the strongest reported TCI states in descending order. In the continuing example, the measurement results are valid for 3 msec. (three cycles), and only four beams (**411**, **412**, **413**, and **414**) of five available beams will be swept.

(99) Referring to FIG. **13**, and continuing to refer to prior figures for context, a base station **310** for wireless communication disclosed herein is shown, in accordance with examples of the technology disclosed herein. Base station **310** includes base station sweeping component **144** as described in conjunction with FIG. **3** above. Base station sweeping component **144** includes first transmitting component **144***a*. In some examples, first transmitting component **144***a* first transmits, to a UE of the network, the conditions for sweeping beams between the UE **184** and the base station **102**. Accordingly, the first transmitting component **144***a* may provide means for first transmitting, to a UE **184** of the network, the conditions for sweeping beams between the UE **184** and the base station **102**.

(100) The base station **180** second transmits, after the first transmitting, a reference signal over the beams on downlink—Block **1020**. In the continuing example, the base station **180** second transmits CSI-RS swept across beams **411***c*, **412***c*, **413***c*, **414***c*, and **415***c* in downlink in accordance with the CSI-MeasConfig transmitted in RRCR **432***b*. Referring to FIG. **13**, base station sweeping component **144** includes second transmitting component **144***b*. In some examples, second transmitting component **144***b* second transmits, after the first transmitting, a reference signal over the beams on downlink. Accordingly, the second transmitting component **144***b* may provide means for transmitting, after the first transmitting, a reference signal over the beams on downlink.

(101) Base station **180** first receives from the UE **184**, in response to the first and second transmitting, downlink beam measurements in accordance with the beam measurement configuration—Block **1030**. In the continuing example, the UE **184** transmits the results shown in TABLE 2 to the base station **180** along with an ACK as part of PUCCH **451***d* on beam **411***d* in uplink. Referring to FIG. **13**, base station sweeping component **144** includes receiving component **144***c*. In some examples, receiving component **144***c* first receives from the UE **184**, in response to the first and second transmitting, downlink beam measurements in accordance with the beam measurement configuration. Accordingly, the first receiving component **144***c* may provide means for first receiving from the UE **184**, in response to the first and second transmitting, downlink beam measurements in accordance with the beam measurement configuration.

(102) Base station **180** prepares, in response to the first receiving, at least one beam not currently used in downlink—Block **1040**. In some examples, the base station **180** uses PTRS transmitted on each of a plurality of beams as a way to prepare the UE **184** for use of currently unused beams for both sweeping and for data transfer upon detection of a trigger. Referring to FIG. **13**, base station sweeping component **144** includes preparing component **144***d*. In some examples, preparing component **144***d* prepares, in response to the first receiving, at least one beam not currently used in downlink. Accordingly, the preparing component **144***d* may provide means to prepare, in response to the first receiving, at least one beam not currently used in downlink.

(103) Base station **180** second receives, on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule—Block **1050**. In the continuing example, the four beams (**411**, **412**, **413**, and **414**) of the five measured beams having the strongest CQI are swept by the UE **184**. "Sweeping" in the continuing example includes transmitting a NACK in PUCCH **451***f* on each beam **411***f*, **412***f*, **413***f*, and **414***f* in sequence in uplink. Referring to FIG. **13**, base station sweeping component **144** includes second receiving component **144***e*. In some examples, second receiving component **144***e* receives, on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule. Accordingly, the second receiving component **144***e* may provide means to receive, on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule.

(104) Base station **180** third transmits, by the base station to the UE, at least one physical channel on at least one prepared beam—Block **1060**. In the continuing example, the base station **180** after receiving PUCCH **451***f* carrying NACK (the K=1 trigger condition) on beams **413***f* and **414***f* in uplink, transmits both DCI **462***g* on at least beam **413***g* in downlink to the UE **184** and SPS PDSCH

422*g* across now-active beams **413***g* and **414***g*. The UE **184** can then acknowledge successful reception and decoding of SPS PDSCH **422***g* using ACK on PUCCH **451***g* in uplink on beams **413***g* and **414***g*. Without further blocking or interference, the base station will continue to transmit subsequent SPS PDSCH, e.g., SPS PDSCH **422***h*, on beams **413** and **414** in downlink, e.g., beams **413***h* and **414***h*.

(105) Referring to FIG. **13**, base station sweeping component **144** includes third transmitting component **144***f*. In some examples, third transmitting component **144***f* transmits, to the UE, at least one physical channel on at least one prepared beam. Accordingly, the third transmitting component **144***f* may provide means to transmit, to the UE, at least one physical channel on at least one prepared beam.

(106) Referring to FIG. **11**, and continuing to refer to prior figures for context, a flowchart of methods **1100** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **1100**, Block **1010**, Block **1020**, Block **1030**, Block **1040**, Block **1050**, and Block **1060** are performed as described in connection with FIG. **10**. In such methods **1100**, the base station **180** third receives, from the UE **184**, a request for conditions for sweeping beams of a physical channel between a base station **180** and the UE **184**—Block **1170**. In such methods **700**, the UE receiving conditions for sweeping beams between a base station of the network and the UE is in response to the requesting.

(107) Referring to FIG. **13**, base station sweeping component **144** includes third receiving component **144***g*. In some examples, third receiving component **144***g* receives, from the UE **184**, a request for conditions for sweeping beams of a physical channel between a base station **180** and the UE **184**. Accordingly, third receiving component **144***g* may provide means for receiving, from the UE **184**, a request for conditions for sweeping beams of a physical channel between a base station **180** and the UE **184**.

(108) Referring to FIG. **12**, and continuing to refer to prior figures for context, a flowchart of methods **1200** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **1200**, Block **1010**, Block **1020**, Block **1030**, Block **1040**, Block **1050**, and Block **1060** are performed as described in connection with FIG. **10**. In such methods **1200**, the base station **180** fourth transmits data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station **180**—Block **1280**. In such methods, each second received beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding a trigger detected in accordance with the sweeping trigger rule.

(109) In the continuing example, each of beams **411***f*, **412***f*, **413***f*, and **414***f* (four of the five measured beams) carries a NACK on PUCCH **451***f* in uplink from the UE **184** to the base station **180**. Uplink-downlink channel symmetry applies in the continuing example, and beams **411***f* and **412***f* are not received by the base station **180**. However, the base station **180** does receive PUCCH **451***f* carrying NACK (the K=1 trigger condition) on beams **413***f* and **414***f* in uplink. As a consequence, the base station **180** transmits and the UE **184** receives both DCI **462***g* on at least beam **413***g* in downlink and SPS PDSCH **422***g* across now-active beams **413***g* and **414***g*. The UE **184** can then acknowledge successful reception and decoding of SPS PDSCH **422***g* using ACK on PUCCH **451***g* in uplink on beams **413***g* and **414***g*. Without further blocking or interference, the base station will continue to transmit subsequent SPS PDSCH, e.g., SPS PDSCH **422***h*, on beams **413** and **414** in downlink, e.g., beams **413***h* and **414***h*.

(110) Referring to FIG. **13**, base station sweeping component **144** includes fourth transmitting component **144***h*. In some examples, fourth transmitting component **144***h* transmits data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station **180**. Accordingly, the fourth transmitting component **144***h* may provide means for transmitting data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding

to the beams on which the information element was successfully received by the base station **180**.

(111) Referring to FIG. **14**, and continuing to refer to prior figures for context, a second notional representation of transmissions between a base station **180** (also referred to as "gNB" in the example) and a UE **184** is shown, in accordance with examples of the technology disclosed herein. In the second continuing example, the UE **184** and the gNB **180** are initially connected in an URLLC usage scenario under semi-persistent scheduling (SPS) as indicated by two copies of PUSCH **1491***a*. One copy of PUSCH **1491***a* is carried on beam **1411***a* in uplink from the UE **184** to the base station **180**, while the other copy of PUSCH **1491***a* is carried on beam **1412***a* in uplink from the UE **184**.

(112) Referring to FIG. **15**, and continuing to refer to prior figures for context, a flowchart of methods **1500** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods, the base station **180** transmits, to a UE **184**, a beam sweeping configuration specifying a reference signal—Block **1510**. In the second continuing example, the reference signal specification carried as information element (IEs) in a Radio Resource Control-level (RRC-level) message, specifically as part of RRCReconfiguration (RRCR) **1431***b* via beam **1411***b* on downlink. RRCR **1431***b* includes an SRS-Config IE modified with a beam sweeping IEs described above in a manner similar to that described in conjunction with FIG. **5** and TABLE 1, an example of which is shown in TABLE 3. In the example of TABLE 3, the conditions include a "beamSweepingUponNack" flag for DL traffic. The flag can take on the Boolean values "true" (beam sweeping enabled) and false (beam sweeping disabled). The conditions include an "Origin" designator for sweeping originated by the UE **184** and sweeping originated by the gNB **180**. In the second continuing example, the "Origin" flag is set to "gNB originated." The conditions include a trigger rule that is trigged upon detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. K can take on an integer values from 1-12. The particular value of K is determined, at least in part, on the reliability level required for the connection. Note that with sweeping in the second continuing example, K is not used since the "Origin" flag is set to "gNB Originated." Note that beam sweeping by the UE takes place only if the "beamSweepingUponNack" flag is "true" and the "Origin" indicates "gNB Originates" "UL Beam Sweeping." In the second continuing example, beam sweeping is enabled, and the "Origin" flag is set to "gNB Originated." K is not specified since the base station **180** trigger criteria (not receiving a single session—similar to K=1—of PUSCH when expected) does not need to be communicated to the UE **184**.

(113) TABLE-US-00003 TABLE 3 SRS-Config information element -- ASNISTART -- TAG-SRS-CONFIG-START SRS-Config ::= SEQUENCE { srs-ResourceSetToReleaseList SEQUENCE (SIZE(1..maxNrofSRS-ResourceSets)) OF SRS- ResourceSetId OPTIONAL, -- Need N srs-ResourceSetToAddModList SEQUENCE (SIZE(1..maxNrofSRS-ResourceSets)) OF SRS-ResourceSet OPTIONAL, -- Need N srs-ResourceToReleaseList SEQUENCE (SIZE(1..maxNrofSRS-Resources)) OF SRS-ResourceId OPTIONAL, -- Need N srs-ResourceToAddModList SEQUENCE (SIZE(1..maxNrofSRS-Resources)) OF SRS-Resource OPTIONAL, -- Need N . . . OPTIONAL, -- Need N beamSweepingUponNack (DL Traffic) : Boolean {true, false} (if "beamSweepingUponNack" true, Beam Sweeping After K Nacks, K (1, 2, 3, 4, . . , 12} Origin: {UL Beam Sweeping - UE Originated, DL Beam Sweeping - gNB Originated} }

(114) In some examples of the technology disclosed herein, the IEs for beam sweeping can be carried in other RRC-level messages such as RRCSetup, RRCResume, and System Information Blocks (SIBs) SIB2 or SIB 3. More generally, the IEs for beam sweeping can be carried in any RRC-level message without the IEs being part of SRS-Config used here as an example.

(115) In addition, the technology disclosed herein can control an order of the beams for sweeping, and a number of beams to sweep. In the second continuing example, the order of sweeping and number of beams to sweep is specified in SRS-Config. In the second continuing example, all five

of the available beams will be swept on uplink from the UE **184**. In general, each of the enable/disable flag, K, order, number of beams, and order of beams can be sent as IEs or can be system parameters set in the UE **184** and gNB by other means such as backhaul or sidelink channels or as part of manufacturing.

(116) Referring to FIG. **19**, and continuing to refer to prior figures for context, a base station **310** for wireless communication disclosed herein is shown, in accordance with examples of the technology disclosed herein. Base station **310** includes base station sweeping component **144**′ as described in conjunction with FIG. **3** above. Base station sweeping component **144**′ includes transmitting component **144***a*′. In some examples, transmitting component **144***a*′ transmits, to a UE **184**, a beam sweeping configuration specifying a reference signal. Accordingly, the transmitting component **144***a*′ may provide means for transmitting, to a UE **184**, a beam sweeping configuration specifying a reference signal.

(117) The base station **180** measures at least one characteristic of each of a plurality of beams of a physical channel and comprising the specified reference signal from the UE to the base station on uplink—Block **1530**. The beams include each beam currently in use for communication between the base station and the UE and a plurality of beams not currently in use for downlink data transfer to the UE. In the second continuing example, the base station **180** measures SRS swept across beams **1411***c*, **1412***c*, **1413***c*, **1414***c*, and **1415***c* in uplink giving the results shown in TABLE 4.

(118) TABLE-US-00004 TABLE 4 TCI State Beam 1411 (CQI): A dB TCI State Beam 1412 (CQI): B (<A) dB TCI State Beam 1413 (CQI): C (<B) dB TCI State Beam 1414 (CQI): D (< C) dB TCI State Beam 1415 (CQI): E (< D) dB

(119) Referring to FIG. **19**, and continuing to refer to prior figures for context, a base station **310** for wireless communication disclosed herein is shown, in accordance with examples of the technology disclosed herein. Base station **310** includes base station sweeping component **144**′ as described in conjunction with FIG. **3** above. Base station sweeping component **144**′ includes measuring component **144***b*′. In some examples, measuring component **144***b*′ measures at least one characteristic of each of a plurality of beams of a physical channel and comprising the specified reference signal from the UE to the base station on uplink. Accordingly, the measuring component **144***b*′ may provide means for measuring at least one characteristic of each of a plurality of beams of a physical channel and comprising the specified reference signal from the UE to the base station on uplink.

(120) The base station **180** detects, after the measuring, a beam sweeping trigger condition—Block **1550**. In the second continuing example, the base station **180** does not receive the expected two copies of PUSCH **1491***e* on beams **1411***e* and **1412***e* at the beginning of the second cycle and after having transmitted DCI **1461***e*. Not receiving a single expected PUSCH—similar to K=1—of PUSCH when expected results in a detected trigger. In other examples, triggers such as bit error rate on decoding over a time window can be used.

(121) Referring again to FIG. **19**, base station sweeping component **144**′ includes detecting component **144***c*′. In some examples, detecting component **144***c*′ detects, after the measuring, a beam sweeping trigger condition. Accordingly, the measuring component **144***b*′ may provide means for detecting, after the measuring, a beam sweeping trigger condition.

(122) The base station **180** sweeps, in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration—Block **1560**. In the second continuing example, base station sweeps the five beams (**1411***f*, **1412***f*, **1413***f*, **1414***f*, and **1415***f*) in order of strength. “Sweeping” in the second continuing example includes transmitting DCI **1461***f* on downlink on each beam in order of decreasing measure uplink power. Note that in both uplink and downlink sweeping, the base station **180** or UE **184** can use criteria other than decreasing power to order some or all of the available beams for sweeping. For example, the base station **180** may exclude beams presumed blocked for failure of PUSCH on uplink, e.g., **1411** and **1412**. As another example, the base station may exclude beams reserved for some other purpose.

(123) Referring again to FIG. **19**, base station sweeping component **144**′ includes sweeping component **144***d*′. In some examples, sweeping component **144***d*′ sweeps, in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration. Accordingly, the measuring component **144***b*′ may provide means for sweeping, in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration.
(124) Referring to FIG. **16**, and continuing to refer to prior figures for context, a flowchart of methods **1600** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **1600**, Block **1510**, Block **1530**, Block **1550**, and Block **1560** are performed as described in connection with FIG. **15**. In such methods **1600**, the base station **180** receives, from the UE and prior to the measuring, a confirmation of configuration of the UE in accordance with the transmitted beam sweeping configuration—Block **1620**. In the second continuing example, the base station receives RRCRConfirmation **1432***b* on beam **1411***b* in uplink confirming that the UE **184** is configured according to the RRCR **1431***b* sent by the base station **180** on **1411***b* in downlink earlier in the cycle. Referring again to FIG. **19**, base station sweeping component **144**′ includes receiving component **144***e*′. In some examples, receiving component **144***e*′ receives, from the UE and prior to the measuring, a confirmation of configuration of the UE in accordance with the transmitted beam sweeping configuration. Accordingly, receiving component **144***e*′ may provide means for receiving, from the UE and prior to the measuring, a confirmation of configuration of the UE in accordance with the transmitted beam sweeping configuration.
(125) Referring to FIG. **17**, and continuing to refer to prior figures for context, a flowchart of methods **1700** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **1700**, Block **1510**, Block **1530**, Block **1550**, and Block **1560** are performed as described in connection with FIG. **15**. In such methods **1700** after the measuring, the base station prepares a plurality of the not currently-used beams for sweeping upon detection of a beam sweeping trigger condition—Block **1740**. In some examples, the base station **180** uses PTRS transmitted on each of a plurality of beams as a way to prepare the UE **184** for use of currently unused beams for both sweeping and for data transfer upon detection of a trigger.
(126) Referring again to FIG. **19**, base station sweeping component **144**′ includes preparing component **144***f*′. In some examples, preparing component **144***f*′ prepares a plurality of the not currently-used beams for sweeping upon detection of a beam sweeping trigger condition. Accordingly, preparing component **144***f*′ may provide means for preparing a plurality of the not currently-used beams for sweeping upon detection of a beam sweeping trigger condition.
(127) Referring to FIG. **18**, and continuing to refer to prior figures for context, a flowchart of methods **1800** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **1800**, Block **1510**, Block **1530**, Block **1550**, and Block **1560** are performed as described in connection with FIG. **15**. In such methods **1800** the base station **180** second receives, from the UE and after the sweeping, an acknowledgement of successful transmission on each of a plurality of the swept beams—Block **1870**. In such methods **1800** the base station **180** third transmits data on one or more of the acknowledged beams—Block **1880**. In the second continuing example, the UE **184**, upon successfully receiving and decoding the swept signal on one or more of beams **1411***f*-**1414***f* retransmits the PUSCH **1491***e* as PUSCH **1491***g* on beams **1413***g* and **1414***g*.
(128) Referring again to FIG. **19**, base station sweeping component **144**′ includes second receiving component **144***g*′. In some examples, second receiving component **144***g*′ receives, from the UE and after the sweeping, an acknowledgement of successful transmission on each of a plurality of the swept beams. Accordingly, second receiving component **144***g*′ may provide means for receiving, from the UE and after the sweeping, an acknowledgement of successful transmission on each of a plurality of the swept beams. Base station sweeping component **144**′ also includes third

transmitting component **144***h*′. In some examples, third transmitting component **144***h*′ transmits data on one or more of the acknowledged beams. Accordingly, third transmitting component **144***h*′ may provide means for transmitting data on one or more of the acknowledged beams.

(129) Referring to FIG. **20**, and continuing to refer to prior figures for context, a flowchart of methods **2000** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods, the UE **184** receives, from the base station **180**, a beam sweeping configuration specifying a reference signal—Block **2010**. Similar to the description of FIG. **15**, but from the view of the UE **184** rather than the base station **180**, in the second continuing example, the reference signal specification is carried (IEs) in a Radio Resource Control-level (RRC-level) message, specifically as part of RRCReconfiguration (RRCR) **1431***b* via beam **1411***b* on downlink. RRCR **1431***b* includes an SRS-Config IE modified with a beam sweeping IEs described above in a manner similar to that described in conjunction with FIG. **15** and TABLE 3. In the second continuing example, beam sweeping is enabled, and the "Origin" flag is set to "gNB Originated." K is not specified since the base station **180** trigger criteria (not receiving a single session—similar to K=1—of PUSCH when expected) does not need to be communicated to the UE **184**.

(130) Referring to FIG. **25**, and continuing to refer to prior figures for context, a UE **350** for wireless communication disclosed herein is shown, in accordance with examples of the technology disclosed herein. UE **350** includes UE sweeping component **142**′ as described in conjunction with FIG. **3** above. UE sweeping component **142**′ includes receiving component **142***a*′. In some examples, receiving component **142***a*′ receives, from the base station **180**, a beam sweeping configuration specifying a reference signal. Accordingly, receiving component **142***a*′ may provide means for receiving, from the base station **180**, a beam sweeping configuration specifying a reference signal.

(131) UE **184** first transmits, on each of a plurality of beams of a physical channel, the specified reference signal to the base station **180**, the beams including each beam currently in use for data transfer between the base station **180** and the UE **184** and a plurality of the beams not currently in use for data transfer to the UE **184** from the base station **180**—Block **2020**. In the second continuing example, the UE **184** transmits SRS (as configures in Block **2010**) swept across beams **1411***c*, **1412***c*, **1413***c*, **1414***c*, and **1415***c* to the base station **180**. Beams **1411** and **1412** are currently in use between the UE **184** and the base station **180**.

(132) Referring again to FIG. **25**, UE sweeping component **142**′ includes first transmitting component **142***b*′. In some examples, first transmitting component **142***b* ′ transmits, on each of a plurality of beams of a physical channel, the specified reference signal to the base station **180**, the beams including each beam currently in use for data transfer between the base station **180** and the UE **184** and a plurality of the beams not currently in use for data transfer to the UE **184** from the base station **180**. Accordingly, first transmitting component **142***b*′ may provide means for transmitting, on each of a plurality of beams of a physical channel, the specified reference signal to the base station **180**, the beams including each beam currently in use for data transfer between the base station **180** and the UE **184** and a plurality of the beams not currently in use for data transfer to the UE **184** from the base station **180**.

(133) UE **184** second receives a plurality of the transmitted beams swept on downlink to the UE **184**, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE—Block **2030**. In the second continuing example, In the second continuing example, the UE **184** receives five beams (**1411***f*, **1412***f*, **1413***f*, **1414***f*, and **1415***f*) swept in order of strength. "Sweeping" in the second continuing example includes transmitting DCI **1461***f* on downlink on each beam in order of decreasing measure uplink power.

(134) Referring again to FIG. **25**, UE sweeping component **142**′ includes second receiving component **142***c*′. In some examples, second receiving component **142***c*′ receives a plurality of the transmitted beams swept on downlink to the UE **184**, based on the measuring and the

configuration, for use in downlink data transfer from the base station to the UE. Accordingly, second receiving component **142***c*′ may provide means for receiving a plurality of the transmitted beams swept on downlink to the UE **184**, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE.

(135) Referring to FIG. **21**, and continuing to refer to prior figures for context, a flowchart of methods **2100** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **2100**, Block **2010**, Block **2020**, and Block **2030** are performed as described in connection with FIG. **20**. In such methods **2100**, the UE **184** determines that a subset of the second received beams successfully transferred data from the base station **180** to the UE **184**—Block **2140**. The UE **184** acknowledges, to the base station **180**, the successful transfer on a subset of the received beams successfully transferring data to the UE **184** from the base station **180**—Block **2150**. In the second continuing example, the UE **184**, upon successfully receiving and decoding the swept signal on one or more of beams **1411***f***-1414***f* retransmits the PUSCH **1491***e* as PUSCH **1491***g* on beams **1413***g* and **1414***g*.

(136) Referring again to FIG. **25**, UE sweeping component **142**′ includes determining component **142***d*′. In some examples, determining component **142***d*′ determines that a subset of the second received beams successfully transferred data from the base station **180** to the UE **184**. Accordingly, determining component **142***d*′ may provide means for determining that a subset of the second received beams successfully transferred data from the base station **180** to the UE **184**. Also, UE sweeping component **142**′ includes acknowledgement component **142***e*′. In some examples, acknowledgement component **142***e*′ acknowledges, to the base station **180**, the successful transfer on a subset of the received beams successfully transferring data to the UE **184** from the base station **180**. Accordingly, acknowledgement component **142***e*′ may provide means for acknowledging, to the base station **180**, the successful transfer on a subset of the received beams successfully transferring data to the UE **184** from the base station **180**.

(137) Referring to FIG. **22**, and continuing to refer to prior figures for context, a flowchart of methods **2200** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **2200**, Block **2010**, Block **2020**, and Block **2030** are performed as described in connection with FIG. **20**. In such methods **2200**, the UE **184** second transmits, to the base station **180** and prior to the first transmitting, a confirmation of configuration of the UE **184** in accordance with the received beam sweeping configuration—Block **2260**. In the second continuing example, the UE **184** transmits RRCRConfirmation **1432***b* on beam **1411***b* in uplink confirming that the UE **184** is configured according to the RRCR **1431***b* sent by the base station **180** on **1411***b* in downlink earlier in the cycle.

(138) Referring again to FIG. **25**, UE sweeping component **142**′ includes second transmitting component **142***f*′. In some examples, second transmitting component **142***f*′ transmits, to the base station **180** and prior to the first transmitting, a confirmation of configuration of the UE **184** in accordance with the received beam sweeping configuration. Accordingly, second transmitting component **142***f*′ may provide means for transmitting, to the base station **180** and prior to the first transmitting, a confirmation of configuration of the UE **184** in accordance with the received beam sweeping configuration.

(139) Referring to FIG. **23**, and continuing to refer to prior figures for context, a flowchart of methods **2300** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **2300**, Block **2010**, Block **2020**, and Block **2030** are performed as described in connection with FIG. **20**. In such methods **2300**, the UE **184** third receives, from the base station **180**, after the first transmitting and before the second receiving, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE **184**, wherein the second receiving is based on the received PTRS—Block **2370**. In some examples, the base station **180** uses PTRS transmitted on each of a plurality of beams as a way to prepare the UE **184** for use of currently unused beams for both sweeping and for data

transfer upon detection of a trigger.

(140) Referring again to FIG. **25**, UE sweeping component **142**′ includes third receiving component **142***g*′. In some examples, third receiving component **142***g*′ receives, from the base station **180**, after the first transmitting and before the second receiving, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE **184**, wherein the second receiving is based on the received PTRS. Accordingly, third receiving component **142***g*′ may provide means for receiving, from the base station **180**, after the first transmitting and before the second receiving, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE **184**, wherein the second receiving is based on the received PTRS.

(141) Referring to FIG. **24**, and continuing to refer to prior figures for context, a flowchart of methods **2400** of wireless communication is shown, in accordance with examples of the technology disclosed herein. In such methods **2400**, Block **2010**, Block **2020**, and Block **2030** are performed as described in connection with FIG. **20**. In such methods **2400**, the UE **184** successfully decoding, by the UE, at least one of the second received beams—Block **2480**. The UE **184** then third transmits, to the base station on each of the successfully decoded beams, an acknowledgement of the successful decoding—Block **2490**. In the second continuing example, the UE **184**, upon successfully receiving and decoding the swept signal on one or more of beams **1411***f*-**1414***f* retransmits the PUSCH **1491***e* as PUSCH **1491***g* on beams **1413***g* and **1414***g*. Afterwards, and in the absence of other transmission unsuccessfully received by the base station **180**, the UE **184** continues to transmit, to the base station on each of the successfully decoded beams, an acknowledgement of the successful decoding in subsequent cycles. In the second continuing example, the UE **184** transmits PUSCH **1491***h* on beams **1413***h* and **1414***h* in the next cycle.

(142) Referring again to FIG. **25**, UE sweeping component **142**′ includes decoding component **142***h*′. In some examples, decoding component **142***h*′ decodes at least one of the second received beams. Accordingly, decoding component **142***h*′ may provide means for decoding at least one of the second received beams.

(143) It is understood that the specific order or hierarchy of blocks in the processes/flowcharts disclosed is an illustration of example approaches. Based upon design preferences, it is understood that the specific order or hierarchy of blocks in the processes/flowcharts may be rearranged. Further, some blocks may be combined or omitted. The accompanying method claims present elements of the various blocks in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

(144) The following examples are illustrative only and aspects thereof may be combined with aspects of other embodiments or teaching described herein, without limitation.

(145) Example 1 is method of wireless communication, including receiving, by a user equipment (UE) of a wireless communication network, conditions for sweeping beams between a base station of the network and the UE; the conditions comprising a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink; measuring, by the UE, at least one characteristic of each of the beams in accordance with the measurement configuration; after the measuring, detecting, by the UE a trigger in accordance with the trigger rule; and in response to detecting the trigger, sweeping, by the UE, the beams on uplink based on the measuring.

(146) In Example 2 the method of Example 1 further includes wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. In Example 3 the method of Example 1 or Example 2 further includes the conditions comprising: a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping; and the sweeping is performed only upon: the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the UE as the origin of sweeping.

In Example 4, the method of any of Examples 1-3 further includes the conditions comprising a time period over which the measuring remains valid; and the sweeping is performed only during the period over which the measuring remains valid. In Example 5, the method of any of Examples 1-4 further includes the conditions comprising an order for sweeping among the beams; and the sweeping is performed among the beams in the order. In Example 6, the method of any of Examples 1-5 further includes the conditions comprising a number of the beams to sweep; and the sweeping is performed among the number of the beams in the order. In Example 7 the method of any of Examples 1-6 further includes that the conditions are contained in information elements in one of a Radio Resource Control (RRC) message, a Medium Access Control-Control Element (MAC-CE) message, and a Downlink Control Information (DCI) message. In Example 8, the method of any of Examples 1-7 further includes that the conditions are contained in information elements in an RRC message of one of the types: RRCSetup, RRCReconfiguration, RRCResume, and System Information Block. In Example 9 the method of any of Examples 1-8 further includes transmitting, by the UE to the base station, the measured at least one characteristic for each of the beams; second receiving, by the UE from the base station, an acknowledgement of successful reception of the transmitted measured at least one characteristic of each of the beams; and third receiving, by the UE from the base station and after the second receiving, phase tracking reference signals on at least one of the reported beams. In Example 10 the method of any of Examples 1-9 further includes, prior to receiving the conditions, requesting, by the UE, conditions for sweeping beams of a physical channel between a base station of the network and the UE; and wherein the receiving is in response to the requesting. In Example 11 the method of any of Examples 1-10 further includes wherein each swept beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding the detected trigger; and the method further comprises fourth receiving, by the UE, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

(147) In Example 12 a method of wireless communication includes sending, by a base station of a wireless communication network to a UE of the network, conditions for sweeping beams between the UE and the base station, the conditions comprising: a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink; transmitting, by the base station after the sending, a reference signal over the beams on downlink; first receiving, by the base station in response to the transmitting and the sending and from the UE, downlink beam measurements in accordance with the beam measurement configuration; preparing, by the base station in response to the receiving, at least one beam not currently used in downlink; second receiving, by the base station on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule; and second transmitting, by the base station to the UE, at least one physical channel on at least one prepared beam.

(148) In Example 13, the method of Example 12 further includes wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. In Example 14 the method of any of Examples 12-13 further includes wherein: the conditions further comprise: a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping; wherein, the preparing is performed only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled and the beam sweeping origin flag indicating the UE as the origin of sweeping. In Example 15 the method of any of Examples 12-14 further includes wherein the conditions further comprise a time period over which the measuring remains valid; and the preparing is performed only in response to receiving measurements from the period over which the measuring remains valid. In Example 16 the method of any of Examples 12-15 further includes wherein the conditions further comprise an order for sweeping among the beams; and the preparing

is performed only in response to receiving measurements among the beams in the order. In Example 17, the method of any of Examples 12-16 further includes wherein: the conditions further comprise a number of the beams to sweep; and the preparing is performed only in response to receiving measurements among the number of the beams in the order. In Example 18 the method of any of Examples 12-17 further includes wherein the conditions are contained in information elements in one of a Radio Resource Control (RRC) message, a Medium Access Control-Control Element (MAC-CE) message, and a Downlink Control Information (DCI) message. In Example 19, the method of any of Examples 12-18 further includes wherein the conditions are contained in information elements in an RRC message of one of the types: RRCSetup, RRCReconfiguration, RRCResume, and System Information Block. In Example 20 the method of any of Examples 12-19 further includes, prior to sending the conditions, third receiving, from the UE, a request for conditions for sweeping beams of a physical channel between a base station of the network and the UE; and wherein the sending is in response to the requesting. In Example 21 the method of any of Examples 12-20 further includes wherein each second received beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding a trigger detected in accordance with the sweeping trigger rule; and the method further comprises third transmitting, by the base station, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

(149) In Example 22 a method of wireless communication includes transmitting, from a base station of a wireless communication network to a user equipment (UE) of the network, a beam sweeping configuration specifying a reference signal; measuring, by the base station, at least one characteristic of each of a plurality of beams of a physical channel and comprising the specified reference signal from the UE to the base station on uplink, the beams including each beam currently in use for communication between the base station and the UE and a plurality of beams not currently in use for downlink data transfer to the UE; detecting, by the base station after the measuring, a beam sweeping trigger condition; sweeping, by the base station and in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration.

(150) In Example 23, the method of Examples 22 further includes wherein the reference signal is a sounding reference signal (SRS). In Example 24, the method of any of Examples 22-23 further includes receiving, by the base station from the UE and prior to the measuring, a confirmation of configuration of the UE in accordance with the transmitted beam sweeping configuration; and wherein the measuring is performed only upon receiving the confirmation. In Example 25, the method of any of Examples 22-24 further includes wherein the beam sweeping configuration comprises a beam sweeping enabled/disabled indicator set to enabled. In Example 26 the method of any of Examples 22-25 further includes, after the measuring, preparing a plurality of the not currently-used beams for sweeping upon detection of a beam sweeping trigger condition. In Example 27, the method of any of Examples 22-26 further includes wherein the preparing includes second transmitting, by the base station, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE. In Example 28 the method of any of Examples 22-27 further includes second receiving, from the UE and after the sweeping, an acknowledgement of successful transmission on each of a plurality of the swept beams; and third transmitting data to the UE on a plurality of the acknowledged beams. In Example 29 the method of any of Examples 22-28 further includes wherein detecting comprises determining over K consecutive communication cycles between the base station and the UE that the UE has not successfully received DL transmissions of the K consecutive cycles.

(151) In Example 30 the method includes receiving, from a base station of a wireless communication network by a user equipment (UE) of the network, a beam sweeping configuration specifying a reference signal; first transmitting, by the UE and on each of a plurality of beams of a

physical channel, the specified reference signal to the base station, the beams including each beam currently in use for data transfer between the base station and the UE and a plurality of the beams not currently in use for data transfer to the UE from the base station; and second receiving, by the UE, a plurality of the transmitted beams swept on downlink to the UE, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE.

(152) In Example 31 the method of Example 30 includes determining, by the UE, that a subset of the second received beams successfully transferred data from the base station to the UE; and acknowledging, by the UE to the base station, the successful transfer on a subset of the received beams successfully transferring data to the UE from the base station. In Example 32, the method of any of Examples 30-31 includes wherein the reference signal is a sounding reference signal (SRS). In Example 33 the method of any of Examples 31-32 includes second transmitting, by the UE to the base station and prior to the first transmitting, a confirmation of configuration of the UE in accordance with the received beam sweeping configuration. In Example 34, the method of any of Examples 31-33 includes wherein the beam sweeping configuration comprises a beam sweeping enabled/disabled indicator set to enabled. In Example 35, the method of any of Examples 31-34 includes third receiving, by the UE from the base station, after the first transmitting and before the second receiving, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE, wherein the second receiving is based on the received PTRS. In Example 36, the method of any of Examples 31-35 includes successfully decoding, by the UE, at least one of the second received beams; and third transmitting, by the UE to the base station on each of the successfully decoded beams, an acknowledgement of the successful decoding.

(153) Example 37 includes an apparatus for wireless communication, comprising: a memory; and at least one processor coupled to the memory and configured to execute the method of any one or more of claims 1-36.

(154) Example 38 includes a computer-readable medium storing computer executable code, the code when executed by a processor cause the processor to execute the method of any one or more of claims 1-36.

(155) Example 39 includes an apparatus for wireless communications including means for receiving, by a user equipment (UE) of a wireless communication network, conditions for sweeping beams between a base station of the network and the UE, the conditions comprising: a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink; means for measuring, by the UE, at least one characteristic of each of the beams in accordance with the measurement configuration; means for after the measuring, detecting, by the UE a trigger in accordance with the trigger rule; and means for in response to detecting the trigger, sweeping, by the UE, the beams on uplink based on the measuring.

(156) In Example 40, the apparatus of Example 39 includes wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. In Example 41, the apparatus of any of Examples 39-40 includes wherein: the conditions further comprise: a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping; and the sweeping is performed only upon: the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the UE as the origin of sweeping. In Example 42, the apparatus of any of Examples 39-41 includes wherein: the conditions further comprise a time period over which the measuring remains valid; and the sweeping is performed only during the period over which the measuring remains valid. In Example 43, the apparatus of any of Examples 39-42 includes wherein: the conditions further comprise an order for sweeping among the beams; and the sweeping is performed among the beams in the order. In Example 44, the apparatus of any of Examples 39-43 includes wherein: the conditions further

comprise a number of the beams to sweep; and the sweeping is performed among the number of the beams in the order. In Example 45 the apparatus of any of Examples 39-44 includes wherein the conditions are contained in information elements in one of a Radio Resource Control (RRC) message, a Medium Access Control—Control Element (MAC-CE) message, and a Downlink Control Information (DCI) message. In Example 46, the apparatus of any of Examples 39-45 includes wherein the conditions are contained in information elements in an RRC message of one of the types: RRCSetup, RRCReconfiguration, RRCResume, and System Information Block. In Example 47 the apparatus of any of Examples 39-46 includes means for transmitting, by the UE to the base station, the measured at least one characteristic for each of the beams; means for second receiving, by the UE from the base station, an acknowledgement of successful reception of the transmitted measured at least one characteristic of each of the beams; and means for third receiving, by the UE from the base station and after the second receiving, phase tracking reference signals on at least one of the reported beams. In Example 48 the apparatus of any of Examples 39-47 includes means for, prior to receiving the conditions, requesting, by the UE, conditions for sweeping beams of a physical channel between a base station of the network and the UE; and wherein the receiving is in response to the requesting. In Example 49 the apparatus of any of Examples 39-48 includes wherein each swept beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding the detected trigger; and the apparatus further comprises means for fourth receiving, by the UE, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

(157) Example 50 includes an apparatus for wireless communication, including means for sending, by a base station of a wireless communication network to a UE of the network, conditions for sweeping beams between the UE and the base station, the conditions comprising: a beam sweeping trigger rule, and a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink. Example 50 further includes means for transmitting, by the base station after the sending, a reference signal over the beams on downlink; means for receiving, by the base station in response to the transmitting and the sending and from the UE, downlink beam measurements in accordance with the beam measurement configuration; means for preparing, by the base station in response to the receiving, at least one beam not currently used in downlink; means for second receiving, by the base station on at least one of the prepared beams swept by the UE, an indication that a trigger has been detected at the UE in accordance with the trigger rule; and means for second transmitting, by the base station to the UE, at least one physical channel on at least one prepared beam.

(158) In Example 51, in the apparatus of Example 50 the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams. In Example 52, in the apparatus of any of Example 50-51 the conditions further comprise: a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping. In such examples, the preparing is performed only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled and the beam sweeping origin flag indicating the UE as the origin of sweeping. In Example 53, in the apparatus of any of Example 50-52, the conditions further comprise a time period over which the measuring remains valid; and the preparing is performed only in response to receiving measurements from the period over which the measuring remains valid. In Example 54, in the apparatus of any of Example 50-53 the conditions further comprise an order for sweeping among the beams; and the preparing is performed only in response to receiving measurements among the beams in the order. In Example 55, in the apparatus of any of Example 50-54, the conditions further comprise a number of the beams to sweep; and the preparing is performed only in response to receiving measurements among the number of the beams in the order. In Example 56, in the apparatus of any of Example 50-55, the conditions are contained in information elements

in one of a Radio Resource Control (RRC) message, a Medium Access Control—Control Element (MAC-CE) message, and a Downlink Control Information (DCI) message. In Example 57, in the apparatus of any of Example 50-56, the conditions are contained in information elements in an RRC message of one of the types: RRCSetup, RRCReconfiguration, RRCResume, and System Information Block. In Example 58, the apparatus of any of Example 50-57 further includes means for third receiving, from the UE and prior to sending the conditions, a request for conditions for sweeping beams of a physical channel between a base station of the network and the UE. In such examples, the sending is in response to the requesting. In Example 59, in the apparatus of any of Example 50-58, each second received beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding a trigger detected in accordance with the sweeping trigger rule. Such examples further include means for third transmitting, by the base station, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

(159) Example 60 includes an apparatus of wireless communication, including means for transmitting, from a base station of a wireless communication network to a user equipment (UE) of the network, a beam sweeping configuration specifying a reference signal; means for measuring, by the base station, at least one characteristic of each of a plurality of beams of a physical channel, each of the beams comprising the specified reference signal, from the UE to the base station on uplink, the beams including each beam currently in use for communication between the base station and the UE and a plurality of beams not currently in use for downlink data transfer to the UE; means for detecting, by the base station after the measuring, a beam sweeping trigger condition; and means for sweeping, by the base station and in response to the detecting, a plurality of the measured beams on downlink to the UE based on the measuring and the configuration

(160) In Example 61, in the apparatus of Example 60 the reference signal is a sounding reference signal (SRS). In Example 62, any of Examples 60-61 further includes means for receiving, by the base station from the UE and prior to the measuring, a confirmation of configuration of the UE in accordance with the transmitted beam sweeping configuration. In such examples, the measuring is performed only upon receiving the confirmation. In Example 63, in the apparatus of any of Examples 60-62, the beam sweeping configuration comprises a beam sweeping enabled/disabled indicator set to enabled. In Example 64, any of Examples 60-63 further includes means for preparing, after the measuring, a plurality of the not currently-used beams for sweeping upon detection of a beam sweeping trigger condition. In Example 65, in the apparatus of any of Examples 60-64, the preparing includes second transmitting, by the base station, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE. In Example 66, any of Examples 60-65 further includes means for receiving, from the UE and after the sweeping, an acknowledgement of successful transmission on each of a plurality of the swept beams; and means for third transmitting data to the UE on a plurality of the acknowledged beams. In Example 67, in the apparatus of any of Examples 60-66, detecting includes determining over K consecutive communication cycles between the base station and the UE that the UE has not successfully received DL transmissions of the K consecutive cycles.

(161) Example 68 includes an apparatus for wireless communication, including means for receiving, from a base station of a wireless communication network by a user equipment (UE) of the network, a beam sweeping configuration specifying a reference signal; means for transmitting, by the UE and on each of a plurality of beams of a physical channel, the specified reference signal to the base station, the beams including each beam currently in use for data transfer between the base station and the UE and a plurality of beams not currently in use for data transfer to the UE from the base station; and means for second receiving, by the UE, a plurality of the transmitted beams swept on downlink to the UE, based on the measuring and the configuration, for use in downlink data transfer from the base station to the UE.

(162) In Example 69, Example 68 further includes means for determining, by the UE, that a subset of the second received beams successfully transferred data from the base station to the UE; and means for acknowledging, by the UE to the base station, the successful transfer on a subset of the received beams successfully transferring data to the UE from the base station. In Example 70, in the apparatus of any of Examples 68-69, the reference signal is a sounding reference signal (SRS). In Example 71, any of Examples 68-70 further includes means for second transmitting, by the UE to the base station and prior to the first transmitting, a confirmation of configuration of the UE in accordance with the received beam sweeping configuration. In Example 72, in the apparatus of any of Examples 68-71, the beam sweeping configuration comprises a beam sweeping enabled/disabled indicator set to enabled. In Example 73, any of Examples 68-72 further includes means for third receiving, by the UE from the base station, after the first transmitting and before the second receiving, a Phase Tracking Reference Signal (PTRS) on each of a plurality of the beams not currently used for downlink data transfer to the UE, wherein the second receiving is based on the received PTRS. In Example 74, any of Examples 68-73 further includes means for successfully decoding, by the UE, at least one of the second received beams; and means for third transmitting, by the UE to the base station on each of the successfully decoded beams, an acknowledgement of the successful decoding.
(163) The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any aspect described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects. Unless specifically stated otherwise, the term “some” refers to one or more. Combinations such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” include any combination of A, B, and/or C, and may include multiples of A, multiples of B, or multiples of C. Specifically, combinations such as “at least one of A, B, or C,” “one or more of A, B, or C,” “at least one of A, B, and C,” “one or more of A, B, and C,” and “A, B, C, or any combination thereof” may be A only, B only, C only, A and B, A and C, B and C, or A and B and C, where any such combinations may contain one or more member or members of A, B, or C. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. The words “module,” “mechanism,” “element,” “device,” and the like may not be a substitute for the word “means.” As such, no claim element is to be construed as a means plus function unless the element is expressly recited using the phrase “means for.”

Claims

1. A method of wireless communication, comprising: receiving, by a user equipment (UE) of a wireless communication network, conditions for sweeping beams between a base station of the network and the UE, the conditions comprising: a beam sweeping trigger rule, a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink; a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping; measuring, by the UE, at least one

characteristic of each of the beams in accordance with the measurement configuration; after the measuring, detecting, by the UE, a trigger in accordance with the trigger rule; and in response to detecting the trigger, sweeping, by the UE, the beams on uplink based on the measuring, and only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the UE as the origin of sweeping.

2. The method of claim 1, wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams.

3. The method of claim 1, wherein: the conditions further comprise a time period over which the measuring remains valid; and the sweeping is performed only during the period over which the measuring remains valid.

4. The method of claim 1, wherein: the conditions further comprise an order for sweeping among the beams and a number of the beams to sweep; and the sweeping is performed among the number of the beams in the order.

5. The method of claim 1, wherein the conditions are contained in information elements in one: of a Radio Resource Control (RRC) message of one of RRCSetup, RRCReconfiguration, RRCResume, and System Information Block; a Medium Access Control-Control Element (MAC-CE) message; and a Downlink Control Information (DCI) message.

6. The method of claim 1, further comprising: transmitting, by the UE to the base station, the measured at least one characteristic for each of the beams; second receiving, by the UE from the base station, an acknowledgement of successful reception of the transmitted measured at least one characteristic of each of the beams; and third receiving, by the UE from the base station and after the second receiving, phase tracking reference signals on at least one of the measured beams.

7. The method of claim 1: further comprising prior to receiving the conditions, requesting, by the UE, conditions for sweeping beams of a physical channel between the base station of the network and the UE; wherein the receiving is in response to the requesting.

8. The method of claim 1: wherein each swept beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding the detected trigger; and the method further comprises fourth receiving, by the UE, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.

9. An apparatus for wireless communication in a wireless communication network, comprising: a memory; and at least one processor coupled to the memory, the memory including instructions executable by the at least one processor to cause the apparatus to: the network, conditions for sweeping beams between a base station of the network and the apparatus, the conditions comprising: a beam sweeping trigger rule, a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink, a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the apparatus or the base station as an origin of sweeping; measure, by the apparatus, at least one characteristic of each of the beams in accordance with the measurement configuration; after the measuring, detect, by the apparatus, a trigger in accordance with the trigger rule; and in response to detecting the trigger, sweep, by the apparatus, the beams on uplink based on the measuring, and only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the apparatus as the origin of sweeping.

10. The apparatus of claim 9, wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the apparatus of a downlink transmission on a physical channel carried on the beams.

11. The apparatus of claim 9, wherein: the conditions further comprise a time period over which the measuring remains valid; and the sweeping is performed only during the period over which the measuring remains valid.

12. The apparatus of claim 9, wherein: the conditions further comprise an order for sweeping among the beams and a number of the beams to sweep; and the sweeping is performed among the number of the beams in the order.
13. The apparatus of claim 9, wherein the conditions are contained in information elements in one: of a Radio Resource Control (RRC) message of one of RRCSetup, RRCReconfiguration, RRCResume, and System Information Block; a Medium Access Control-Control Element (MAC-CE) message; and a Downlink Control Information (DCI) message.
14. A non-transitory computer-readable medium storing computer executable code, the code when executed by a processor cause the processor to: receive, by a user equipment (UE) of a wireless communication network, conditions for sweeping beams between a base station of the network and the UE, the conditions comprising: a beam sweeping trigger rule, a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink, a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the UE or the base station as an origin of sweeping; measure, by the UE, at least one characteristic of each of the beams in accordance with the measurement configuration; after the measuring, detect, by the UE, a trigger in accordance with the trigger rule; and in response to detecting the trigger, sweep, by the UE, the beams on uplink based on the measuring, and only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the UE as the origin of sweeping.
15. The non-transitory computer-readable medium of claim 14, wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the UE of a downlink transmission on a physical channel carried on the beams.
16. The non-transitory computer-readable medium of claim 14, wherein the code when executed by a processor further causes the processor to: transmit, by the UE to the base station, the measured at least one characteristic for each of the beams; second receive, by the UE from the base station, an acknowledgement of successful reception of the transmitted measured at least one characteristic of each of the beams; and third receive, by the UE from the base station and after the second receiving, phase tracking reference signals on at least one of the measured beams.
17. The non-transitory computer-readable medium of claim 14: wherein the code when executed by a processor further causes the processor to prior to receiving the conditions, request, by the UE, conditions for sweeping beams of a physical channel between the base station of the network and the UE; wherein the receiving is in response to the requesting.
18. The non-transitory computer-readable medium of claim 14: wherein each swept beam carries a Physical Uplink Control Channel (PUCCH) of the UE that includes an information element regarding the detected trigger; and wherein the code when executed by a processor further causes the processor to fourth receive, by the UE, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.
19. An apparatus for wireless communications in a wireless communication network, comprising: means for receiving, by the apparatus of the network, conditions for sweeping beams between a base station of the network and the apparatus, the conditions comprising: a beam sweeping trigger rule, a beam measurement configuration for measuring at least one characteristic of each of the beams on downlink, a beam sweeping enabled/disabled flag, and a beam sweeping origin flag indicating either the apparatus or the base station as an origin of sweeping; means for measuring, by the apparatus, at least one characteristic of each of the beams in accordance with the measurement configuration; means for after the measuring, detecting, by the apparatus, a trigger in accordance with the trigger rule; and means for in response to detecting the trigger, sweeping, by the apparatus, the beams on uplink based on the measuring, and only upon the beam sweeping enabled/disabled flag indicating beam sweeping enabled, and the beam sweeping origin flag indicating the apparatus as the origin of sweeping.

20. The apparatus of claim 19, wherein the trigger rule comprises detecting a number K of consecutive unsuccessful receptions by the apparatus of a downlink transmission on a physical channel carried on the beams.
21. The apparatus of claim 19, wherein: the conditions further comprise a time period over which the measuring remains valid; and the sweeping is performed only during the period over which the measuring remains valid.
22. The apparatus of claim 19, wherein: the conditions further comprise an order for sweeping among the beams and a number of the beams to sweep; and the sweeping is performed among the number of the beams in the order.
23. The apparatus of claim 19, wherein the conditions are contained in information elements in one of: a Radio Resource Control (RRC) message of one of RRCSetup, RRCReconfiguration, RRCResume, and System Information Block; a Medium Access Control-Control Element (MAC-CE) message; and a Downlink Control Information (DCI) message.
24. The apparatus of claim 19, further comprising: means for transmitting, by the apparatus to the base station, the measured at least one characteristic for each of the beams; means for second receiving, by the apparatus from the base station, an acknowledgement of successful reception of the transmitted measured at least one characteristic of each of the beams; and means for third receiving, by the apparatus from the base station and after the second receiving, phase tracking reference signals on at least one of the measured beams.
25. The apparatus of claim 19: further comprising means for, prior to receiving the conditions, requesting, by the apparatus, conditions for sweeping beams of a physical channel between the base station of the network and the apparatus; wherein the receiving is in response to the requesting.
26. The apparatus of claim 19: wherein each swept beam carries a Physical Uplink Control Channel (PUCCH) of the apparatus that includes an information element regarding the detected trigger; and the apparatus further comprises means for fourth receiving, by the apparatus, data on one or more Physical Downlink Shared Channels (PDSCH) via one or more beams corresponding to the beams on which the information element was successfully received by the base station.