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## INTERFERENCE MANAGEMENT FOR ARRAY PUNCTURING

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### Abstract

Systems and techniques are provided for wireless communications. For example, a process can include, obtaining a message for transmission to a receiving device, determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device. A number of beamforming weights is equal to a number of transmit array elements. Each beamforming weight corresponds to a respective transmit array element. A beamforming weight is configured to turn off a transmit array element during transmission of the portion of the message. The process can include outputting an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

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### Background/Summary

## FIELD

[0001] The present disclosure generally relates to wireless communications. For example, aspects of the present disclosure relate to systems and techniques for providing interference management for array puncturing in wireless systems such as wireless communication systems.

## BACKGROUND

[0002] Wireless communications systems are deployed to provide various telecommunications and data services, including telephony, video, data, messaging, and broadcasts. Broadband wireless communications systems have developed through various generations, including a first-generation analog wireless phone service (1G), a second-generation (2G) digital wireless phone service (including interim 2.5G networks), a third-generation (3G) high speed data, Internet-capable wireless device, and a fourth-generation (4G) service (e.g., Long-Term Evolution (LTE), WiMax). Examples of wireless communications systems 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, Global System for Mobile communication (GSM) systems, etc. Other wireless communications technologies include 802.11 Wi-Fi, Bluetooth, among others.

[0003] A fifth-generation (5G) mobile standard calls for higher data transfer speeds, greater number of connections, and better coverage, among other improvements. The 5G standard (also referred to as “New Radio” or “NR”), according to Next Generation Mobile Networks Alliance, is designed to provide data rates of several tens of megabits per second to each of tens of thousands of users, with 1 gigabit per second to tens of workers on an office floor. Several hundreds of thousands of simultaneous connections should be supported in order to support large sensor deployments.

[0004] Although wireless communication systems have made great technological advancements over many years, challenges still exist. For example, certain transmissions from a wireless system may need to be made without cryptographic protection (encryption) to protect against potential eavesdropping, replay attacks, etc. Thus, techniques to help protect such messages against eavesdropping may be useful.

## SUMMARY

[0005] The following presents a simplified summary relating to one or more aspects disclosed herein. Thus, the following summary should not be considered an extensive overview relating to all contemplated aspects, nor should the following summary be considered to identify key or critical elements relating to all contemplated aspects or to delineate the scope associated with any particular aspect. Accordingly, the following summary presents certain concepts relating to one or more aspects relating to the mechanisms disclosed herein in a simplified form to precede the detailed description presented below.

[0006] Disclosed are systems, methods, apparatuses, and computer-readable media for performing wireless communications. According to at least one illustrative example, a method for wireless communications is provided. The method includes: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, where a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements, each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements, and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message; outputting an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and transmitting the portion of the message by the plurality of transmit array elements with the transmit

array element corresponding to the beamforming weight turned off.

[0007] In another illustrative example, an apparatus for wireless communications is provided that includes a memory and a processor coupled to the memory. The processor is configured to: obtain a message for transmission to a receiving device; and determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, where a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements, and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, where the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0008] In another illustrative example, a non-transitory computer-readable medium is provided that has stored thereon instructions that, when executed by one or more processors, cause the one or more processors to: obtain a message for transmission to a receiving device; and determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, where a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements, and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, where the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0009] In another illustrative example, an apparatus for wireless communications is provided. The apparatus includes: means for obtaining a message for transmission to a receiving device; means for determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, where a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements, each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements, and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message; means for outputting an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and means for transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0010] According to at least one illustrative example, a method for wireless communications is provided. The method includes: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit

array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0011] In another illustrative example, an apparatus for wireless communications is provided that includes a memory and a processor coupled to the memory. The processor is configured to: obtain a message for transmission to a receiving device; determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0012] In another illustrative example, a non-transitory computer-readable medium is provided that has stored thereon instructions that, when executed by one or more processors, cause the one or more processors to: obtain a message for transmission to a receiving device; determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0013] In another illustrative example, an apparatus for wireless communications is provided. The apparatus includes: means for obtaining a message for transmission to a receiving device; means for determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; means for determining a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free

sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and means for transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0014] In some aspects, one or more of the apparatuses described herein is, is a part of, or includes a mobile device (e.g., a mobile telephone or so-called “smart phone”, a tablet computer, or other type of mobile device), a wearable device, an extended reality device (e.g., a virtual reality (VR) device, an augmented reality (AR) device, or a mixed reality (MR) device), a personal computer, a laptop computer, a video server, a television (e.g., a network-connected television), a vehicle (or a computing device or system of a vehicle), or other device. In some aspects, the apparatus includes at least one camera for capturing one or more images or video frames. For example, the apparatus can include a camera (e.g., an RGB camera) or multiple cameras for capturing one or more images and/or one or more videos including video frames. In some aspects, the apparatus includes a display for displaying one or more images, videos, notifications, or other displayable data. In some aspects, the apparatus includes a transmitter configured to transmit one or more video frame and/or syntax data over a transmission medium to at least one device. In some aspects, the processor includes a neural processing unit (NPU), a central processing unit (CPU), a graphics processing unit (GPU), or other processing device or component.

[0015] The foregoing has outlined rather broadly the features and technical advantages of examples according to the disclosure in order that the detailed description that follows may be better understood. Additional features and advantages will be described hereinafter. The conception and specific examples disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. Such equivalent constructions do not depart from the scope of the appended claims. Characteristics of the concepts disclosed herein, both their organization and method of operation, together with associated advantages, will be better understood from the following description when considered in connection with the accompanying figures. Each of the figures is provided for the purposes of illustration and description, and not as a definition of the limits of the claims.

[0016] While aspects are described in the present disclosure by illustration to some examples, those skilled in the art will understand that such aspects may be implemented in many different arrangements and scenarios. Techniques described herein may be implemented using different platform types, devices, systems, shapes, sizes, and/or packaging arrangements. For example, some aspects may be implemented via integrated chip embodiments or other non-module-component based devices (e.g., end-user devices, vehicles, communication devices, computing devices, industrial equipment, retail/purchasing devices, medical devices, and/or artificial intelligence devices). Aspects may be implemented in chip-level components, modular components, non-modular components, non-chip-level components, device-level components, and/or system-level components. Devices incorporating described aspects and features may include additional components and features for implementation and practice of claimed and described aspects. For example, transmission and reception of wireless signals may include one or more components for analog and digital purposes (e.g., hardware components including antennas, radio frequency (RF) chains, power amplifiers, modulators, buffers, processors, interleavers, adders, and/or summers). It is intended that aspects described herein may be practiced in a wide variety of devices, components, systems, distributed arrangements, and/or end-user devices of varying size, shape, and constitution.

[0017] Other objects and advantages associated with the aspects disclosed herein will be apparent to those skilled in the art based on the accompanying drawings and detailed description.

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## Description

## BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Examples of various implementations are described in detail below with reference to the following figures:

[0019] FIG. 1 is a block diagram illustrating an example of a wireless communication network, in accordance with some examples of the present disclosure;

[0020] FIG. 2 is a diagram illustrating a design of a base station and a User Equipment (UE) device that enable transmission and processing of signals exchanged between the UE and the base station, in accordance with some examples of the present disclosure;

[0021] FIG. 3 is a diagram illustrating an example of a disaggregated base station, in accordance with some examples of the present disclosure;

[0022] FIG. 4 is a block diagram illustrating components of a user equipment, in accordance with some examples of the present disclosure;

[0023] FIGS. 5A-5D depict various example aspects of data structures for a wireless communication network, in accordance with some examples of the present disclosure;

[0024] FIG. 6 is a schematic view illustrating an example of a wireless communication system performing beamforming, in accordance with some examples of the present disclosure;

[0025] FIG. 7A is a schematic view illustrating a communication configuration that incorporates array puncturing, in accordance with some examples of the present disclosure;

[0026] FIG. 7B is a schematic view illustrating an additional communication configuration that incorporates interference management for array puncturing, in accordance with some examples of the present disclosure;

[0027] FIG. 8 illustrates a plot of a transmitted power profile for an example array puncturing configuration incorporating array tapering for interference management, in accordance with some examples of the present disclosure;

[0028] FIG. 9A illustrates a plot of a phase distortion profile for an example array puncturing configuration without array tapering for interference management, in accordance with some examples of the present disclosure;

[0029] FIG. 9B illustrates a plot of a phase distortion for the example array puncturing configuration incorporating array tapering for interference management, in accordance with some examples of the present disclosure;

[0030] FIG. 10 is a schematic view illustrating a communication configuration that incorporates interference management for array puncturing, in accordance with some examples of the present disclosure;

[0031] FIG. 11A illustrates a diagram showing plots of transmitted power for different array puncturing patterns of an example communication configuration that incorporates interference management for array puncturing, in accordance with some examples of the present disclosure;

[0032] FIG. 11B illustrates a diagram showing plots of phase for different array puncturing patterns of an example communication configuration that incorporates interference management for array puncturing, in accordance with some examples of the present disclosure;

[0033] FIG. 12 is a schematic view illustrating an additional communication configuration that incorporates interference management for array puncturing, in accordance with some examples of the present disclosure;

[0034] FIG. 13A is a flow diagram of a process for wireless communications, in accordance with some examples of the present disclosure;

[0035] FIG. 13B is a flow diagram of an additional process for wireless communications, in accordance with some examples of the present disclosure;

[0036] FIG. 14 is a diagram illustrating an example of a computing system, in accordance with some examples of the present disclosure.

## DETAILED DESCRIPTION

[0037] Certain aspects and embodiments of this disclosure are provided below. Some of these aspects and embodiments may be applied independently and some of them may be applied in combination as would be apparent to those of skill in the art. In the following description, for the purposes of explanation, specific details are set forth in order to provide a thorough understanding of embodiments of the application. However, it will be apparent that various embodiments may be practiced without these specific details. The figures and description are not intended to be restrictive.

[0038] The ensuing description provides example embodiments only, and is not intended to limit the scope, applicability, or configuration of the disclosure. Rather, the ensuing description of the exemplary embodiments will provide those skilled in the art with an enabling description for implementing an exemplary embodiment. It should be understood that various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the application as set forth in the appended claims.

[0039] In some cases, a wireless network and/or wireless device may transmit certain broadcast and/or control messages without cryptographic protection (e.g., encryption). For example, system information messages containing information about how to access the wireless system, such as system information block 1 (SIB 1) message, PUCCH/PUSCH, etc., may be transmitted without encryption to allow a receiving device to decode the message. In one illustrative example, system information can be transmitted without encryption to a device that does not yet have secure access to a wireless system via cryptographic means (e.g., authentication). Such cryptographically unprotected transmissions may be subject to possible eavesdropping. For example, a false base station may eavesdrop on system information messages transmitted by a legitimate base station and the false base station may then send fake system information messages using the eavesdropped system information messages (with or without modifying them) to attack on the legitimate user and associated wireless network (e.g., denial-of-service attacks).

[0040] One technique that may be useful for providing some protection against eavesdropping that may be implemented in a physical (PHY) layer is array puncturing. Array puncturing may be performed by turning off one or more transmit array elements (e.g., one or more antennas of the transmit array of antennas). Turning off one or more transmit array elements may be performed in such a way as to induce intentional phase distortion in any direction other than the beamforming direction. However, controlling the phase distortion provided by array puncturing can include changing the selection of which particular element(s) to turn off and/or the number of array elements to turn off. As used herein, “array puncturing pattern” refers to the selection of particular element(s) to turn off and/or the number of array elements to turn off for a transmission. In some cases, array puncturing can produce unwanted amplitude fluctuation in a direction other than the beamforming direction (e.g., toward an additional receiving device that is not the intended recipient of the transmission in the beamforming direction), which may interfere with the ability of the additional receiving device to receive its own messages from a transmitter. In some cases, if the transmitting device changes between two or more different array puncturing patterns during a transmission (e.g., during different symbols of a transmission), the additional receiving device may have more difficulty (e.g., in performing interference measurements) compensating for the resulting interference (arising from the amplitude fluctuations due to the array puncturing).

[0041] Systems, apparatuses, electronic devices, methods (also referred to as processes), and computer-readable media (collectively referred to herein as “systems and techniques”) are described herein for managing interference in a direction other than the beamforming direction that can be caused by protections against eavesdropping. For example, array puncturing is a technique that may be useful for providing some protection against eavesdropping but may also interfere with receiving devices located in directions other than the beamforming direction.

[0042] According to some aspects, array puncturing may be performed by modifying a beamforming vector for one or more transmit array elements (e.g., one or more antennas of an

antenna array). Modifying the beamforming vector may be performed by applying a coefficient that modifies a beamforming weight for a transmit array element. As used herein, “beamforming weight” refers to phase and/or relative gain applied to a transmit array element. In some cases, beamforming weights provided by a beamforming vector can be configured such that radio signals transmitted by the transmit array elements constructively interfere when received by a receiving device located at a particular angle relative to a broadside of the antenna array. As used herein, “broadside” refers the direction that is perpendicular to a radiating side of the plane of the antenna array. As used herein, a “beamforming angle” refers to a desired angle (i.e., direction of the intended receiving device), relative to broadside, for transmitting a signal. Array puncturing may be performed in such a way as to induce phase distortion in any direction other than the beamforming angle.

[0043] The systems and techniques described herein may include broadcasting notification messages to a wireless network and/or between base stations to indicate that particular directions may be affected by a transmission utilizing array puncturing transmitted by a first base station to a first receiving device. In some cases, the first base station and/or the network may broadcast a notification message including a time/frequency pattern of the transmission by the first base station. In some cases, the first base station and/or the network may broadcast a notification message including a start time and/or a stop time for the transmission by the first base station. In some cases, a second base station communicating with a second receiving device may receive a notification message and determine, based on the notification message, that the transmission utilizing array puncturing may cause interference in the direction of the second receiving device. In some cases, the second base station can configure the second receiving device to perform interference measurements based on the notification message. In some implementations, the second base station may request the network and/or first base station to limit the array puncturing patterns that the first base station may use and/or prohibiting the first base station from utilizing array puncturing. In some aspects, the first base station can employ array tapering to suppress interference in the direction of the second receiving device.

[0044] In some implementations, the first base station may include a list of fluctuation free observation angle windows and associated array puncturing patterns that can be used interchangeably within each of the fluctuation free observation angle windows included in the list. In some cases, if the first base station knows the location of the second receiving device, the first base station can apply puncturing patterns corresponding to a fluctuation free observation angle window that includes the location of the second receiving device. In some examples, the first base station can sweep between multiple fluctuation free observation angle windows over time. In some cases, each fluctuation free observation angle window can be applied for a fixed time period. In some aspects, the first base station can select between fluctuation free observation angle windows based on information about the location and/or presence of receiving devices.

[0045] Additional aspects of the present disclosure are described in more detail below.

[0046] Wireless networks are deployed to provide various communication services, such as voice, video, packet data, messaging, broadcast, and the like. A wireless network may support both access links for communication between wireless devices. An access link may refer to any communication link between a client device (e.g., a user equipment (UE), a station (STA), or other client device) and a base station (e.g., a 3GPP gNodeB (gNB) for 5G/NR, a 3GPP eNodeB (eNB) for LTE, a Wi-Fi access point (AP), or other base station) or a component of a disaggregated base station (e.g., a central unit, a distributed unit, and/or a radio unit). In one example, an access link between a UE and a 3GPP gNB may be over a Uu interface. In some cases, an access link may support uplink signaling, downlink signaling, connection procedures, etc.

[0047] In some aspects, wireless communications networks may be implemented using one or more modulation schemes. For example, a wireless communication network may be implemented using a quadrature amplitude modulation (QAM) scheme such as 16QAM, 32QAM, 64QAM, etc.



[0048] As used herein, the terms “user equipment” (UE) and “network entity” are not intended to be specific or otherwise limited to any particular radio access technology (RAT), unless otherwise noted. In general, a UE may be any wireless communication device (e.g., a mobile phone, router, tablet computer, laptop computer, and/or tracking device, etc.), wearable (e.g., smartwatch, smart-glasses, wearable ring, and/or an extended reality (XR) device such as a virtual reality (VR) headset, an augmented reality (AR) headset or glasses, or a mixed reality (MR) headset), vehicle (e.g., automobile, motorcycle, bicycle, etc.), and/or Internet of Things (IoT) device, etc., used by a user to communicate over a wireless communications network. A UE may be mobile or may (e.g., at certain times) be stationary, and may communicate with a radio access network (RAN). As used herein, the term “UE” may be referred to interchangeably as an “access terminal” or “AT,” a “client device,” a “wireless device,” a “subscriber device,” a “subscriber terminal,” a “subscriber station,” a “user terminal” or “UT,” a “mobile device,” a “mobile terminal,” a “mobile station,” or variations thereof. Generally, UEs may communicate with a core network via a RAN, and through the core network the UEs may be connected with external networks such as the Internet and with other UEs. Of course, other mechanisms of connecting to the core network and/or the Internet are also possible for the UEs, such as over wired access networks, wireless local area network (WLAN) networks (e.g., based on IEEE 802.11 communication standards, etc.) and so on.

[0049] A network entity may be implemented in an aggregated or monolithic base station architecture, or alternatively, in a disaggregated base station architecture, and may include one or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC), or a Non-Real Time (Non-RT) RIC. A base station (e.g., with an aggregated/monolithic base station architecture or disaggregated base station architecture) may operate according to one of several RATs in communication with UEs depending on the network in which it is deployed, and may be alternatively referred to as an access point (AP), a network node, a NodeB (NB), an evolved NodeB (eNB), a next generation eNB (ng-eNB), a New Radio (NR) Node B (also referred to as a gNB or gNodeB), etc. A base station may be used primarily to support wireless access by UEs, including supporting data, voice, and/or signaling connections for the supported UEs. In some systems, a base station may provide edge node signaling functions while in other systems it may provide additional control and/or network management functions. A communication link through which UEs may send signals to a base station is called an uplink (UL) channel (e.g., a reverse traffic channel, a reverse control channel, an access channel, etc.). A communication link through which the base station may send signals to UEs is called a downlink (DL) or forward link channel (e.g., a paging channel, a control channel, a broadcast channel, or a forward traffic channel, etc.). The term traffic channel (TCH), as used herein, may refer to either an uplink, reverse or downlink, and/or a forward traffic channel.

[0050] The term “network entity” or “base station” (e.g., with an aggregated/monolithic base station architecture or disaggregated base station architecture) may refer to a single physical transmit receive point (TRP) or to multiple physical TRPs that may or may not be co-located. For example, where the term “network entity” or “base station” refers to a single physical TRP, the physical TRP may be an antenna of the base station corresponding to a cell (or several cell sectors) of the base station. Where the term “network entity” or “base station” refers to multiple co-located physical TRPs, the physical TRPs may be an array of antennas (e.g., as in a multiple-input multiple-output (MIMO) system or where the base station employs beamforming) of the base station. Where the term “base station” refers to multiple non-co-located physical TRPs, the physical TRPs may be a distributed antenna system (DAS) (a network of spatially separated antennas connected to a common source via a transport medium) or a remote radio head (RRH) (a remote base station connected to a serving base station). Alternatively, the non-co-located physical TRPs may be the serving base station receiving the measurement report from the UE and a neighbor base station whose reference radio frequency (RF) signals (or simply “reference signals”) the UE is measuring. Because a TRP is the point from which a base station transmits and receives wireless

signals, as used herein, references to transmission from or reception at a base station are to be understood as referring to a particular TRP of the base station.

[0051] In some implementations that support positioning of UEs, a network entity or base station may not support wireless access by UEs (e.g., may not support data, voice, and/or signaling connections for UEs), but may instead transmit reference signals to UEs to be measured by the UEs, and/or may receive and measure signals transmitted by the UEs. Such a base station may be referred to as a positioning beacon (e.g., when transmitting signals to UEs) and/or as a location measurement unit (e.g., when receiving and measuring signals from UEs).

[0052] An RF signal comprises an electromagnetic wave of a given frequency that transports information through the space between a transmitter and a receiver. As used herein, a transmitter may transmit a single “RF signal” or multiple “RF signals” to a receiver. However, the receiver may receive multiple “RF signals” corresponding to each transmitted RF signal due to the propagation characteristics of RF signals through multipath channels. The same transmitted RF signal on different paths between the transmitter and receiver may be referred to as a “multipath” RF signal. As used herein, an RF signal may also be referred to as a “wireless signal” or simply a “signal” where it is clear from the context that the term “signal” refers to a wireless signal or an RF signal.

[0053] Various aspects of the systems and techniques described herein will be discussed below with respect to the figures. According to various aspects, FIG. 1 illustrates an example of a wireless communications system **100**. The wireless communications system **100** (which may also be referred to as a wireless wide area network (WWAN)) may include various base stations **102** and various UEs **104**. In some aspects, the base stations **102** may also be referred to as “network entities” or “network nodes.” One or more of the base stations **102** may be implemented in an aggregated or monolithic base station architecture. Additionally, or alternatively, one or more of the base stations **102** may be implemented in a disaggregated base station architecture, and may include one or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC), or a Non-Real Time (Non-RT) RIC. The base stations **102** may include macro cell base stations (high power cellular base stations) and/or small cell base stations (low power cellular base stations). In an aspect, the macro cell base station may include eNBs and/or ng-eNBs where the wireless communications system **100** corresponds to a long term evolution (LTE) network, or gNBs where the wireless communications system **100** corresponds to a NR network, or a combination of both, and the small cell base stations may include femtocells, picocells, microcells, etc.

[0054] The base stations **102** may collectively form a RAN and interface with a core network **170** (e.g., an evolved packet core (EPC) or a 5G core (5GC)) through backhaul links **122**, and through the core network **170** to one or more location servers **172** (which may be part of core network **170** or may be external to core network **170**). In addition to other functions, the base stations **102** may perform functions that relate to one or more of transferring 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, 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 with each other directly or indirectly (e.g., through the EPC or 5GC) over backhaul links **134**, which may be wired and/or wireless.

[0055] 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**. In an aspect, one or more cells may be supported by a base station **102** in each coverage area **110**. A “cell” is a logical communication entity used for communication with a base station (e.g., over some frequency resource, referred to as a carrier frequency, component carrier, carrier, band, or the

like), and may be associated with an identifier (e.g., a physical cell identifier (PCI), a virtual cell identifier (VCI), a cell global identifier (CGI)) for distinguishing cells operating via the same or a different carrier frequency. In some cases, different cells may be configured according to different protocol types (e.g., machine-type communication (MTC), narrowband IoT (NB-IoT), enhanced mobile broadband (eMBB), or others) that may provide access for different types of UEs. Because a cell is supported by a specific base station, the term “cell” may refer to either or both of the logical communication entity and the base station that supports it, depending on the context. In addition, because a TRP is typically the physical transmission point of a cell, the terms “cell” and “TRP” may be used interchangeably. In some cases, the term “cell” may also refer to a geographic coverage area of a base station (e.g., a sector), insofar as a carrier frequency may be detected and used for communication within some portion of geographic coverage areas **110**.

[0056] While neighboring macro cell base station **102** geographic coverage areas **110** may partially overlap (e.g., in a handover region), some of the geographic coverage areas **110** may be substantially overlapped by a larger geographic coverage area **110**. For example, a small cell base station **102'** may have a coverage area **110'** that substantially overlaps with the coverage area **110** of one or more macro cell base stations **102**. A network that includes both small cell and macro cell base stations may be known as a heterogeneous network. A heterogeneous network may also include home eNBs (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG).

[0057] The communication links **120** between the base stations **102** and the UEs **104** may include uplink (also referred to as reverse link) transmissions from a UE **104** to a base station **102** and/or downlink (also referred to as forward link) transmissions from a base station **102** to a UE **104**. The communication links **120** may use MIMO antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. The communication links **120** may be through one or more carrier frequencies. Allocation of carriers may be asymmetric with respect to downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink).

[0058] The wireless communications system **100** may further include a WLAN AP **150** in communication with WLAN stations (STAs) **152** via communication links **154** in an unlicensed frequency spectrum (e.g., 5 Gigahertz (GHz)). When communicating in an unlicensed frequency spectrum, the WLAN STAs **152** and/or the WLAN AP **150** may perform a clear channel assessment (CCA) or listen before talk (LBT) procedure prior to communicating in order to determine whether the channel is available. In some examples, the wireless communications system **100** may include devices (e.g., UEs, etc.) that communicate with one or more UEs **104**, base stations **102**, APs **150**, etc. utilizing the ultra-wideband (UWB) spectrum. The UWB spectrum may range from 3.1 to 10.5 GHz.

[0059] The small cell base station **102'** may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell base station **102'** may employ LTE or NR technology and use the same 5 GHz unlicensed frequency spectrum as used by the WLAN AP **150**. The small cell base station **102'**, employing LTE and/or 5G in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network. NR in unlicensed spectrum may be referred to as NR-U. LTE in an unlicensed spectrum may be referred to as LTE-U, licensed assisted access (LAA), or MulteFire.

[0060] The wireless communications system **100** may further include a millimeter wave (mmW) base station **180** that may operate in mmW frequencies and/or near mmW frequencies in communication with a UE **182**. The mmW base station **180** may be implemented in an aggregated or monolithic base station architecture, or alternatively, in a disaggregated base station architecture (e.g., including one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC). 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 this 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 and/or near mmW radio frequency band have high path loss and a relatively short range. The mmW base station **180** and the UE **182** may utilize beamforming (transmit and/or receive) over an mmW communication link **184** to compensate for the extremely high path loss and short range. Further, it will be appreciated that in alternative configurations, one or more base stations **102** may also transmit using mmW or near mmW and beamforming. Accordingly, it will be appreciated that the foregoing illustrations are merely examples and should not be construed to limit the various aspects disclosed herein.

[0061] In some aspects relating to 5G, the frequency spectrum in which wireless network nodes or entities (e.g., base stations **102/180**, UEs **104/182**) operate is divided into multiple frequency ranges, FR1 (from 450 to 6000 Megahertz (MHz)), FR2 (from 24250 to 52600 MHz), FR3 (above 52600 MHz), and FR4 (between FR1 and FR2). In a multi-carrier system, such as 5G, one of the carrier frequencies is referred to as the “primary carrier” or “anchor carrier” or “primary serving cell” or “PCell,” and the remaining carrier frequencies are referred to as “secondary carriers” or “secondary serving cells” or “SCells.” In carrier aggregation, the anchor carrier is the carrier operating on the primary frequency (e.g., FR1) utilized by a UE **104/182** and the cell in which the UE **104/182** either performs the initial radio resource control (RRC) connection establishment procedure or initiates the RRC connection re-establishment procedure. The primary carrier carries all common and UE-specific control channels and may be a carrier in a licensed frequency (however, this is not always the case). A secondary carrier is a carrier operating on a second frequency (e.g., FR2) that may be configured once the RRC connection is established between the UE **104** and the anchor carrier and that may be used to provide additional radio resources. In some cases, the secondary carrier may be a carrier in an unlicensed frequency. The secondary carrier may contain only necessary signaling information and signals, for example, those that are UE-specific may not be present in the secondary carrier, since both primary uplink and downlink carriers are typically UE-specific. This means that different UEs **104/182** in a cell may have different downlink primary carriers. The same is true for the uplink primary carriers. The network is able to change the primary carrier of any UE **104/182** at any time. This is done, for example, to balance the load on different carriers. Because a “serving cell” (whether a PCell or an SCell) corresponds to a carrier frequency and/or component carrier over which some base station is communicating, the term “cell,” “serving cell,” “component carrier,” “carrier frequency,” and the like may be used interchangeably.

[0062] For example, still referring to FIG. 1, one of the frequencies utilized by the macro cell base stations **102** may be an anchor carrier (or “PCell”) and other frequencies utilized by the macro cell base stations **102** and/or the mmW base station **180** may be secondary carriers (“SCells”). In carrier aggregation, the base stations **102** and/or the UEs **104** may use spectrum up to Y MHz (e.g., 5, 10, 15, 20, 100 MHz) bandwidth per carrier up to a total of Yx MHz (x component carriers) for transmission in each direction. The component carriers may or may not be adjacent to each other on the frequency spectrum. Allocation of carriers may be asymmetric with respect to the downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink). The simultaneous transmission and/or reception of multiple carriers enables the UE **104/182** to significantly increase its data transmission and/or reception rates. For example, two 20 MHz aggregated carriers in a multi-carrier system would theoretically lead to a two-fold increase in data rate (i.e., 40 MHz), compared to that attained by a single 20 MHz carrier.

[0063] In order to operate on multiple carrier frequencies, a base station **102** and/or a UE **104** may be equipped with multiple receivers and/or transmitters. For example, a UE **104** may have two receivers, “Receiver 1” and “Receiver 2,” where “Receiver 1” is a multi-band receiver that may be tuned to band (i.e., carrier frequency) ‘X’ or band ‘Y,’ and “Receiver 2” is a one-band receiver tuneable to band ‘Z’ only. In this example, if the UE **104** is being served in band ‘X,’ band ‘X’

would be referred to as the PCell or the active carrier frequency, and “Receiver 1” would need to tune from band ‘X’ to band ‘Y’ (an SCell) in order to measure band ‘Y’ (and vice versa). In contrast, whether the UE **104** is being served in band ‘X’ or band ‘Y,’ because of the separate “Receiver 2,” the UE **104** may measure band ‘Z’ without interrupting the service on band ‘X’ or band ‘Y.’

[0064] The wireless communications system **100** may further include a UE **164** that may communicate with a macro cell base station **102** over a communication link **120** and/or the mmW base station **180** over an mmW communication link **184**. For example, the macro cell base station **102** may support a PCell and one or more SCells for the UE **164** and the mmW base station **180** may support one or more SCells for the UE **164**.

[0065] The wireless communications system **100** may further include one or more UEs, such as UE **190**, that connects indirectly to one or more communication networks via one or more device-to-device (D2D) peer-to-peer (P2P) links (referred to as “sidelinks”). In the example of FIG. 1, UE **190** has a D2D P2P link **192** with one of the UEs **104** connected to one of the base stations **102** (e.g., through which UE **190** may indirectly obtain cellular connectivity) and a D2D P2P link **194** with WLAN STA **152** connected to the WLAN AP **150** (through which UE **190** may indirectly obtain WLAN-based Internet connectivity). In an example, the D2D P2P links **192** and **194** may be supported with any well-known D2D RAT, such as LTE Direct (LTE-D), Wi-Fi Direct (Wi-Fi-D), Bluetooth®, and so on.

[0066] FIG. 2 shows a block diagram of a design of a base station **102** and a UE **104** that enable transmission and processing of signals exchanged between the UE and the base station. Design **200** includes components of a base station **102** and a UE **104**, which may be one of the base stations **102** and one of the UEs **104** in FIG. 1. Base station **102** may be equipped with T antennas **234a** through **234t**, and UE **104** may be equipped with R antennas **252a** through **252r**, where in general  $T \geq 1$  and  $R \geq 1$ .

[0067] At base station **102**, a transmit processor **220** may receive data from a data source **212** for one or more UEs, select one or more modulation and coding schemes (MCS) for each UE based at least in part on channel quality indicators (CQIs) received from the UE, process (e.g., encode and modulate) the data for each UE based at least in part on the MCS(s) selected for the UE, and provide data symbols for all UEs. Transmit processor **220** may also process system information (e.g., for semi-static resource partitioning information (SRPI) and/or the like) and control information (e.g., CQI requests, grants, upper layer signaling, and/or the like) and provide overhead symbols and control symbols. Transmit processor **220** may also generate reference symbols for reference signals (e.g., the cell-specific reference signal (CRS)) and synchronization signals (e.g., the primary synchronization signal (PSS) and secondary synchronization signal (SSS)). A transmit (TX) multiple-input multiple-output (MIMO) processor **230** may perform spatial processing (e.g., precoding) on the data symbols, the control symbols, the overhead symbols, and/or the reference symbols, if applicable, and may provide T output symbol streams to T modulators (MODs) **232a** through **232t**. The modulators **232a** through **232t** are shown as a combined modulator-demodulator (MOD-DEMOD). In some cases, the modulators and demodulators may be separate components. Each modulator of the modulators **232a** to **232t** may process a respective output symbol stream, e.g., for an orthogonal frequency-division multiplexing (OFDM) scheme and/or the like, to obtain an output sample stream. Each modulator of the modulators **232a** to **232t** may further process (e.g., convert to analog, amplify, filter, and upconvert) the output sample stream to obtain a downlink signal. T downlink signals may be transmitted from modulators **232a** to **232t** via T antennas **234a** through **234t**, respectively. According to certain aspects described in more detail below, the synchronization signals may be generated with location encoding to convey additional information.

[0068] At UE **104**, antennas **252a** through **252r** may receive the downlink signals from base station **102** and/or other base stations and may provide received signals to demodulators (DEMODs) **254a** through **254r**, respectively. The demodulators **254a** through **254r** are shown as a combined

modulator-demodulator (MOD-DEMOD). In some cases, the modulators and demodulators may be separate components. Each demodulator of the demodulators **254a** through **254r** may condition (e.g., filter, amplify, downconvert, and digitize) a received signal to obtain input samples. Each demodulator of the demodulators **254a** through **254r** may further process the input samples (e.g., for OFDM and/or the like) to obtain received symbols. A MIMO detector **256** may obtain received symbols from all R demodulators **254a** through **254r**, perform MIMO detection on the received symbols if applicable, and provide detected symbols. A receive processor **258** may process (e.g., demodulate and decode) the detected symbols, provide decoded data for UE **104** to a data sink **260**, and provide decoded control information and system information to a controller/processor **280**. A channel processor may determine reference signal received power (RSRP), received signal strength indicator (RSSI), reference signal received quality (RSRQ), channel quality indicator (CQI), and/or the like.

[0069] On the uplink, at UE **104**, a transmit processor **264** may receive and process data from a data source **262** and control information (e.g., for reports comprising RSRP, RSSI, RSRQ, CQI, and/or the like) from controller/processor **280**. Transmit processor **264** may also generate reference symbols for one or more reference signals (e.g., based at least in part on a beta value or a set of beta values associated with the one or more reference signals). The symbols from transmit processor **264** may be precoded by a TX-MIMO processor **266** if applicable, further processed by modulators **254a** through **254r** (e.g., for DFT-s-OFDM, CP-OFDM, and/or the like), and transmitted to base station **102**. At base station **102**, the uplink signals from UE **104** and other UEs may be received by antennas **234a** through **234t**, processed by demodulators **232a** through **232t**, detected by a MIMO detector **236** if applicable, and further processed by a receive processor **238** to obtain decoded data and control information sent by UE **104**. Receive processor **238** may provide the decoded data to a data sink **239** and the decoded control information to controller (processor) **240**. Base station **102** may include communication unit **244** and communicate to a network controller **231** via communication unit **244**. Network controller **231** may include communication unit **294**, controller/processor **290**, and memory **292**.

[0070] In some aspects, one or more components of UE **104** may be included in a housing. Controller **240** of base station **102**, controller/processor **280** of UE **104**, and/or any other component(s) of FIG. **2** may perform one or more techniques associated with implicit UCI beta value determination for NR.

[0071] Memories **242** and **282** may store data and program codes for the base station **102** and the UE **104**, respectively. A scheduler **246** may schedule UEs for data transmission on the downlink, uplink, and/or sidelink.

[0072] In some aspects, deployment of communication systems, such as 5G new radio (NR) systems, may be arranged in multiple manners with various components or constituent parts. In a 5G NR system, or network, a network node, a network entity, a mobility element of a network, a radio access network (RAN) node, a core network node, a network element, or a network equipment, such as a base station (BS), or one or more units (or one or more components) performing base station functionality, may be implemented in an aggregated or disaggregated architecture. For example, a BS (such as a Node B (NB), evolved NB (eNB), NR BS, 5G NB, access point (AP), a transmit receive point (TRP), or a cell, etc.) may be implemented as an aggregated base station (also known as a standalone BS or a monolithic BS) or a disaggregated base station.

[0073] An aggregated base station may be configured to utilize a radio protocol stack that is physically or logically integrated within a single RAN node. A disaggregated base station may be configured to utilize a protocol stack that is physically or logically distributed among two or more units (such as one or more central or centralized units (CUs), one or more distributed units (DUs), or one or more radio units (RUs)). In some aspects, a CU may be implemented within a RAN node, and one or more DUs may be co-located with the CU, or alternatively, may be geographically or

virtually distributed throughout one or multiple other RAN nodes. The DUs may be implemented to communicate with one or more RUs. Each of the CU, DU and RU also may be implemented as virtual units, i.e., a virtual central unit (VCU), a virtual distributed unit (VDU), or a virtual radio unit (VRU).

[0074] Base station-type operation or network design may consider aggregation characteristics of base station functionality. For example, disaggregated base stations may be utilized in an integrated access backhaul (IAB) network, an open radio access network (O-RAN (such as the network configuration sponsored by the O-RAN Alliance)), or a virtualized radio access network (vRAN, also known as a cloud radio access network (C-RAN)). Disaggregation may include distributing functionality across two or more units at various physical locations, as well as distributing functionality for at least one unit virtually, which may enable flexibility in network design. The various units of the disaggregated base station, or disaggregated RAN architecture, may be configured for wired or wireless communication with at least one other unit.

[0075] FIG. 3 shows a diagram illustrating an example disaggregated base station **300** architecture. The disaggregated base station **300** architecture may include one or more central units (CUs) **310** that may communicate directly with a core network **320** via a backhaul link, or indirectly with the core network **320** through one or more disaggregated base station units (such as a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC) **325** via an E2 link, or a Non-Real Time (Non-RT) RIC **315** associated with a Service Management and Orchestration (SMO) Framework **305**, or both). A CU **310** may communicate with one or more distributed units (DUs) **330** via respective midhaul links, such as an F1 interface. The DUs **330** may communicate with one or more radio units (RUs) **340** via respective fronthaul links. The RUs **340** may communicate with respective UEs **104** via one or more radio frequency (RF) access links. In some implementations, the UE **104** may be simultaneously served by multiple RUs **340**.

[0076] Each of the units, e.g., the CUs **310**, the DUs **330**, the RUs **340**, as well as the Near-RT RICs **325**, the Non-RT RICs **315** and the SMO Framework **305**, may include one or more interfaces or be coupled to one or more interfaces configured to receive or transmit signals, data, or information (collectively, signals) via a wired or wireless transmission medium. Each of the units, or an associated processor or controller providing instructions to the communication interfaces of the units, may be configured to communicate with one or more of the other units via the transmission medium. For example, the units may include a wired interface configured to receive or transmit signals over a wired transmission medium to one or more of the other units.

Additionally, the units may include a wireless interface, which may include a receiver, a transmitter or transceiver (such as a radio frequency (RF) transceiver), configured to receive or transmit signals, or both, over a wireless transmission medium to one or more of the other units.

[0077] In some aspects, the CU **310** may host one or more higher layer control functions. Such control functions may include radio resource control (RRC), packet data convergence protocol (PDCP), service data adaptation protocol (SDAP), or the like. Each control function may be implemented with an interface configured to communicate signals with other control functions hosted by the CU **310**. The CU **310** may be configured to handle user plane functionality (i.e., Central Unit-User Plane (CU-UP)), control plane functionality (i.e., Central Unit-Control Plane (CU-CP)), or a combination thereof. In some implementations, the CU **310** may be logically split into one or more CU-UP units and one or more CU-CP units. The CU-UP unit may communicate bidirectionally with the CU-CP unit via an interface, such as the E1 interface when implemented in an O-RAN configuration. The CU **310** may be implemented to communicate with the DU **330**, as necessary, for network control and signaling.

[0078] The DU **330** may correspond to a logical unit that includes one or more base station functions to control the operation of one or more RUs **340**. In some aspects, the DU **330** may host one or more of a radio link control (RLC) layer, a medium access control (MAC) layer, and one or more high physical (PHY) layers (such as modules for forward error correction (FEC) encoding

and decoding, scrambling, modulation and demodulation, or the like) depending, at least in part, on a functional split, such as those defined by the 3rd Generation Partnership Project (3GPP). In some aspects, the DU **330** may further host one or more low PHY layers. Each layer (or module) may be implemented with an interface configured to communicate signals with other layers (and modules) hosted by the DU **330**, or with the control functions hosted by the CU **310**.

[0079] Lower-layer functionality may be implemented by one or more RUs **340**. In some deployments, an RU **340**, controlled by a DU **330**, may correspond to a logical node that hosts RF processing functions, or low-PHY layer functions (such as performing fast Fourier transform (FFT), inverse FFT (iFFT), digital beamforming, physical random access channel (PRACH) extraction and filtering, or the like), or both, based at least in part on the functional split, such as a lower layer functional split. In such an architecture, the RU(s) **340** may be implemented to handle over the air (OTA) communication with one or more UEs **104**. In some implementations, real-time and non-real-time aspects of control and user plane communication with the RU(s) **340** may be controlled by the corresponding DU **330**. In some scenarios, this configuration may enable the DU(s) **330** and the CU **310** to be implemented in a cloud-based RAN architecture, such as a vRAN architecture.

[0080] The SMO Framework **305** may be configured to support RAN deployment and provisioning of non-virtualized and virtualized network elements. For non-virtualized network elements, the SMO Framework **305** may be configured to support the deployment of dedicated physical resources for RAN coverage requirements which may be managed via an operations and maintenance interface (such as an O1 interface). For virtualized network elements, the SMO Framework **305** may be configured to interact with a cloud computing platform (such as an open cloud (O-Cloud) **390**) to perform network element life cycle management (such as to instantiate virtualized network elements) via a cloud computing platform interface (such as an O2 interface). Such virtualized network elements may include, but are not limited to, CUs **310**, DUs **330**, RUs **340** and Near-RT RICs **325**. In some implementations, the SMO Framework **305** may communicate with a hardware aspect of a 4G RAN, such as an open eNB (O-eNB) **311**, via an O1 interface. Additionally, in some implementations, the SMO Framework **305** may communicate directly with one or more RUs **340** via an O1 interface. The SMO Framework **305** also may include a Non-RT RIC **315** configured to support functionality of the SMO Framework **305**.

[0081] The Non-RT RIC **315** may be configured to include a logical function that enables non-real-time control and optimization of RAN elements and resources, Artificial Intelligence/Machine Learning (AI/ML) workflows including model training and updates, or policy-based guidance of applications/features in the Near-RT RIC **325**. The Non-RT RIC **315** may be coupled to or communicate with (such as via an A1 interface) the Near-RT RIC **325**. The Near-RT RIC **325** may be configured to include a logical function that enables near-real-time control and optimization of RAN elements and resources via data collection and actions over an interface (such as via an E2 interface) connecting one or more CUs **310**, one or more DUs **330**, or both, as well as an O-eNB, with the Near-RT RIC **325**.

[0082] In some implementations, to generate AI/ML models to be deployed in the Near-RT RIC **325**, the Non-RT RIC **315** may receive parameters or external enrichment information from external servers. Such information may be utilized by the Near-RT RIC **325** and may be received at the SMO Framework **305** or the Non-RT RIC **315** from non-network data sources or from network functions. In some examples, the Non-RT RIC **315** or the Near-RT RIC **325** may be configured to tune RAN behavior or performance. For example, the Non-RT RIC **315** may monitor long-term trends and patterns for performance and employ AI/ML models to perform corrective actions through the SMO Framework **305** (such as reconfiguration via O1) or via creation of RAN management policies (such as A1 policies).

[0083] FIG. 4 illustrates an example of a computing system **470** of a wireless device **407**. The wireless device **407** may include a client device such as a UE (e.g., UE **104**, UE **152**, UE **190**) or



other type of device (e.g., a station (STA) configured to communication using a Wi-Fi interface) that may be used by an end-user. For example, the wireless device **407** may include a mobile phone, router, tablet computer, laptop computer, tracking device, wearable device (e.g., a smart watch, glasses, an extended reality (XR) device such as a virtual reality (VR), augmented reality (AR) or mixed reality (MR) device, etc.), Internet of Things (IoT) device, access point, and/or another device that is configured to communicate over a wireless communications network. The computing system **470** includes software and hardware components that may be electrically or communicatively coupled via a bus **489** (or may otherwise be in communication, as appropriate). For example, the computing system **470** includes one or more processors **484**. The one or more processors **484** may include one or more CPUs, ASICs, FPGAs, APs, GPUs, VPUs, NSPs, microcontrollers, dedicated hardware, any combination thereof, and/or other processing device or system. The bus **489** may be used by the one or more processors **484** to communicate between cores and/or with the one or more memory devices **486**.

[0084] The computing system **470** may also include one or more memory devices **486**, one or more digital signal processors (DSPs) **482**, one or more subscriber identity modules (SIMs) **474**, one or more modems **476**, one or more wireless transceivers **478**, one or more antennas **487**, one or more input devices **472** (e.g., a camera, a mouse, a keyboard, a touch sensitive screen, a touch pad, a keypad, a microphone, and/or the like), and one or more output devices **480** (e.g., a display, a speaker, a printer, and/or the like).

[0085] In some aspects, computing system **470** may include one or more radio frequency (RF) interfaces configured to transmit and/or receive RF signals. In some examples, an RF interface may include components such as modem(s) **476**, wireless transceiver(s) **478**, and/or antennas **487**. The one or more wireless transceivers **478** may transmit and receive wireless signals (e.g., wireless signal **488**) via antenna **487** from one or more other devices, such as other wireless devices, network devices (e.g., base stations such as eNBs and/or gNBs, Wi-Fi access points (APs) such as routers, range extenders or the like, etc.), cloud networks, and/or the like. In some examples, the computing system **470** may include multiple antennas or an antenna array that may facilitate simultaneous transmit and receive functionality. Antenna **487** may be an omnidirectional antenna such that radio frequency (RF) signals may be received from and transmitted in all directions. The wireless signal **488** may be transmitted via a wireless network. The wireless network may be any wireless network, such as a cellular or telecommunications network (e.g., 3G, 4G, 5G, etc.), wireless local area network (e.g., a Wi-Fi network), a Bluetooth™ network, and/or other network.

[0086] In some examples, the wireless signal **488** may be transmitted directly to other wireless devices using sidelink communications (e.g., using a PC5 interface, using a DSRC interface, etc.). Wireless transceivers **478** may be configured to transmit RF signals for performing sidelink communications via antenna **487** in accordance with one or more transmit power parameters that may be associated with one or more regulation modes. Wireless transceivers **478** may also be configured to receive sidelink communication signals having different signal parameters from other wireless devices.

[0087] In some examples, the one or more wireless transceivers **478** may include an RF front end including one or more components, such as an amplifier, a mixer (also referred to as a signal multiplier) for signal down conversion, a frequency synthesizer (also referred to as an oscillator) that provides signals to the mixer, a baseband filter, an analog-to-digital converter (ADC), one or more power amplifiers, among other components. The RF front-end may generally handle selection and conversion of the wireless signals **488** into a baseband or intermediate frequency and may convert the RF signals to the digital domain.

[0088] In some cases, the computing system **470** may include a coding-decoding device (or CODEC) configured to encode and/or decode data transmitted and/or received using the one or more wireless transceivers **478**. In some cases, the computing system **470** may include an encryption-decryption device or component configured to encrypt and/or decrypt data (e.g.,

according to the AES and/or DES standard) transmitted and/or received by the one or more wireless transceivers **478**.

[0089] The one or more SIMs **474** may each securely store an international mobile subscriber identity (IMSI) number and related key assigned to the user of the wireless device **407**. The IMSI and key may be used to identify and authenticate the subscriber when accessing a network provided by a network service provider or operator associated with the one or more SIMs **474**. The one or more modems **476** may modulate one or more signals to encode information for transmission using the one or more wireless transceivers **478**. The one or more modems **476** may also demodulate signals received by the one or more wireless transceivers **478** in order to decode the transmitted information. In some examples, the one or more modems **476** may include a Wi-Fi modem, a 4G (or LTE) modem, a 5G (or NR) modem, and/or other types of modems. The one or more modems **476** and the one or more wireless transceivers **478** may be used for communicating data for the one or more SIMs **474**.

[0090] The computing system **470** may also include (and/or be in communication with) one or more non-transitory machine-readable storage media or storage devices (e.g., one or more memory devices **486**), which may include, without limitation, local and/or network accessible storage, a disk drive, a drive array, an optical storage device, a solid-state storage device such as a RAM and/or a ROM, which may be programmable, flash-updateable and/or the like. Such storage devices may be configured to implement any appropriate data storage, including without limitation, various file systems, database structures, and/or the like.

[0091] In various embodiments, functions may be stored as one or more computer-program products (e.g., instructions or code) in memory device(s) **486** and executed by the one or more processor(s) **484** and/or the one or more DSPs **482**. The computing system **470** may also include software elements (e.g., located within the one or more memory devices **486**), including, for example, an operating system, device drivers, executable libraries, and/or other code, such as one or more application programs, which may comprise computer programs implementing the functions provided by various embodiments, and/or may be designed to implement methods and/or configure systems, as described herein.

[0092] FIGS. 5A-5D depict various example aspects of data structures for a wireless communication system, such as wireless communication system **100** of FIG. 1. FIGS. 5A-5D depict aspects of data structures for a wireless communication network, such as wireless communication network **100** of FIG. 1. In particular, FIG. 5A is a diagram **500** illustrating an example of a first subframe within a 5G (e.g., 5G NR) frame structure, FIG. 5B is a diagram **530** illustrating an example of DL channels within a 5G subframe, FIG. 5C is a diagram **550** illustrating an example of a second subframe within a 5G frame structure, and FIG. 5D is a diagram **580** illustrating an example of UL channels within a 5G subframe.

[0093] In various aspects, the 5G frame structure may be frequency division duplex (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. 5G frame structures may also be time division duplex (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. 5A and 5C, the 5G 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 below applies also to a 5G frame structure that is TDD.

[0094] 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. In some examples, each slot may include 7 or 14 symbols, depending on the slot configuration.

[0095] For example, 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).

[0096] The number of slots within a subframe is based on the slot configuration and the numerology. For slot configuration 0, different numerologies ( $\mu$ ) 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  $\mu$ , there are 14 symbols/slot and  $2^\mu$  slots/subframe. The subcarrier spacing and symbol length/duration are a function of the numerology. The subcarrier spacing may be equal to  $2 \times 15$  kHz, where  $\mu$  is the numerology 0 to 5. As such, the numerology  $\mu=0$  has a subcarrier spacing of 15 kHz and the numerology  $\mu=5$  has a subcarrier spacing of 480 kHz. The symbol length/duration is inversely related to the subcarrier spacing. FIGS. 5A-5D provide an example of slot configuration 0 with 14 symbols per slot and numerology  $\mu=2$  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  $\mu$ s.

[0097] 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. The resource grids shown in FIGS. 5A-5D are arranged with the time domain on the horizontal (or x-) axis and the frequency domain on the vertical (or y-) axis. As an example, a PRB may be 180 kilohertz (kHz) wide in frequency and one slot long in time (with a slot being 1 milliseconds (ms) in time). In some cases, the slot may include fourteen symbols (e.g., in a slot configuration 0). In these examples, the RB includes twelve subcarriers (along the y-axis) and fourteen symbols (along the x-axis). An intersection of a symbol and subcarrier can be referred to as a resource element (RE) or tone. For instance, a RE is 1 subcarrier  $\times$  1 symbol, and is the smallest discrete part of the subframe. A RE includes a single complex value representing data from a physical channel or signal.

[0098] As illustrated in FIG. 5A, some of the REs carry reference (pilot) signals (RS) for a UE (e.g., UE **104**, UE **152**, UE **190**). The RS may include demodulation RS (DM-RS) (indicated as Rx 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).

[0099] FIG. 5B 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.

[0100] A primary synchronization signal (PSS) may be within symbol 2 of particular subframes of a frame. The PSS is used by a UE (e.g., UE **104**, UE **152**, UE **190**) to determine subframe/symbol timing and a physical layer identity.

[0101] 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.

[0102] 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.

[0103] As illustrated in FIG. 5C, 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.

[0104] FIG. 5D 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.

[0105] In some cases, a UE may not be connected to a wireless network (e.g., when there is no NAS signaling connection between the UE and the wireless network). For example, a UE may just have been powered up, may exit from an airplane mode, may have entered a new service area, may receive RRC reconfiguration information, may be involved in a handover procedure, and the like. Such a disconnected UE may be in an idle state and the UE may listen for wireless networks for which to connect. After the UE identifies a wireless network, the UE may then attempt to connect to the wireless network. In some cases, the UE may attempt to connect to the wireless network via a wireless node to establish an RRC connection.

[0106] In some systems, narrow-beam transmission and reception may be useful for improving a link budget, such as at millimeter-wave (mmW) frequencies, but may be susceptible to beam failure. As an example, in mmW, directional beamforming may be used between the UE and a BS, and the UE and BS communicate via a beam pair link (BPL). A beam failure generally refers to a scenario in which the quality of a beam falls below a threshold, which may lead to radio link failure (RLF). NR supports a lower layer signaling to recover from beam failure, referred to as beam recovery. For example, instead of initiating a cell reselection when a beam quality becomes too low, a beam pair reselection within the cell may be performed.

[0107] FIG. 6 is a schematic view illustrating an example of a wireless communication system **600** performing beamforming. Transmit beamforming is a technique for focusing an RF signal in a specific direction. Traditionally, when a network node or entity (e.g., a base station) broadcasts an RF signal, it broadcasts the signal in all directions (omni-directionally). With transmit beamforming, the network node determines where a given receiving device (e.g., a UE) is located (relative to the transmitting network node) and projects a stronger downlink RF signal in that specific direction, thereby providing a faster (in terms of data rate) and stronger RF signal for the receiving device(s). As shown in FIG. 6, a network node **602** may use beamforming to transmit a stronger primary beam **604** towards a receiving device **606**, as compared to secondary beams **608A** and **608B**. The secondary beams **608A** and **608B** may be transmitted in different directions **610A**

and **610B** as compared to a direction **612** of the primary beam **604**. To change the directionality of the RF signal when transmitting, the network node **602** can control beamforming weights (e.g., phase and/or relative amplitude) of the RF signal at each of one or more transmitters that are broadcasting the RF signal. For example, the network node **602** may use an array of antennas (referred to as a “phased array” or an “antenna array”) that creates a beam of RF waves that can be “steered” to point in different directions, without physically moving the antennas. For example, the RF current from the network node **602** can be fed to the individual transmit array elements of the antenna array with the correct beamforming weight (e.g., phase and/or relative gain) relationship so that the radio waves transmitted from the separate transmit array elements add together when received by a device in a desired location (e.g., at a receiving device angle). In some cases, the beamforming weights can result in destructive interference of the transmitted radio waves in undesired directions.

[0108] Transmit beams may be quasi-collocated, meaning that they appear to the receiver (e.g., a UE) as having the same parameters, regardless of whether or not the transmitting antennas of the network node **602** themselves are physically collocated. In NR, there are four types of quasi-collocation (QCL) relations. Specifically, a QCL relation of a given type means that certain parameters about a second reference RF signal on a second beam can be derived from information about a source reference RF signal on a source beam. Thus, if the source reference RF signal is QCL Type A, the receiving device **606** can use the source reference RF signal to estimate the Doppler shift, Doppler spread, average delay, and delay spread of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type B, the receiving device **606** can use the source reference RF signal to estimate the Doppler shift and Doppler spread of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type C, the receiving device **606** can use the source reference RF signal to estimate the Doppler shift and average delay of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type D, the receiving device **606** can use the source reference RF signal to estimate the spatial receive parameter of a second reference RF signal transmitted on the same channel.

[0109] In receiving beamforming, the receiving device **606** uses a receive beam **614** to amplify RF signals detected on a given channel. For example, the receiving device **606** can increase the gain setting and/or adjust the phase setting of an array of antennas in a particular direction to amplify (e.g., to increase the gain level of) the RF signals received from that direction. Thus, when a receiving device **606** is said to beamform in a certain direction, it means the beam gain in that direction is high relative to the beam gain along other directions, or the beam gain in that direction is the highest compared to the beam gain of other beams available to the receiving device **606**. This results in a stronger received signal strength (e.g., reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference-plus-noise ratio (SINR), etc.) of the RF signals received from that direction.

[0110] Receive beams may be spatially related. A spatial relation means that parameters for a transmit beam, such as primary beam **604**, for a second reference signal can be derived from information about a receive beam, such as receive beam **614**, for a first reference signal. For example, a UE may use a particular receive beam to receive one or more reference downlink reference signals (e.g., positioning reference signals (PRS), tracking reference signals (TRS), phase tracking reference signal (PTRS), cell-specific reference signals (CRS), channel state information reference signals (CSI-RS), primary synchronization signals (PSS), secondary synchronization signals (SSS), synchronization signal blocks (SSBs), etc.) from a network node or entity (e.g., a base station). The UE can then form a transmit beam for sending one or more uplink reference signals (e.g., uplink positioning reference signals (UL-PRS), sounding reference signal (SRS), demodulation reference signals (DMRS), PTRS, etc.) to that network node **602** or entity (e.g., a base station) based on the parameters of the receive beam.

[0111] Note that a “downlink” beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a network node or entity (e.g., a base station) is forming the downlink beam to transmit a reference signal to a UE, the downlink beam is a transmit beam. If the UE is forming the downlink beam, however, it is a receive beam to receive the downlink reference signal. Similarly, an “uplink” beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a network node or entity (e.g., a base station) is forming the uplink beam, it is an uplink receive beam, and if a UE is forming the uplink beam, it is an uplink transmit beam.

[0112] FIG. 7A is a schematic view illustrating communication configuration **700** that incorporates array puncturing. In some cases, array puncturing can be used to induce intentional phase distortion by selectively turning off transmit array elements. As shown in FIG. 7A, a transmitting device **702**, such as a wireless node, may use beamforming to transmit a beamformed transmission (e.g., a transmission which has different beamforming weights applied to different transmit array elements to direct the beamformed transmission toward the beamforming angle  $\theta_{\text{sub.BF}}$  **709**) along a beamforming channel  $h(\theta_{\text{sub.BF}})$  **704** (e.g., beam) towards a receiving device **706**, such as a UE. In some cases, the receiving device **706** may be positioned at a receiving device angle  $\theta_{\text{sub.R}}$  **708** off of broadside **710** of the antenna array of the transmitting device **702**. In some cases, the receiving device angle  $\theta_{\text{sub.R}}$  **708** off of broadside **710** of the receiving device **706** may be inferred, for example, based on synchronization signal block (SSB) direction. The transmitting device **702** may apply a phase shift to one or more array elements to induce a phase distortion at an observation angle  $\theta$  not equal to receiving device angle  $\theta_{\text{sub.BF}}$  **708**, (e.g.,  $\theta \neq \theta_{\text{sub.BF}}$ ). For example, an observation angle  $\theta$  corresponding to the location of an adversary device **716** is illustrated as adversary angle  $\theta_{\text{sub.A}}$  **712** (e.g.,  $\theta = \theta_{\text{sub.A}}$ ). In some aspects, the adversary device **716** can be associated with a corresponding channel  $h(\theta_{\text{sub.A}})$  **714**. An effective channel for beamforming towards an observation angle  $\theta$  may be defined as shown in Equation (1) below:

$$[00001] \quad h(\theta) = \sum_{n=0}^{N-1} b_n \exp(j^2 - (n - \frac{N-1}{2})d[\sin(\theta) - \sin(\theta_{\text{sub.BF}})]) \quad (1)$$

[0113] where  $d$  is a distance between array elements,  $\lambda$  is the wavelength of the transmitted signal,  $b$  is an array puncturing vector,  $w$  is a beamforming vector,  $b \odot w$  is a modified beamforming vector,  $x$  is the transmitted complex vector,  $n$  is an array element index, and  $N$  indicates a number of array elements. The beamforming vector  $w$  includes beamforming weights for beamforming toward the beamforming angle  $\theta_{\text{sub.BF}}$ . The array puncturing vector  $b$  defines the array puncturing pattern to be applied to the array elements where array puncturing coefficients  $b_{\text{sub}.n}$  of the array puncturing vector  $b$  correspond with respective transmit array elements of the antenna array. In some cases, the values of array puncturing coefficients  $b_{\text{sub}.n}$  can be 0 when array puncturing is applied to the  $n$ -th element of the antenna array. In some aspects, the values of array puncturing coefficients  $b_{\text{sub}.n}$  can be 1 when no array puncturing is applied to the  $n$ -th element of the antenna array.

[0114] Generally, when performing beamforming without array puncturing, the effective channel may be defined as  $h(\theta)_{\text{sup}} H w(\theta_{\text{sub.BF}})$ . Thus, when array puncturing is not performed and the beam is being transmitted toward the beamforming angle  $\theta_{\text{sub.BF}}$ , all of the transmit array elements of the antenna array are transmitted with consistent with the beamforming vector  $w$  and  $h(\theta)_{\text{sup}} H [b \odot w(\theta_{\text{sub.BF}})] h(\theta)_{\text{sup}} H w(\theta_{\text{sub.BF}})$  (e.g., the modified beamforming vector  $b \odot w$  is equal to the beamforming vector  $w$ ).

[0115] As used herein, “phase distortion profile” refers to a relationship between phase distortion and observation angle  $\theta$  for a particular modified beamforming vector  $b \odot w$ . For example, when array puncturing is used, the phase distortion profile can depend upon the puncturing pattern. As used herein, “puncturing pattern” refers to the antenna element index  $n$  and/or combination of antenna element indices  $n$  of antenna elements selected to be turned off for applying array puncturing. In some cases, different phase distortion profiles and/or different puncturing patterns

may be better suited to different applications.

[0116] In some cases, a puncturing pattern may be selected such that modified beamforming vector  $\mathbf{b}_{\odot w}$  may induce a different phase for a particular observation angle  $\theta$  (e.g.,  $\theta \neq \theta_{\text{sub.BF}}$ ), which distorts channel estimation (and hence coherent demodulation) quality of any adversary at  $\theta$  (e.g.,  $\theta \neq \theta_{\text{sub.BF}}$ ) while keeping an angular region around beamforming angle (i.e.,  $|\theta - \theta_{\text{sub.BF}}| \leq \Delta\theta$ ) intact. As illustrated in FIG. 7A, the angular region around the beamforming angle  $\theta_{\text{sub.BF}}$  **709** can be referred to as the distortion-free angular gap  $2\Delta\theta$ . In some cases, the beamforming angle  $\theta_{\text{sub.BF}}$  **709** can be selected such that the receiving device angle  $\theta_{\text{sub.R}}$  **708** falls within the distortion free angular gap  $2\Delta\theta$ .

[0117] In some cases, a puncturing pattern where one transmit array element is turned off may be applied for a selected time slot to protect symbols of a message within that time slot. In some cases, the puncturing pattern may be applied to either demodulation reference signals or data symbols. Switching off one transmit array element in a symbol of a single slot for a message may be sufficient to induce sufficient distortion to prevent an off direction (e.g., having a different direction than a target device) eavesdropper from successfully receiving the message. In some cases, the puncturing pattern may be changed multiple times during transmission of a message that spans multiple OFDM symbols. In one illustrative example, the puncturing pattern may be changed for each OFDM symbol in a transmission. In some cases, changing the puncturing pattern multiple times during transmission of a message may further prevent an off direction eavesdropper from successfully receiving the message. As used herein, “puncturing pattern cycling” refers to changing the puncturing pattern of array puncturing applied by a transmitting device (e.g., transmitting device **702**). As used herein, a “puncturing pattern cycle” refers to a sequence of puncturing patterns applied by a transmitting device.

[0118] FIG. 7B is a schematic view illustrating an additional communication configuration **750** that illustrates interference that may be caused by the array puncturing in communication configuration **700** of FIG. 7A. In the example of FIG. 7B, an observation angle  $\theta$  corresponding to the location of a victim device **726** (e.g., a UE) is illustrated as victim angle  $\theta_{\text{sub.V}}$  **722** (e.g.,  $\theta = \theta_{\text{sub.V}}$ ). In some aspects, the victim device **726** can be associated with a corresponding channel  $h(\theta_{\text{sub.V}})$  **724**. As shown in FIG. 7B, an additional transmitting device **720**, such as a wireless node, may use beamforming to transmit a beamformed transmission along a channel towards the victim device **726**. While the adversary device **716** in the example of FIG. 7A may attempt to receive and coherently demodulate the signal transmitted by the transmitting device **702**, the victim device **726** of FIG. 7B may perceive any transmissions from the transmitting device **702** as interference with reception of desired transmissions from the additional transmitting device **720**.

[0119] As noted above, a received signal that is received by a receiving device located in the beamforming direction (e.g.,  $\theta_{\text{sub.R}} = \theta_{\text{sub.BF}}$ ) from an array applying array puncturing may not experience any phase distortion in the received signal and may experience minimal impact on the amplitude of the received signal. However, the transmitted signal from transmitting device **702** toward the receiving device **706** that is received at a victim device **726** located outside of the distortion free angular gap  $2\Delta\theta$  (e.g.,  $\theta_{\text{sub.V}} > \theta_{\text{sub.BF}} + \Delta\theta$  or  $\theta_{\text{sub.V}} < \theta_{\text{sub.BF}} - \Delta\theta$ ) may include phase and/or amplitude fluctuations. As noted above, the victim device **726** may be unaffected by the phase fluctuations of the signal transmitted by transmitting device **702** because the victim device **726** is not attempting to coherently demodulate the signal transmitted by transmitting device **702**.

[0120] However, as noted above, in some cases, the transmitting device **702** may be configured to change puncturing patterns. For example, the transmitting device **702** may be configured to change puncturing patterns multiple times during transmission of a message. In some cases, the amplitude of the transmissions from the transmitting device **702** and received by the victim device **726** may interfere with the ability of the victim device **726** to receive transmissions from the additional transmitting device **720**. In some cases, the victim device **726** may include hardware and/or

software for performing interference measurements. In some implementations, the transmitting device (e.g., transmitting device **702**, additional transmitting device **720**) serving a receiving device (e.g., receiving device **706**, victim device **726**) may have the capability to configure the UE to perform interference measurements at specific time slots and/or frequencies.

[0121] In some cases, the transmitting device **702** may be configured send one or more array puncturing notifications to the network (e.g., core network **170** of FIG. **1**) and/or nearby transmitting devices (e.g., additional transmitting device **720**). In some examples, a puncturing notification sent by the transmitting device **702** may indicate a puncturing pattern cycle for array puncturing in transmissions by the transmitting device **702** that is based on a time and/or frequency pattern. For example, the puncturing pattern cycle may include frequency bands and/or time slots during which the transmitting device **702** may apply array puncturing. In some cases, the transmitting device **702** and/or the network may broadcast the puncturing pattern cycle specified in the puncturing notification to neighboring transmitting devices (e.g., additional transmitting device **720**). In some cases, providing the additional transmitting device **720** knowledge of the puncturing pattern cycle that will be applied by the transmitting device **702** can assist the additional transmitting device **720** in managing power fluctuations caused by the puncturing pattern cycle that may impact receiving devices (e.g., victim device **726** and/or other UEs) served by the additional transmitting device **720**. In one illustrative example, the additional transmitting device **720** may configure the victim device **726** to perform interference measurements by configuring non-zero power (NZP) CSI-RS or zero power (ZP) CSI-RS resources.

[0122] In some implementations, transmitting device **702** may send an array puncturing notification to the network and/or nearby transmitting devices that includes indication of a start time, stop time, duration, and/or any combination thereof for transmissions using array puncturing. For example, security restrictions for a network may prevent transmitting device **702** from utilizing pre-determined time and/or frequency patterns in a puncturing pattern cycle. In some cases, a nearby transmitting device (e.g., additional transmitting device **720**) may configure UEs served by the additional transmitting device **720** to perform additional interference measurements during the time period indicated by the array puncturing notification. In some implementations, the additional transmitting device **720** may send a request to the network to limit the array puncturing that the transmitting device **702** is permitted to use. For example, the additional transmitting device **720** may request that the transmitting device **702** limit array puncturing to specific puncturing patterns and/or puncturing pattern cycles. In some cases, the additional transmitting device **720** may request the network to prevent the transmitting device **702** from performing any array puncturing. In examples, the additional transmitting device **720** may request the network to prevent the transmitting device **702** from performing array puncturing to prevent interference with transmission by the additional transmitting device **720** to a particularly important receiving device. For example, the additional transmitting device **720** may request the network to prevent the transmitting device **702** from performing array puncturing to prevent interference with transmissions to first responders in an emergency situation. As another illustrative example, the additional transmitting device **720** may request the network to prevent the transmitting device **702** from performing array puncturing to prevent interference (e.g., by introducing delay) with Ultra-Reliable Low Latency Communication (URLLC) services.

[0123] In some cases, a puncturing pattern cycle for a transmitting device **702** may include changing the number of array elements to be turned off. For example, in some cases, a puncturing pattern cycle may increase the number of array elements to be turned off to two or more. In some aspects, increasing the number of antenna elements that are turned off may cause increases in amplitude fluctuations outside of the distortion free angular gap  $2\Delta\theta$ . In some examples, the transmitting device **702** may send an indication to the network (e.g., core network **170** of FIG. **1**) and/or nearby transmitting devices (e.g., additional transmitting device **720**) over RRC links or PHY links dynamically to indicate changes in the number of antenna elements that will be turned



off during array puncturing. In some cases, nearby transmitting devices (e.g., additional transmitting device **720**) may dynamically configure UEs to perform interference measurements. In some cases, the nearby transmitting devices may report a complaint to the network if the interference resulting from the transmissions of transmitting device **702** are outside of acceptable limits. In some cases, the transmitting device **702**, in response to receiving a complaint from the network, may employ array tapering to suppress interference. However, as discussed in more detail with respect to FIG. **8**, FIG. **9A**, and FIG. **9B** below, array tapering may impact the performance of transmissions from the transmitting device **702** to the receiving device **706**.

[0124] FIG. **8** illustrates a diagram **800** including plots of sidelobe power level for different puncturing patterns for a sixty-four (64) element antenna array. As illustrated in FIG. **8**, the vertical axis represents output power and the horizontal axis represents observation angle (e.g.,  $\theta$ ). In the illustrated example of FIG. **8**, the antenna array is configured to transmit with a beamforming angle of 60 degrees (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ). As illustrated, the diagram **800** includes output power over a range of observation angles between twenty degrees and 100 degrees (e.g.,  $20^\circ \leq \theta \leq 100^\circ$ ). The diagram **800** also includes a sub-diagram **810** including output power over a range of observation angles between 58 degrees and 62 degrees (e.g.,  $58^\circ \leq \theta \leq 62^\circ$ ).

[0125] In the example of FIG. **8**, a first plot **802** represents output power for an antenna array operating without array puncturing (e.g., all array elements are on) in a baseline configuration. In addition, a second plot **804** represents output power for an antenna array operating with a puncturing pattern including a single turned off array element with array index  $n=i$ , where  $i$  is an integer between 1 and  $N$ , and where  $N$  is the number of array elements in the antenna array. Finally, a third plot **806** represents output power for an antenna array operating with the array puncturing pattern including the same single turned off array element with array index  $n=i$ , with further implementation of array tapering with application of a Hanning weighting with  $\eta=2$ .

[0126] In the diagram **800**, the first plot **802** is provided to illustrate a baseline of the sidelobe levels (SLL) (also referred to as sidelobe power levels herein) for the sixty-four (64) element antenna array (e.g.,  $N=64$ ). For example, as illustrated, sidelobe peak **803** shows that the power level of the first plot **802** at an observation angle of twenty-six degrees (e.g.,  $\theta=26^\circ$ ) corresponds to a SLL of  $-55$  dB. In the example of FIG. **8**, the sidelobe peak **805** shows that the power level of the second plot **804** at the same observation angle of twenty-six degrees (e.g.,  $\theta=26^\circ$ ) corresponds to a SLL of  $-52$  dB. Accordingly, the increase in power at the sidelobe peak **805** caused by array puncturing case relative to the sidelobe peak **803** of the baseline array illustrates how array puncturing can result in increased interference in the form of increased sidelobe power at angles other than the beamforming angle  $\theta_{\text{sub.BF}}$ .

[0127] As illustrated in FIG. **8**, sidelobe peak **807** shows that the power level of the third plot **806** at the same observation angle of twenty-six degrees (e.g.,  $\theta=26^\circ$ ) corresponds to a SLL of  $-57$  dB. Therefore, the decrease in power at the sidelobe peak **807** caused by array puncturing case with array tapering relative to the sidelobe peak **805** of the array puncturing case without array tapering illustrates how array tapering can decrease interference in the form of decreased sidelobe power at angles other than the beamforming angle  $\theta_{\text{sub.BF}}$ . Furthermore, FIG. **8** shows that the sidelobe peak **807** of the third plot **806** is also below the sidelobe peak **803** of the first plot **802**, which illustrates that array puncturing combined with array tapering can in some cases perform better than the baseline case in terms of SLL. However, diagram **800** also illustrates that third plot **806** includes a wider main beam with a lower peak power than the first plot **802** and the second plot **804**.

[0128] FIG. **9A** illustrates an example plot **900** of phase distortion for a case of array puncturing without the application of array tapering. For example, the plot **900** may correspond to the array puncturing case for the sixty-four (64) element antenna array (e.g.,  $N=64$ ) illustrated in the second plot **804** of diagram **800** shown in FIG. **8**. As illustrated in FIG. **9A**, the vertical axis represents phase distortion and the horizontal axis represents observation angle (e.g.,  $\theta$ ). In the example plot

**900**, the antenna array is transmitting at a beamforming angle of 60 degrees (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ). As illustrated in the plot **900**, the array puncturing case may have a phase distortion between  $+2^\circ$  between the observation angles of 57.5 degrees and 62.5 degrees (e.g.,  $57.5^\circ \leq \theta \leq 62.5^\circ$ ) as indicated by vertical dashed lines **902**. As illustrated, for observation angles outside of the vertical dashed lines **902**, the phase distortion can reach peak values of  $\pm 45^\circ$ . However, the plot **900** also includes regions **904** where the absolute value of the phase distortion drops below 450.

[0129] FIG. **9B** illustrates an example plot **950** of phase distortion for a case of array puncturing with array tapering. For example, the plot **950** may correspond to the array puncturing case with array tapering for the sixty-four (64) element antenna array (e.g.,  $N=64$ ) illustrated in the third plot **806** of diagram **800** shown in FIG. **8**. As illustrated in FIG. **9B**, the vertical axis represents phase distortion and the horizontal axis represents observation angle (e.g.,  $\theta$ ). In the example plot **950**, the antenna array is transmitting at a beamforming angle of 60 degrees (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ). As illustrated in the plot **950**, the array puncturing case with array tapering may have a phase distortion between  $+3^\circ$  between the observation angles of 57 degrees and 63 degrees (e.g.,  $57^\circ \leq \theta \leq 63^\circ$ ) as indicated by vertical dotted lines **952**. As illustrated, for observation angles outside of the vertical dotted lines **952**, the phase distortion can reach peak values of  $\pm 45^\circ$ . In addition, the plot **950** shows that once the phase distortion reaches an absolute value of  $45^\circ$  at observation angles above  $\pm 5.5^\circ$ , the phase distortion remains consistently at an absolute value of  $45^\circ$  without any regions of reduced phase distortion, in contrast to the regions **904** of FIG. **9A**. Accordingly, plot **950** illustrates how array puncturing with array tapering may lead to significant increases in phase distortion relative to array puncturing without array tapering. As noted above, the application of array tapering may also decrease the peak power output for transmissions by an antenna array (e.g., an antenna array included in transmitting device **702** of FIG. **7B**).

[0130] Returning to the example of FIG. **8**, as illustrated in sub-diagram **810**, the first plot **802** has the highest peak power of the three plots **802**, **804**, **806**. In the illustrated example, the second plot **804** illustrates a loss in peak power resulting from the array puncturing of approximately  $-0.14$  dB. In addition, the third plot **806** illustrates a loss in peak power resulting from the array puncturing with array tapering of approximately  $-1$  dB.

[0131] Returning now to FIG. **7B**, in some cases, the transmitting device **702** may elect to implement array tapering when a  $-1$  dB loss in peak power can be tolerated. However, in some cases, a  $-1$  dB loss may not be acceptable to the transmitting device **702**, receiving device **706**, and/or the network. In such examples, it may be desirable to provide additional techniques for managing interference for array puncturing in addition to array tapering.

[0132] FIG. **10** illustrates a schematic view illustrating a communication configuration **1000** that incorporates interference management for array puncturing. In the illustrated example of FIG. **10**, the transmitting device **1002**, beamforming channel  $h(\theta_{\text{sub.BF}})$  **1004**, receiving device **1006**, receiving device angle **1008**, beamforming angle **1009**, broadside **1010**, additional transmitting device **1020**, victim angle **1022**, corresponding channel  $h(\theta_{\text{sub.V}})$  **1024**, and victim device **1026** may be similar to and perform similar functions to the transmitting device **702**, beamforming channel  $h(\theta_{\text{sub.BF}})$  **704**, receiving device **706**, receiving device angle **708**, beamforming angle **709**, broadside **710**, additional transmitting device **720**, victim angle **722**, corresponding channel  $h(\theta_{\text{sub.V}})$  **724**, and victim device **726** shown in FIG. **7B**, respectively.

[0133] FIG. **10** further illustrates an adversary device **1016** located at adversary angle **1032** (e.g.,  $\theta=\theta_{\text{sub.A}}$ ). In some aspects, the adversary device **1016** can be associated with a corresponding channel  $h(\theta_{\text{sub.A}})$  **1034**. In some cases, as described with respect to FIG. **7B** above, the victim device **1026** may experience interference resulting from array puncturing performed by the transmitting device **1002**. For example, array puncturing can result in increased SLL (e.g., as illustrated in FIG. **8**), which may increase the amount of noise received at the victim device **1026**. In some cases, different array puncturing patterns may include one or more fluctuation free sector(s) **1040** where the power transmitted by transmitting device **1002** while implementing array

puncturing can be similar to the power transmitted by transmitting device **1002** operating without array puncturing (e.g., all array elements are on) in a baseline configuration. In some cases, as long as the victim device **1026** is able to compensate for the power transmitted by transmitting device **1002** in the baseline configuration, the victim device **1026** is also likely to be able to compensate, within the fluctuation free sector **1040**, for the power transmitted by the transmitting device **1002**. [0134] FIG. **11A** illustrates a diagram **1100** showing plots **1102**, **1104**, **1106** of transmitted power for different array puncturing patterns of an example communication configuration that incorporates interference management for array puncturing. As illustrated in FIG. **11A**, the vertical axis represents output power and the horizontal axis represents observation angle (e.g.,  $\theta$ ). In the example of diagram **1100**, the antenna array is a sixty-four (64) element antenna array (e.g.,  $N=64$ ) transmitting at a beamforming angle of 60 degrees (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ). As illustrated in FIG. **11A**, a first plot **1102** corresponds to transmitted power for transmissions by the antenna array without array puncturing. The second plot **1104** corresponds to transmitted power for transmissions with a first puncturing pattern including a single turned off array element with array element index  $n=i$ , where  $i$  is an integer between 1 and  $N$ . Finally, a third plot **1106** represents transmitted power for an antenna array operating with the array puncturing pattern including a different single turned off array element with array element index  $n \neq i$ .

[0135] In the illustrated example of FIG. **11A**, the range of observation angles (e.g.,  $\theta$ ) between twenty degrees ( $20^\circ$ ) and one hundred degrees ( $100^\circ$ ) is divided into a main lobe window **1112** and three sidelobe windows **1114**, **1116**, **1118**. As illustrated, the main lobe window **1112** includes the beamforming angle (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ )  $\pm$  twelve degrees ( $12^\circ$ ). In the illustrated example of FIG. **11A**, all three of the plots **1102**, **1104**, **1106** exhibit nearly identical power curves. In some cases, a selection of puncturing patterns having nearly identical power curves within a window of observation angles may indicate that the individual puncturing patterns included in the selection of puncturing patterns can be used interchangeably for observation angles within the window. For example, in some implementations, the puncturing patterns corresponding to plots **1102**, **1104**, **1106** can be used interchangeably within the main lobe window **1112** (e.g.,  $580 \leq \theta \leq 72^\circ$ ).

[0136] In contrast to the main lobe window **1112**, the three sidelobe windows **1114**, **1116**, **1118** do not exhibit nearly identical power curves for all three of the plots **1102**, **1104**, **1106**. Referring to sidelobe windows **1114**, **1116**, the third plot **1106** is completely out of alignment with the plots **1102**, **1104**. In addition, while the plots **1102**, **1104** exhibit similar power peaks for corresponding sidelobes, the observation angles  $\theta$  at which the peaks occur deviates by as much as one degree ( $1^\circ$ ). Accordingly, an observer located within sidelobe window **1114** (e.g.,  $200 \leq \theta \leq 58^\circ$ ) or sidelobe window **1116** (e.g.,  $830 \leq \theta \leq 100^\circ$ ) may experience amplitude fluctuations any time that the antenna array switches between puncturing patterns corresponding to the three plots **1102**, **1104**, **1106**.

[0137] Referring to sidelobe window **1118**, the plots **1102** and **1104** continue to be relatively well aligned while the third plot **1106** is completely out of alignment. In some cases, the puncturing patterns corresponding to plots **1102** and **1104** may be considered interchangeable within the sidelobe window **1118** (e.g.,  $720 \leq \theta \leq 83^\circ$ ). In some implementations, a transmitting device (e.g., transmitting device **1002** of FIG. **10**) may be able to switch between the puncturing patterns corresponding to plots **1102** and **1104** to maintain a fluctuation free sector (e.g., fluctuation free sector **1040** of FIG. **10**) for a victim device (e.g., victim device **1026** of FIG. **10**) within the sidelobe window **1118**.

[0138] Returning to FIG. **10**, the adversary device **1016** located at the adversary angle **1032** may also be positioned within the fluctuation free sector **1040**. In some aspects, while the power may not fluctuate within the fluctuation free sector **1040**, the adversary device **1016** may still experience phase distortion that prevents the adversary device **1016** from compromising the security of the transmissions between the transmitting device **1002** and the receiving device **1006**.

[0139] FIG. **11B** illustrates a diagram **1150** showing plots **1152**, **1154**, **1156** of phase for different array puncturing patterns of an example communication configuration that incorporates

interference management for array puncturing. As illustrated in FIG. 11B, the vertical axis represents phase and the horizontal axis represents observation angle (e.g.,  $\theta$ ). In the example of diagram 1150, the antenna array is transmitting at a beamforming angle of 60 degrees (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ) for each of the plots 1152, 1154, 1156. In the example of FIG. 11B, a first plot 1152 represents phase for an antenna array operating without array puncturing (e.g., all array elements are on) in a baseline configuration, corresponding to first plot 1102 of FIG. 11A. In addition, a second plot 1154 represents phase for an antenna array operating with an array puncturing pattern including a single turned off array element with array element index  $n=i$ , corresponding to second plot 1104 of FIG. 11A. Finally, a third plot 1156 represents phase for an antenna array operating with the array puncturing pattern including a different single turned off array element with array element index  $n \neq i$ , corresponding to third plot 1106 of FIG. 11A.

[0140] As illustrated in FIG. 11B, each of the puncturing patterns corresponding to the plots 1152, 1154, 1156 can provide a distortion free angular gap 1158 (e.g.,  $2\Delta\theta$  of FIG. 10) around the beamforming angle (e.g.,  $\theta_{\text{sub.BF}}=60^\circ$ ). As illustrated in FIG. 11B, outside of the distortion free angular gap 1158, the phase of each of the plots 1152, 1154, 1156 varies in such a way that prevents an adversary (e.g., adversary device 1016 of FIG. 10) from coherently demodulating signals transmitted by the antenna array. Accordingly, identification of puncturing patterns that can be used interchangeably within windows of observation angles (e.g., sidelobe window 1114 of FIG. 11A) can provide fluctuation free sectors for victim devices (e.g., victim device 1026 of FIG. 10) while maintaining flexibility for the transmitting device to perform puncturing pattern cycling to prevent an adversary (e.g., adversary device 1016) from coherently demodulating transmissions from the transmitting device.

[0141] While FIG. 11A and FIG. 11B illustrate plots corresponding to transmissions without array puncturing and two different single-element array puncturing patterns, an antenna array with  $N$  antenna elements can select between  $N$  different single-element array puncturing patterns. In addition, an antenna array with  $N$  antenna elements can vary the number and/or combination of antenna elements to turn off for array puncturing. It should be understood that each single-element puncturing pattern available to the antenna array may result in a different relationship between output power and observation angle. Similarly, puncturing patterns with different numbers and/or combinations of turned off antenna elements may result in a different relationship between output power and observation angle.

[0142] FIG. 12 is a schematic view 1200 illustrating an additional communication configuration that incorporates interference management for array puncturing. In the illustrated example of FIG. 12, the transmitting device 1202, beamforming channel  $h(\theta_{\text{sub.BF}})$  1204, receiving device 1206, receiving device angle 1208, beamforming angle 1209, broadside 1210, additional transmitting device 1220, victim angle 1222, corresponding channel  $h(\theta_{\text{sub.V}})$  1224, and victim device 1226, adversary angle 1232, and corresponding channel  $h(\theta_{\text{sub.A}})$  1234 may be similar to and perform similar functions to the transmitting device 1002, beamforming channel  $h(\theta_{\text{sub.BF}})$  1004, receiving device 1006, receiving device angle 1008, beamforming angle 1009, broadside 1010, victim angle 1022, additional transmitting device 1020, victim angle 1022, corresponding channel  $h(\theta_{\text{sub.V}})$  1024, victim device 1026, adversary angle 1032 and corresponding channel  $h(\theta_{\text{sub.A}})$  1034 shown in FIG. 10, respectively.

[0143] In some implementations, a transmitting device (e.g., transmitting device 1002 of FIG. 10) can store a list of fluctuation free observation angle windows in which multiple puncturing patterns can be used interchangeably. In some cases, two or more puncturing patterns that are aligned within each corresponding fluctuation free window of observation angles can be stored in the list of fluctuation free observation angle windows and associated with the corresponding fluctuation free window of observation angles. As illustrated, FIG. 12 includes three fluctuation free sectors 1252, 1254, 1256. In one illustrative example, the three fluctuation free sectors 1252, 1254, 1256 can correspond to fluctuation free windows of observation angles included in the list of fluctuation free

observation angle windows.

[0144] In some examples, the transmitting device **1202** may obtain information about the location of one or more victim devices (e.g., victim device **1226**) from the network and/or neighboring transmitting devices (e.g., additional transmitting device **1220**). In some implementations, the transmitting device **1202** can compare the location of a victim device **1226** with the fluctuation free windows of observation angles included in the list of fluctuation free observation angle windows. In some aspects, the transmitting device **1202** can perform array puncturing utilizing the puncturing patterns corresponding to a fluctuation free window of observation angles corresponding to the location of the victim device **1226**. For example, as illustrated in FIG. **12**, the fluctuation free sector **1256** includes the victim angle **1222** of the victim device **1226**. In some examples, the transmitting device **1202** can perform array puncturing utilizing the puncturing patterns corresponding to the fluctuation free sector **1256** to reduce interference with the victim device **1226** while still preventing the adversary device **1216** from coherently demodulating messages transmitted by the transmitting device **1202**.

[0145] In some implementations, the network and/or neighboring transmitting devices (e.g., additional transmitting device **1220**) may not report any directions corresponding to victim devices to the transmitting device **1202**. In some cases, the transmitting device **1202** may implement a puncturing pattern cycle that sweeps between the three fluctuation free sectors **1252**, **1254**, **1256**. For example, during a first fixed time period  $\Delta t_{\text{sub.1}}$ , the transmitting device **1202** may select puncturing patterns corresponding to the fluctuation free sector **1252**. In some cases, during a second fixed time period  $\Delta t_{\text{sub.2}}$ , the transmitting device **1202** may select puncturing patterns corresponding to the fluctuation free sector **1254**. In some aspects, during a second fixed time period  $\Delta t_{\text{sub.3}}$ , the transmitting device **1202** may select puncturing patterns corresponding to the fluctuation free sector **1256**. In some implementations, the transmitting device **1202** may select puncturing patterns corresponding to  $n$  fluctuation free sectors for fixed time periods  $\Delta t_{\text{sub.n}}$ . In some cases, by sweeping through fluctuation free sectors corresponding to different observation angles, the transmitting device **1202** can provide a time period for a victim device to receive transmissions from additional transmitting device **1220** and/or another neighboring transmitting device.

[0146] In some cases, the transmitting device **1202** may obtain information about the presence and/or location of one or more victim devices that may experience interference when the transmitting device **1202** applies array puncturing. In some cases, the information about the presence and/or location of the one or more victim devices can include statistical information, a priori information, and/or any combination thereof. In some examples, the transmitting device **1202** may utilize the information about the presence and/or location of the one or more victim devices to determine the time period(s) for applying puncturing patterns corresponding to different fluctuation free sectors (e.g., fluctuation free sectors **1252**, **1254**, **1256**). In one illustrative example, the transmitting device **1202** may obtain information about the trajectory of a victim device that is in motion and apply puncturing patterns in a way that maintains the victim device within a fluctuation free sector as it moves.

[0147] FIG. **13A** is a flow diagram of a process **1300** for wireless communications. The process **1300** may be performed by a computing device (or apparatus) or a component (e.g., a chipset, codec, etc.) of the computing device. The computing device may be a mobile device (e.g., a UE, such as UEs **104**, **152**, **164**, and **182** of FIG. **1** and FIG. **2**, wireless device **407** of FIG. **4**, and/or computing system **1400** of FIG. **14**), a network-connected wearable such as a watch, an extended reality (XR) device such as a virtual reality (VR) device or augmented reality (AR) device, a vehicle or component or system of a vehicle, a network node/entity/device (e.g., a BS **102**, AP **150**, mmW BS **180** of FIG. **1**, RU **340** of FIG. **3**, network node **602** of FIG. **6**), wireless device (e.g., receiving device **606** of FIG. **6**, transmitting device **702** of FIG. **7A**), or other type of computing device. The operations of the process **1300** may be implemented as software components that are

executed and run on one or more processors.

[0148] At block **1302**, the computing device (or component thereof) may obtain a message for transmission to a receiving device (e.g., receiving device **606** of FIG. **6**, receiving device **706** of FIG. **7A** and FIG. **7B**, receiving device **1006** of FIG. **10**).

[0149] At block **1304**, the computing device (or component thereof) may determine a plurality of beamforming weights (see, e.g., Equation (1)) for transmitting a portion of the message toward a direction of the receiving device (e.g., beamforming angle **709** of FIG. **7A** and FIG. **7B**, beamforming angle **1009** of FIG. **10**). In some cases, a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements. In some examples, each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements. In some aspects, a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message. In some implementations, the array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off includes one or more of a start top, a stop time, or a duration.

[0150] At block **1306**, the computing device (or component thereof) may output an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off (e.g.,  $b_{\text{sub}.n}=0$  in Equation (1)).

[0151] At block **1308**, the computing device (or component thereof) may transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off. In some cases, the beamforming weight of the plurality of beamforming weights is configured to turn off a corresponding transmit array element of the plurality of transmit array elements during transmission of the portion of the message according to one or more of a time pattern or a frequency pattern and the array puncturing notification includes one or more of the time pattern or the frequency pattern.

[0152] In some cases, the computing device (or component thereof) may obtain an indication that transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off may interfere with a transmission between a transmitting device and an additional receiving device and adjust the plurality of beamforming weights to manage interference with the transmission between the transmitting device and an additional receiving device.

[0153] In some examples, the computing device (or component thereof) may determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device. In some cases, a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements. In some examples, each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements. In some aspects, an additional beamforming weight of the additional plurality of beamforming weights is configured to turn off a different transmit array element of the plurality of transmit array elements during transmission of the additional portion of the message. In some aspects, the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights is configured to turn on the transmit array element during transmission of the additional portion of the message. The computing device (or component thereof) may transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight of the additional plurality of beamforming weights turned off and the transmit array element

corresponding to the beamforming weight of the plurality of beamforming weights turned on. [0154] In some cases, the portion of the message includes a first OFDM symbol of the message and the additional portion of the message includes a includes OFDM symbol of the message, the first OFDM symbol of the message being different from the second OFDM symbol of the message. In some examples, the array puncturing notification is further indicative of transmission of the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off and the transmit array element corresponding to the beamforming weight turned on.

[0155] In some examples, the computing device (or component thereof) may obtain an additional array puncturing notification indicative of transmission of an additional message toward the direction of an additional receiving device by an additional plurality of transmit array elements, the additional plurality of transmit array elements being different from the plurality of transmit array elements. In some cases, the additional array puncturing notification further indicates that the additional plurality of transmit array elements will transmit a portion of the additional message with at least one transmit array element of the additional plurality of transmit array elements turned off. The computing device (or component thereof) may configure the receiving device, based on the additional array puncturing notification, to increase a frequency of performing interference measurements in accordance with the additional array puncturing notification.

[0156] FIG. 13B is a flow diagram of a process 1320 for wireless communications. The process 1320 may be performed by a computing device (or apparatus) or a component (e.g., a chipset, codec, etc.) of the computing device. The computing device may be a mobile device (e.g., a UE, such as UEs 104, 152, 164, and 182 of FIG. 1 and FIG. 2, wireless device 407 of FIG. 4, and/or computing system 1400 of FIG. 14), a network-connected wearable such as a watch, an XR device such as a VR device or AR device, a vehicle or component or system of a vehicle, a network node/entity/device (e.g., a BS 102, AP 150, mmW BS 180 of FIG. 1, RU 340 of FIG. 3, network node 602 of FIG. 6), wireless device (e.g., receiving device 606 of FIG. 6, transmitting device 702 of FIG. 7A), or other type of computing device. The operations of the process 1320 may be implemented as software components that are executed and run on one or more processors.

[0157] At block 1322, the computing device (or component thereof) may obtain a message for transmission to a receiving device (e.g., receiving device 606 of FIG. 6, receiving device 706 of FIG. 7A and FIG. 7B, receiving device 1006 of FIG. 10).

[0158] At block 1324, the computing device (or component thereof) may determine a plurality of beamforming weights (see, e.g., Equation (1)) for transmitting a portion of the message toward a direction of the receiving device (e.g., beamforming angle 709 of FIG. 7A and FIG. 7B, beamforming angle 1009 of FIG. 10). In some cases, a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements. In some examples, each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements.

[0159] At block 1326, the computing device (or component thereof) may determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message. In some cases, the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements.

[0160] At block 1328, the computing device (or component thereof) may transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0161] In some implementations, the computing device (or component thereof) may determine an additional plurality of beamforming weights for transmitting an additional portion of the message

toward the direction of the receiving device. In some cases, a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements. In some examples, each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements. In some examples, the computing device (or component thereof) may determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message. In some cases, the additional beamforming weight to configure to turn off the different transmit array element is determined based on the fluctuation free sector corresponding to the window of observation angles relative to the broadside of the plurality of transmit array elements. In some aspects, the computing device (or component thereof) may transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off. [0162] In some cases, a power level of the portion of the message is aligned with a power level of the additional portion of the message within the window of observation angles.

[0163] In some aspects, the computing device (or component thereof) may determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device. In some cases, a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements. In some examples, each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements. In some examples, the computing device (or component thereof) may determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message. In some cases, the additional beamforming weight to configure to turn off the different transmit array element is determined based on an additional fluctuation free sector corresponding to a different window of observation angles relative to the broadside of the plurality of transmit array elements. In some aspects, the computing device (or component thereof) may transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

[0164] In some examples, the fluctuation free sector and the additional fluctuation free sector are selected based on information about one or more of a presence or a location of an additional receiving device.

[0165] In some aspects, the information about one or more of the presence or the location of the additional receiving device is obtained from a communication network.

[0166] In some examples, the processes described herein (e.g., process **1300**, process **1320**, and/or other process described herein) may be performed by a computing device or apparatus (e.g., a UE or a base station). In another example, the process **1300** may be performed by the UE **104** of FIG. **1**. In another example, the process **1300** may be performed by a computing device with the computing system **1400** shown in FIG. **14**. In another example, the process **1320** may be performed by the UE **104** of FIG. **1**. In another example, the process **1320** may be performed by a computing device with the computing system **1400** shown in FIG. **14**.

[0167] In some cases, the devices or apparatuses configured to perform the operations of the process **1300**, the process **1320**, and/or other processes described herein may include a processor, microprocessor, microcomputer, or other component of a device that is configured to carry out the steps of the process **1300**, the process **1320**, and/or other process. In some examples, such devices or apparatuses may include one or more sensors configured to capture image data and/or other



sensor measurements. In some examples, such computing device or apparatus may include one or more sensors and/or a camera configured to capture one or more images or videos. In some cases, such device or apparatus may include a display for displaying images. In some examples, the one or more sensors and/or camera are separate from the device or apparatus, in which case the device or apparatus receives the sensed data. Such device or apparatus may further include a network interface configured to communicate data.

[0168] The components of the device or apparatus configured to carry out one or more operations of the process **1300**, the process **1320**, and/or other processes described herein can be implemented in circuitry. For example, the components can include and/or can be implemented using electronic circuits or other electronic hardware, which can include one or more programmable electronic circuits (e.g., microprocessors, graphics processing units (GPUs), digital signal processors (DSPs), central processing units (CPUs), and/or other suitable electronic circuits), and/or can include and/or be implemented using computer software, firmware, or any combination thereof, to perform the various operations described herein. The computing device may further include a display (as an example of the output device or in addition to the output device), a network interface configured to communicate and/or receive the data, any combination thereof, and/or other component(s). The network interface may be configured to communicate and/or receive Internet Protocol (IP) based data or other type of data.

[0169] The process **1300** and the process **1320** are illustrated as logical flow diagrams, the operations of which represent sequences of operations that can be implemented in hardware, computer instructions, or a combination thereof. In the context of computer instructions, the operations represent computer-executable instructions stored on one or more computer-readable storage media that, when executed by one or more processors, perform the recited operations. Generally, computer-executable instructions include routines, programs, objects, components, data structures, and the like that perform particular functions or implement particular data types. The order in which the operations are described is not intended to be construed as a limitation, and any number of the described operations can be combined in any order and/or in parallel to implement the processes.

[0170] Additionally, the processes described herein (e.g., the process **1300**, the process **1320**, and/or other processes) may be performed under the control of one or more computer systems configured with executable instructions and may be implemented as code (e.g., executable instructions, one or more computer programs, or one or more applications) executing collectively on one or more processors, by hardware, or combinations thereof. As noted above, the code may be stored on a computer-readable or machine-readable storage medium, for example, in the form of a computer program including a plurality of instructions executable by one or more processors. The computer-readable or machine-readable storage medium may be non-transitory.

[0171] FIG. **14** is a diagram illustrating an example of a system for implementing certain aspects of the present technology. In particular, FIG. **14** illustrates an example of computing system **1400**, which may be for example any computing device making up internal computing system, a remote computing system, a camera, or any component thereof in which the components of the system are in communication with each other using connection **1405**. Connection **1405** may be a physical connection using a bus, or a direct connection into processor **1410**, such as in a chipset architecture. Connection **1405** may also be a virtual connection, networked connection, or logical connection.

[0172] In some embodiments, computing system **1400** is a distributed system in which the functions described in this disclosure may be distributed within a datacenter, multiple data centers, a peer network, etc. In some embodiments, one or more of the described system components represents many such components each performing some or all of the function for which the component is described. In some embodiments, the components may be physical or virtual devices.

[0173] Example computing system **1400** includes at least one processing unit (CPU or processor) **1410** and connection **1405** that communicatively couples various system components including

system memory **1415**, such as read-only memory (ROM) **1420** and random access memory (RAM) **1425** to processor **1410**. Computing system **1400** may include a cache **1412** of high-speed memory connected directly with, in close proximity to, or integrated as part of processor **1410**.

[0174] Processor **1410** may include any general purpose processor and a hardware service or software service, such as services **1432**, **1434**, and **1436** stored in storage device **1430**, configured to control processor **1410** as well as a special-purpose processor where software instructions are incorporated into the actual processor design. Processor **1410** may essentially be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric.

[0175] To enable user interaction, computing system **1400** includes an input device **1445**, which may represent any number of input mechanisms, such as a microphone for speech, a touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech, etc. Computing system **1400** may also include output device **1435**, which may be one or more of a number of output mechanisms. In some instances, multimodal systems may enable a user to provide multiple types of input/output to communicate with computing system **1400**.

[0176] Computing system **1400** may include communications interface **1440**, which may generally govern and manage the user input and system output. The communication interface may perform or facilitate receipt and/or transmission wired or wireless communications using wired and/or wireless transceivers, including those making use of an audio jack/plug, a microphone jack/plug, a universal serial bus (USB) port/plug, an Apple™ Lightning™ port/plug, an Ethernet port/plug, a fiber optic port/plug, a proprietary wired port/plug, 3G, 4G, 5G and/or other cellular data network wireless signal transfer, a Bluetooth™ wireless signal transfer, a Bluetooth™ low energy (BLE) wireless signal transfer, an IBEACON™ wireless signal transfer, a radio-frequency identification (RFID) wireless signal transfer, near-field communications (NFC) wireless signal transfer, dedicated short range communication (DSRC) wireless signal transfer, 802.11 Wi-Fi wireless signal transfer, wireless local area network (WLAN) signal transfer, Visible Light Communication (VLC), Worldwide Interoperability for Microwave Access (WiMAX), Infrared (IR) communication wireless signal transfer, Public Switched Telephone Network (PSTN) signal transfer, Integrated Services Digital Network (ISDN) signal transfer, ad-hoc network signal transfer, radio wave signal transfer, microwave signal transfer, infrared signal transfer, visible light signal transfer, ultraviolet light signal transfer, wireless signal transfer along the electromagnetic spectrum, or some combination thereof. The communications interface **1440** may also include one or more Global Navigation Satellite System (GNSS) receivers or transceivers that are used to determine a location of the computing system **1400** based on receipt of one or more signals from one or more satellites associated with one or more GNSS systems. GNSS systems include, but are not limited to, the US-based Global Positioning System (GPS), the Russia-based Global Navigation Satellite System (GLONASS), the China-based BeiDou Navigation Satellite System (BDS), and the Europe-based Galileo GNSS. There is no restriction on operating on any particular hardware arrangement, and therefore the basic features here may easily be substituted for improved hardware or firmware arrangements as they are developed.

[0177] Storage device **1430** may be a non-volatile and/or non-transitory and/or computer-readable memory device and may be a hard disk or other types of computer readable media which may store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, a floppy disk, a flexible disk, a hard disk, magnetic tape, a magnetic strip/stripe, any other magnetic storage medium, flash memory, memristor memory, any other solid-state memory, a compact disc read only memory (CD-ROM) optical disc, a rewritable compact disc (CD) optical disc, digital video disk (DVD) optical disc, a blu-ray disc (BDD) optical disc, a holographic optical disk, another optical medium, a secure digital (SD) card, a micro secure digital (microSD) card, a Memory Stick® card, a smartcard chip, a EMV chip, a subscriber identity module (SIM) card, a mini/micro/nano/pico SIM card, another

integrated circuit (IC) chip/card, random access memory (RAM), static RAM (SRAM), dynamic RAM (DRAM), read-only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash EPROM (FLASH-EPROM), cache memory (e.g., Level 1 (L1) cache, Level 2 (L2) cache, Level 3 (L3) cache, Level 4 (L4) cache, Level 5 (L5) cache, or other (L#) cache), resistive random-access memory (RRAM/ReRAM), phase change memory (PCM), spin transfer torque RAM (STT-RAM), another memory chip or cartridge, and/or a combination thereof. [0178] The storage device **1430** may include software services, servers, services, etc., that when the code that defines such software is executed by the processor **1410**, it causes the system to perform a function. In some embodiments, a hardware service that performs a particular function may include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as processor **1410**, connection **1405**, output device **1435**, etc., to carry out the function. The term “computer-readable medium” includes, but is not limited to, portable or non-portable storage devices, optical storage devices, and various other mediums capable of storing, containing, or carrying instruction(s) and/or data. A computer-readable medium may include a non-transitory medium in which data may be stored and that does not include carrier waves and/or transitory electronic signals propagating wirelessly or over wired connections. Examples of a non-transitory medium may include, but are not limited to, a magnetic disk or tape, optical storage media such as compact disk (CD) or digital versatile disk (DVD), flash memory, memory or memory devices. A computer-readable medium may have stored thereon code and/or machine-executable instructions that may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, or the like.

[0179] Specific details are provided in the description above to provide a thorough understanding of the embodiments and examples provided herein, but those skilled in the art will recognize that the application is not limited thereto. Thus, while illustrative embodiments of the application have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art. Various features and aspects of the above-described application may be used individually or jointly. Further, embodiments may be utilized in any number of environments and applications beyond those described herein without departing from the broader scope of the specification. The specification and drawings are, accordingly, to be regarded as illustrative rather than restrictive. For the purposes of illustration, methods were described in a particular order. It should be appreciated that in alternate embodiments, the methods may be performed in a different order than that described.

[0180] For clarity of explanation, in some instances the present technology may be presented as including individual functional blocks comprising devices, device components, steps or routines in a method embodied in software, or combinations of hardware and software. Additional components may be used other than those shown in the figures and/or described herein. For example, circuits, systems, networks, processes, and other components may be shown as components in block diagram form in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques may be shown without unnecessary detail in order to avoid obscuring the embodiments.

[0181] Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To

clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[0182] Individual embodiments may be described above as a process or method which is depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations may be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed but could have additional steps not included in a figure. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination may correspond to a return of the function to the calling function or the main function.

[0183] Processes and methods according to the above-described examples may be implemented using computer-executable instructions that are stored or otherwise available from computer-readable media. Such instructions may include, for example, instructions and data which cause or otherwise configure a general purpose computer, special purpose computer, or a processing device to perform a certain function or group of functions. Portions of computer resources used may be accessible over a network. The computer executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, firmware, source code. Examples of computer-readable media that may be used to store instructions, information used, and/or information created during methods according to described examples include magnetic or optical disks, flash memory, USB devices provided with non-volatile memory, networked storage devices, and so on.

[0184] In some embodiments the computer-readable storage devices, mediums, and memories may include a cable or wireless signal containing a bitstream and the like. However, when mentioned, non-transitory computer-readable storage media expressly exclude media such as energy, carrier signals, electromagnetic waves, and signals per se.

[0185] Those of skill in the art will appreciate that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof, in some cases depending in part on the particular application, in part on the desired design, in part on the corresponding technology, etc.

[0186] The various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed using hardware, software, firmware, middleware, microcode, hardware description languages, or any combination thereof, and may take any of a variety of form factors. When implemented in software, firmware, middleware, or microcode, the program code or code segments to perform the necessary tasks (e.g., a computer-program product) may be stored in a computer-readable or machine-readable medium. A processor(s) may perform the necessary tasks. Examples of form factors include laptops, smart phones, mobile phones, tablet devices or other small form factor personal computers, personal digital assistants, rackmount devices, standalone devices, and so on. Functionality described herein also may be embodied in peripherals or add-in cards. Such functionality may also be implemented on a circuit board among different chips or different processes executing in a single device, by way of further example.

[0187] The instructions, media for conveying such instructions, computing resources for executing

them, and other structures for supporting such computing resources are example means for providing the functions described in the disclosure.

[0188] The techniques described herein may also be implemented in electronic hardware, computer software, firmware, or any combination thereof. Such techniques may be implemented in any of a variety of devices such as general purposes computers, wireless communication device handsets, or integrated circuit devices having multiple uses including application in wireless communication device handsets and other devices. Any features described as modules or components may be implemented together in an integrated logic device or separately as discrete but interoperable logic devices. If implemented in software, the techniques may be realized at least in part by a computer-readable data storage medium comprising program code including instructions that, when executed by one or more processors, performs one or more of the methods, algorithms, and/or operations described above. The computer-readable data storage medium may form part of a computer program product, which may include packaging materials. The computer-readable medium and/or memory system may comprise any memory or data storage media, such as random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, system memory **1415**, read-only memory (ROM) **1420**, random access memory (RAM) **1425**, storage device **1430**, and the like, and the computer-readable medium may include multiple memories or data storage media. The techniques additionally, or alternatively, may be realized at least in part by a computer-readable communication medium that carries or communicates program code in the form of instructions or data structures and that may be accessed, read, and/or executed by a computer, such as propagated signals or waves.

[0189] The program code may be executed by a processor system, which may include one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, an application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Such a processor system may be configured to perform any of the techniques described in this disclosure. A general-purpose processor may be a microprocessor; but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor system may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. Accordingly, the term “processor system,” as used herein may refer to any of the foregoing structure, any combination of the foregoing structure, or any other structure or apparatus suitable for implementation of the techniques described herein.

[0190] One of ordinary skill will appreciate that the less than (“<”) and greater than (“>”) symbols or terminology used herein may be replaced with less than or equal to (“≤”) and greater than or equal to (“≥”) symbols, respectively, without departing from the scope of this description.

[0191] Where components are described as being “configured to” perform certain operations, such configuration may be accomplished, for example, by designing electronic circuits or other hardware to perform the operation, by programming programmable electronic circuits (e.g., microprocessors, or other suitable electronic circuits) to perform the operation, or any combination thereof.

[0192] The phrase “coupled to” or “communicatively coupled to” refers to any component that is physically connected to another component either directly or indirectly, and/or any component that is in communication with another component (e.g., connected to the other component over a wired or wireless connection, and/or other suitable communication interface) either directly or indirectly.

[0193] Claim language or other language reciting “at least one of” a set and/or “one or more” of a set indicates that one member of the set or multiple members of the set (in any combination) satisfy the claim. For example, claim language reciting “at least one of A and B” or “at least one of A or

B” means A, B, or A and B. In another example, claim language reciting “at least one of A, B, and C” or “at least one of A, B, or C” means A, B, C, or A and B, or A and C, or B and C, A and B and C, or any duplicate information or data (e.g., A and A, B and B, C and C, A and A and B, and so on), or any other ordering, duplication, or combination of A, B, and C. The language “at least one of” a set and/or “one or more” of a set does not limit the set to the items listed in the set. For example, claim language reciting “at least one of A and B” or “at least one of A or B” may mean A, B, or A and B, and may additionally include items not listed in the set of A and B. The phrases “at least one” and “one or more” are used interchangeably herein.

[0194] Claim language or other language reciting “at least one processor configured to,” “at least one processor being configured to,” “one or more processors configured to,” “one or more processors being configured to,” or the like indicates that one processor or multiple processors (in any combination) can perform the associated operation(s). For example, claim language reciting “at least one processor configured to: X, Y, and Z” means a single processor can be used to perform operations X, Y, and Z; or that multiple processors are each tasked with a certain subset of operations X, Y, and Z such that together the multiple processors perform X, Y, and Z; or that a group of multiple processors work together to perform operations X, Y, and Z. In another example, claim language reciting “at least one processor configured to: X, Y, and Z” can mean that any single processor may only perform at least a subset of operations X, Y, and Z.

[0195] Where reference is made to one or more elements performing functions (e.g., steps of a method), one element may perform all functions, or more than one element may collectively perform the functions. When more than one element collectively performs the functions, each function need not be performed by each of those elements (e.g., different functions may be performed by different elements) and/or each function need not be performed in whole by only one element (e.g., different elements may perform different sub-functions of a function). Similarly, where reference is made to one or more elements configured to cause another element (e.g., an apparatus) to perform functions, one element may be configured to cause the other element to perform all functions, or more than one element may collectively be configured to cause the other element to perform the functions.

[0196] Where reference is made to an entity (e.g., any entity or device described herein) performing functions or being configured to perform functions (e.g., steps of a method), the entity may be configured to cause one or more elements (individually or collectively) to perform the functions. The one or more components of the entity may include at least one memory, at least one processor, at least one communication interface, another component configured to perform one or more (or all) of the functions, and/or any combination thereof. Where reference to the entity performing functions, the entity may be configured to cause one component to perform all functions, or to cause more than one component to collectively perform the functions. When the entity is configured to cause more than one component to collectively perform the functions, each function need not be performed by each of those components (e.g., different functions may be performed by different components) and/or each function need not be performed in whole by only one component (e.g., different components may perform different sub-functions of a function).

[0197] Illustrative aspects of the disclosure include:

[0198] Aspect 1: An apparatus comprising: a memory; and a processor coupled to the memory and configured to: obtain a message for transmission to a receiving device; determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the

portion of the message; output an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0199] Aspect 2: The apparatus of aspect 1, wherein: the beamforming weight of the plurality of beamforming weights is configured to turn off a corresponding transmit array element of the plurality of transmit array elements during transmission of the portion of the message according to one or more of a time pattern or a frequency pattern; and the array puncturing notification includes one or more of the time pattern or the frequency pattern.

[0200] Aspect 3: The apparatus of Aspect 2, wherein the processor is further configured to: obtain an indication that transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off may interfere with a transmission between a transmitting device and an additional receiving device; and adjust the plurality of beamforming weights to manage interference with the transmission between the transmitting device and an additional receiving device.

[0201] Aspect 4: The apparatus of any of Aspects 1 to 3, wherein the array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off comprises one or more of a start time, a stop time, or a duration.

[0202] Aspect 5: The apparatus of any of Aspects 1 to 4, wherein the processor is further configured to: determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; an additional beamforming weight of the additional plurality of beamforming weights is configured to turn off a different transmit array element of the plurality of transmit array elements during transmission of the additional portion of the message; and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights is configured to turn on the transmit array element during transmission of the additional portion of the message; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight of the additional plurality of beamforming weights turned off and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights turned on.

[0203] Aspect 6: The apparatus of Aspect 5, wherein the portion of the message comprises a first orthogonal frequency division multiplexing (OFDM) symbol of the message and the additional portion of the message comprises a second OFDM symbol of the message, the first OFDM symbol of the message being different from the second OFDM symbol of the message.

[0204] Aspect 7: The apparatus of Aspect 5, wherein the array puncturing notification is further indicative of transmission of the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off and the transmit array element corresponding to the beamforming weight turned on.

[0205] Aspect 8: The apparatus of any of Aspects 1 to 7, wherein the processor is further configured to: obtain an additional array puncturing notification indicative of transmission of an additional message toward the direction of an additional receiving device by an additional plurality of transmit array elements, the additional plurality of transmit array elements being different from the plurality of transmit array elements, wherein the additional array puncturing notification further

indicates that the additional plurality of transmit array elements will transmit a portion of the additional message with at least one transmit array element of the additional plurality of transmit array elements turned off; and configure the receiving device, based on the additional array puncturing notification, to increase a frequency of performing interference measurements in accordance with the additional array puncturing notification.

[0206] Aspect 9: A method for wireless communications, the method comprising: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message; outputting an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0207] Aspect 10: The method of Aspect 9, wherein: the beamforming weight of the plurality of beamforming weights is configured to turn off a corresponding transmit array element of the plurality of transmit array elements during transmission of the portion of the message according to one or more of a time pattern or a frequency pattern; and the array puncturing notification includes one or more of the time pattern or the frequency pattern.

[0208] Aspect 11: The method of Aspect 10, further comprising: obtaining an indication that transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off may interfere with a transmission between a transmitting device and an additional receiving device; and adjusting the plurality of beamforming weights to manage interference with the transmission between the transmitting device and an additional receiving device.

[0209] Aspect 12: The method of any of Aspects 9 to 11, wherein the array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off comprises one or more of a start time, a stop time, or a duration.

[0210] Aspect 13: The method of any of Aspects 9 to 12, further comprising: determining an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; an additional beamforming weight of the additional plurality of beamforming weights is configured to turn off a different transmit array element of the plurality of transmit array elements during transmission of the additional portion of the message; and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights is configured to turn on the transmit array element during transmission of the additional portion of the message; and transmitting the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight of the additional plurality of beamforming weights turned off and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights turned on.

[0211] Aspect 14: The method of Aspect 13, wherein the portion of the message comprises a first



OFDM symbol of the message and the additional portion of the message comprises a second OFDM symbol of the message, the first OFDM symbol of the message being different from the second OFDM symbol of the message.

[0212] Aspect 15: The method of Aspect 13, wherein the array puncturing notification is further indicative of transmission of the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off and the transmit array element corresponding to the beamforming weight turned on.

[0213] Aspect 16: The method of any of Aspects 9 to 15, further comprising: obtaining an additional array puncturing notification indicative of transmission of an additional message toward the direction of an additional receiving device by an additional plurality of transmit array elements, the additional plurality of transmit array elements being different from the plurality of transmit array elements, wherein the additional array puncturing notification further indicates that the additional plurality of transmit array elements will transmit a portion of the additional message with at least one transmit array element of the additional plurality of transmit array elements turned off; and configuring the receiving device, based on the additional array puncturing notification, to increase a frequency of performing interference measurements in accordance with the additional array puncturing notification.

[0214] Aspect 17: An apparatus for wireless communications, comprising: a memory; and a processor coupled to the memory and configured to: obtain a message for transmission to a receiving device; determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0215] Aspect 18: The apparatus of Aspect 17, wherein the processor is further configured to: determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on the fluctuation free sector corresponding to the window of observation angles relative to the broadside of the plurality of transmit array elements; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

[0216] Aspect 19: The apparatus of Aspect 18, wherein a power level of the portion of the message is aligned with a power level of the additional portion of the message within the window of observation angles.

[0217] Aspect 20: The apparatus of any of Aspects 17 to 19, wherein the processor is further configured to: determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on an additional fluctuation free sector corresponding to a different window of observation angles relative to the broadside of the plurality of transmit array elements; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

[0218] Aspect 21: The apparatus of Aspect 20, wherein the fluctuation free sector and the additional fluctuation free sector are selected based on information about one or more of a presence or a location of an additional receiving device.

[0219] Aspect 22: The apparatus of Aspect 21, wherein the information about one or more of the presence or the location of the additional receiving device is obtained from a communication network.

[0220] Aspect 23: A method for wireless communications, the method comprising: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

[0221] Aspect 24: The method of Aspect 23, further comprising: determining an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on the fluctuation free sector corresponding to the window of observation angles relative to the broadside of the plurality of transmit array elements; and transmitting the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

[0222] Aspect 25: The method of Aspect 24, wherein a power level of the portion of the message is aligned with a power level of the additional portion of the message within the window of observation angles.

[0223] Aspect 26: The method of any of Aspects 23 to 25, further comprising: determining an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on an additional fluctuation free sector corresponding to a different window of observation angles relative to the broadside of the plurality of transmit array elements; and transmitting the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

[0224] Aspect 27: The method of Aspect 26, wherein the fluctuation free sector and the additional fluctuation free sector are selected based on information about one or more of a presence or a location of an additional receiving device.

[0225] Aspect 28: The method of Aspect 27, wherein the information about one or more of the presence or the location of the additional receiving device is obtained from a communication network.

[0226] Aspect 29: A non-transitory computer-readable storage medium having stored thereon instructions which, when executed by one or more processors, cause the one or more processors to perform any of the operations of aspects 1 to 16.

[0227] Aspect 30: An apparatus comprising means for performing any of the operations of aspects 1 to 16.

[0228] Aspect 31: A non-transitory computer-readable storage medium having stored thereon instructions which, when executed by one or more processors, cause the one or more processors to perform any of the operations of aspects 17 to 28.

[0229] Aspect 32: An apparatus comprising means for performing any of the operations of aspects 17 to 28.

[0230] Aspect 33: A method comprising operations according to any of Aspects 1 to 16 and any of Aspects 17 to 28.

[0231] Aspect 34: An apparatus for wireless communication. The apparatus includes a memory (e.g., implemented in circuitry) and one or more processors (e.g., one processor or multiple processors) coupled to the memory. The one or more processors are configured to perform operations according to any of any of Aspects 1 to 16 and any of Aspects 17 to 28.

[0232] Aspect 35: A computer-readable storage medium storing instructions that, when executed by one or more processors, cause the one or more processors to perform operations according to any of any of Aspects 1 to 16 and any of Aspects 17 to 28.

[0233] Aspect 36: An apparatus comprising means for performing operations according to any of any of Aspects 1 to 16 and any of Aspects 17 to 28.

## Claims

1. An apparatus for wireless communications, comprising: a memory; and a processor coupled to the memory and configured to: obtain a message for transmission to a receiving device; determine

a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message; output an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

2. The apparatus of claim 1, wherein: the beamforming weight of the plurality of beamforming weights is configured to turn off a corresponding transmit array element of the plurality of transmit array elements during transmission of the portion of the message according to one or more of a time pattern or a frequency pattern; and the array puncturing notification includes one or more of the time pattern or the frequency pattern.

3. The apparatus of claim 2, wherein the processor is further configured to: obtain an indication that transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off may interfere with a transmission between a transmitting device and an additional receiving device; and adjust the plurality of beamforming weights to manage interference with the transmission between the transmitting device and an additional receiving device.

4. The apparatus of claim 1, wherein the array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off comprises one or more of a start time, a stop time, or a duration.

5. The apparatus of claim 1, wherein the processor is further configured to: determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; an additional beamforming weight of the additional plurality of beamforming weights is configured to turn off a different transmit array element of the plurality of transmit array elements during transmission of the additional portion of the message; and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights is configured to turn on the transmit array element during transmission of the additional portion of the message; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight of the additional plurality of beamforming weights turned off and the transmit array element corresponding to the beamforming weight of the plurality of beamforming weights turned on.

6. The apparatus of claim 5, wherein the portion of the message comprises a first orthogonal frequency division multiplexing (OFDM) symbol of the message and the additional portion of the message comprises a second OFDM symbol of the message, the first OFDM symbol of the message being different from the second OFDM symbol of the message.

7. The apparatus of claim 5, wherein the array puncturing notification is further indicative of transmission of the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off and the transmit array element corresponding to the beamforming weight turned on.

**8.** The apparatus of claim 1, wherein the processor is further configured to: obtain an additional array puncturing notification indicative of transmission of an additional message toward the direction of an additional receiving device by an additional plurality of transmit array elements, the additional plurality of transmit array elements being different from the plurality of transmit array elements, wherein the additional array puncturing notification further indicates that the additional plurality of transmit array elements will transmit a portion of the additional message with at least one transmit array element of the additional plurality of transmit array elements turned off; and configure the receiving device, based on the additional array puncturing notification, to increase a frequency of performing interference measurements in accordance with the additional array puncturing notification.

**9.** A method for wireless communications, the method comprising: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; and a beamforming weight of the plurality of beamforming weights is configured to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message; outputting an array puncturing notification indicative of transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off; and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

**10.** The method of claim 9, wherein: the beamforming weight of the plurality of beamforming weights is configured to turn off a corresponding transmit array element of the plurality of transmit array elements during transmission of the portion of the message according to one or more of a time pattern or a frequency pattern; and the array puncturing notification includes one or more of the time pattern or the frequency pattern.

**11.** The method of claim 10, further comprising: obtaining an indication that transmission of the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off may interfere with a transmission between a transmitting device and an additional receiving device; and adjusting the plurality of beamforming weights to manage interference with the transmission between the transmitting device and an additional receiving device.

**12.** An apparatus for wireless communications, comprising: a memory; and a processor coupled to the memory and configured to: obtain a message for transmission to a receiving device; determine a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmit the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

**13.** The apparatus of claim 12, wherein the processor is further configured to: determine an

additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on the fluctuation free sector corresponding to the window of observation angles relative to the broadside of the plurality of transmit array elements; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

**14.** The apparatus of claim 13, wherein a power level of the portion of the message is aligned with a power level of the additional portion of the message within the window of observation angles.

**15.** The apparatus of claim 12, wherein the processor is further configured to: determine an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determine an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on an additional fluctuation free sector corresponding to a different window of observation angles relative to the broadside of the plurality of transmit array elements; and transmit the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

**16.** The apparatus of claim 15, wherein the fluctuation free sector and the additional fluctuation free sector are selected based on information about one or more of a presence or a location of an additional receiving device.

**17.** The apparatus of claim 16, wherein the information about one or more of the presence or the location of the additional receiving device is obtained from a communication network.

**18.** A method for wireless communications, the method comprising: obtaining a message for transmission to a receiving device; determining a plurality of beamforming weights for transmitting a portion of the message toward a direction of the receiving device, wherein: a number of beamforming weights of the plurality of beamforming weights is equal to a number of transmit array elements of a plurality of transmit array elements; and each beamforming weight of the plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining a beamforming weight of the plurality of beamforming weights to configure to turn off a transmit array element of the plurality of transmit array elements corresponding to the beamforming weight during transmission of the portion of the message, wherein the beamforming weight to configure to turn off the transmit array element is determined based on a fluctuation free sector corresponding to a window of observation angles relative to a broadside of the plurality of transmit array elements; and transmitting the portion of the message by the plurality of transmit array elements with the transmit array element corresponding to the beamforming weight turned off.

**19.** The method of claim 18, further comprising: determining an additional plurality of beamforming weights for transmitting an additional portion of the message toward the direction of the receiving device, wherein: a number of beamforming weights of the additional plurality of beamforming weights is equal to the number of transmit array elements of the plurality of transmit array elements; and each beamforming weight of the additional plurality of beamforming weights corresponds to a respective transmit array element of the plurality of transmit array elements; determining an additional beamforming weight of the additional plurality of beamforming weights to configure to turn off a different transmit array element of the plurality of transmit array elements corresponding to the additional beamforming weight during transmission of the additional portion of the message, wherein the additional beamforming weight to configure to turn off the different transmit array element is determined based on the fluctuation free sector corresponding to the window of observation angles relative to the broadside of the plurality of transmit array elements; and transmitting the additional portion of the message by the plurality of transmit array elements with the different transmit array element corresponding to the additional beamforming weight turned off.

**20.** The method of claim 19, wherein a power level of the portion of the message is aligned with a power level of the additional portion of the message within the window of observation angles.

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