



- (51) **International Patent Classification:**
H04B 7/0456 (2017.01) *H04B 7/06* (2006.01)
- (21) **International Application Number:**
PCT/IB2019/058612
- (22) **International Filing Date:**
09 October 2019 (09.10.2019)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
62/743,717 10 October 2018 (10.10.2018) US
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- (81) **Designated States (unless otherwise indicated, for every
kind of national protection available):** AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,

DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States (unless otherwise indicated, for every
kind of regional protection available):** ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE

(54) **Title:** HYBRID FD-MIMO: COMBINING CODEBOOK-BASED AND RECIPROCITY-BASED BEAMFORMING

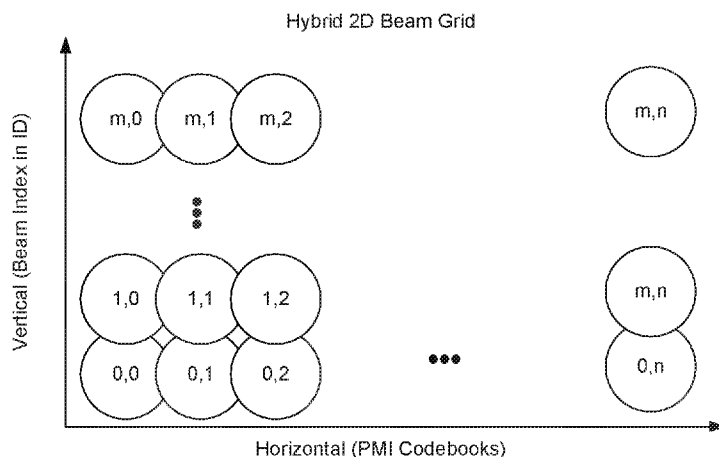


FIG. 1

(57) **Abstract:** A method, system and apparatus for realizing FD_MIMO in codebook-based transmissions. The method, system and apparatus include the combining of one or more horizontal codebooks and one or more vertical codebooks. A 2D beamformer for downlink transmissions is generated based on the combination of the one or more horizontal codebooks and one or more vertical codebooks.

WO 2020/075094 A1

HYBRID FD-MIMO: COMBINING CODEBOOK-BASED AND RECIPROCITY-BASED BEAMFORMING

5 TECHNICAL FIELD

[001] The present disclosure relates to wireless communications, and in particular, to a hybrid transmission combining codebook-based and reciprocity-based beamforming.

10 BACKGROUND

[002] In codebook-based beamforming, a base station, e.g. enhanced e-node B (eNB), base station in NR (gNB), sends reference signals in the downlink, e.g., CRS, CSI-RS. A user equipment (UE) has a pre-defined set of codebooks which is reviewed to determine the set that maximizes the UE throughput. The index of the selected codebook will be reported back to the base station in the CSI report along with RI and CQI. The base station then has the choice to use that PMI to perform precoding of the PDSCH.

[003] In reciprocity-based beamforming, a UE sends reference signals in uplink e.g., SRS, DMRS. A base station will use these signals to estimate the channel covariance in the uplink. The base station will then use this estimation to perform the downlink (DL) beamforming. There are multiple ways to perform reciprocity-based DL beamforming including Reciprocity Assisted Transmission (RAT) and Grid of Beams (GoB). In GoB, the base station goes through a set of predefined DFT beams (codebooks) with potential oversampling rate and finds the beam that has the maximum power which reveals the information about direction of arrival (DoA). That beam will then be used to beamform the PDSCH.

[004] There currently exist certain challenge(s).

[005] In order to improve the performance and extract the full potential of Full Dimension Multiple Input Multiple Output (FD-MIMO), a base station needs to perform elevation beamforming. However, in certain codebook-based transmission
5 modes, the defined Precoder Matrix Indicators (PMIs) only exploit the horizontal beamforming and do not provide elevation beamforming information to base station. Since the elevation beamforming is not fully utilized, the performance in DL is sub-optimal and could be improved.

SUMMARY

10 [006] Some embodiments herein advantageously combine transmission of codebook-based and reciprocity-based one direction grid of beams (1D GoB) beamforming for codebook-based transmission modes. In general, in these embodiments, a base station estimates the channel from an uplink from a wireless device, or user equipment (UE) and determines the best beam in the vertical direction
15 and combines it with the Precoder Matrix Indicator (PMI) that the UE reports for the horizontal beamforming. This is referred to as Hybrid Transmission. In general, these embodiments allow the base station to perform both horizontal (through PMI) and vertical (through 1D GoB) beamforming in codebook-based transmission modes which extracts the full potential of FD-MIMO.

20 [007] In particular, embodiments herein include a method performed by a network node (360) to realize FD_MIMO in codebook-based transmissions. The method includes combining one or more horizontal codebooks and one or more vertical codebooks and generating a 2D beamformer for downlink transmissions based on the combination of the one or more horizontal codebooks and one or more vertical
25 codebooks.

[008] In some embodiments, the one or more horizontal codebooks may be based on a wireless device reported codebook, while the one or more vertical codebooks may be based on elevation beamforming at a base station side. In some of these embodiments, the elevation beamforming may be based on an 1D grid of beams (GoB) algorithm.

[009] In some embodiments, the method may also include performing a column swap of the PMI every other sub-band to adjust a throughput between two layers in rank-2 transmissions, wherein the adjustment to the throughput of the two layers may be within a predefined range, wherein the wireless device reported codebook may include at least one of a SINR estimate and a rank estimate.

[0010] In some embodiments, the method may also include adjusting at least one of the SINR estimate and rank estimate based on a calculated BF gain.

[0011] Embodiments also include corresponding apparatus and computer programs. For example, embodiments herein include a network node. The network node is configured (e.g., via one or more processing circuits) to receive, from a wireless device, one or more horizontal codebooks. These horizontal codebooks may include a Precoder Matrix Indicator (PMI). The network node is also configured to best beam in the vertical direction. This determination may be performed through a one direction grid of beams calculation. The network node is also configured to combining one or more horizontal codebooks and one or more vertical codebooks and generating a 2D beamformer for downlink transmissions based on the combination of the one or more horizontal codebooks and one or more vertical codebooks.

[0012] In some embodiments, the method may use PMI for the vertical beam forming and reciprocity based beam forming for horizontal beamforming.

25

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more complete understanding of the present embodiments, and the attendant advantages and features thereof, will be more readily understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

[0014] FIG. 1 illustrates a two-dimensional beam grid according to one embodiment of the present invention.

[0015] FIG. 2 illustrates a block diagram of a proposed method according to one embodiment of the present invention.

[0016] FIG. 3 illustrates a wireless network in accordance with some embodiments.

[0017] FIG.4 illustrates a user equipment in accordance with some embodiments.

[0018] FIG.5 illustrates a virtualization environment in accordance with some embodiments

[0019] FIG.6 illustrates a telecommunication network connected via an intermediate network to a host computer in accordance with some embodiments.

[0020] FIG.7 illustrates a host computer communicating via a base station with a user equipment over a partially wireless connection in accordance with some embodiments.

[0021] FIG.8 illustrates a method implemented in a communication system including a host computer, a base station and a user equipment in accordance with some embodiments.

[0022] FIG.9 illustrates a method implemented in a communication system including a host computer, a base station and a user equipment in accordance with some embodiments.

[0023] FIG.10 illustrates a method implemented in a communication system
5 including a host computer, a base station and a user equipment in accordance with some embodiments.

[0024] FIG.11 illustrates a method implemented in a communication system including a host computer, a base station and a user equipment in accordance with some embodiments.

10 [0025] FIG.12 illustrates a method in accordance with some embodiments.

[0026] FIG.13 illustrates a virtualization apparatus in accordance with some
embodiments

DETAILED DESCRIPTION

15 [0027] Before describing in detail exemplary embodiments, it is noted that the embodiments reside primarily in combinations of apparatus components and processing steps related to the hybrid transmission combining codebook-based and reciprocity-based beamforming. Accordingly, components have been represented where appropriate by conventional symbols in the drawings, showing only those
20 specific details that are pertinent to understanding the embodiments so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein. Like numbers refer to like elements throughout the description.

[0028] As used herein, relational terms, such as “first” and “second,” “top”
25 and “bottom,” and the like, may be used solely to distinguish one entity or element

from another entity or element without necessarily requiring or implying any physical or logical relationship or order between such entities or elements. The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the concepts described herein. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0029] In embodiments described herein, the joining term, “in communication with” and the like, may be used to indicate electrical or data communication, which may be accomplished by physical contact, induction, electromagnetic radiation, radio signaling, infrared signaling or optical signaling, for example. One having ordinary skill in the art will appreciate that multiple components may interoperate and modifications and variations are possible of achieving the electrical and data communication.

[0030] In some embodiments described herein, the term “coupled,” “connected,” and the like, may be used herein to indicate a connection, although not necessarily directly, and may include wired and/or wireless connections.

[0031] The term “network node” used herein can be any kind of network node comprised in a radio network which may further comprise any of base station (BS), radio base station, base transceiver station (BTS), base station controller (BSC), radio network controller (RNC), g Node B (gNB), evolved Node B (eNB or eNodeB), Node B, multi-standard radio (MSR) radio node such as MSR BS, multi-cell/multicast

coordination entity (MCE), relay node, donor node controlling relay, radio access point (AP), transmission points, transmission nodes, Remote Radio Unit (RRU) Remote Radio Head (RRH), a core network node (e.g., mobile management entity (MME), self-organizing network (SON) node, a coordinating node, positioning node, 5 MDT node, etc.), an external node (e.g., 3rd party node, a node external to the current network), nodes in distributed antenna system (DAS), a spectrum access system (SAS) node, an element management system (EMS), etc. The network node may also comprise test equipment. The term “radio node” used herein may be used to also denote a wireless device (WD) such as a wireless device (WD) or a radio network 10 node.

[0032] In some embodiments, the non-limiting terms wireless device (WD) or a user equipment (UE) are used interchangeably. The WD herein can be any type of wireless device capable of communicating with a network node or another WD over radio signals, such as wireless device (WD). The WD may also be a radio 15 communication device, target device, device to device (D2D) WD, machine type WD or WD capable of machine to machine communication (M2M), low-cost and/or low-complexity WD, a sensor equipped with WD, Tablet, mobile terminals, smart phone, laptop embedded equipped (LEE), laptop mounted equipment (LME), USB dongles, Customer Premises Equipment (CPE), an Internet of Things (IoT) device, or a 20 Narrowband IoT (NB-IOT) device etc.

[0033] Also, in some embodiments the generic term “radio network node” is used. It can be any kind of a radio network node which may comprise any of base station, radio base station, base transceiver station, base station controller, network controller, RNC, evolved Node B (eNB), Node B, gNB, Multi-cell/multicast

Coordination Entity (MCE), relay node, access point, radio access point, Remote Radio Unit (RRU) Remote Radio Head (RRH).

[0034] Note that although terminology from one particular wireless system, such as, for example, 3GPP LTE and/or New Radio (NR), may be used in this disclosure, this should not be seen as limiting the scope of the disclosure to only the
5 aforementioned system. Other wireless systems, including without limitation Wide Band Code Division Multiple Access (WCDMA), Worldwide Interoperability for Microwave Access (WiMax), Ultra Mobile Broadband (UMB) and Global System for Mobile Communications (GSM), may also benefit from exploiting the ideas covered
10 within this disclosure.

[0035] Note further, that functions described herein as being performed by a wireless device or a network node may be distributed over a plurality of wireless devices and/or network nodes. In other words, it is contemplated that the functions of the network node and wireless device described herein are not limited to performance
15 by a single physical device and, in fact, can be distributed among several physical devices.

[0036] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood
20 that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0037] Certain aspects of the present disclosure and their embodiments may
25 provide solutions to the above or other challenges. In general, some embodiments

may use PMI for the vertical beam forming and reciprocity based beam forming, such as reciprocity-based GoB, for horizontal beamforming.

[0038] According to some aspects of the present disclosure, mixed transmission of codebook-based and reciprocity-based 1D GoB beamforming is proposed for codebook-based transmission modes with high number of CSI-RS ports, i.e., 8, 16 or 32. In particular, base station estimates the channel from the uplink and finds the best beam in the vertical direction and combines it with the PMI that the UE reports for the horizontal beamforming. This is referred herein as “Hybrid Transmission”. In addition, beamforming gain adjustments and rank estimation is also performed based on the Hybrid approach.

[0039] Certain embodiments may provide none, one or more of the following technical advantage(s): Allowing base station to perform both horizontal (through PMI) and vertical (through 1D GoB) beamforming in codebook-based transmission modes and hence, enhancing the performance of FD-MIMO techniques. Some proposed algorithms may allow calculating BF gain, adjust UE reported SINR, potentially override rank indicator, and/or may allow alternating the columns of the PMI to aim at alleviating the imbalance throughput between layers in rank-2 transmissions. Therefore, in scenarios where the number of CSI-RS ports are medium to high, some of the disclosed embodiments may outperform codebook-based and reciprocity-based approaches.

[0040] According to some embodiments of the disclosure an efficient method to realize FD_MIMO in codebook-based transmissions is proposed. In this proposed method, the horizontal beamforming is performed using the UE reported codebook. The elevation beamforming is realized at base station side using 1D GoB algorithm to find the best elevation beamformer. Combining the horizontal and vertical codebooks, a

2D beamformer is generated to be used for downlink transmissions. In addition, to balance the throughput between the two layers in rank-2 transmissions, column swap of the PMI every other sub-band is performed. Also, appropriate adjustments to SINR and rank estimates are applied based on the calculated BF gain. Embodiments of the present invention have lower cost and higher performance compared to methods where both directions are using uplink estimations or only codebook-based beamforming is used, respectively.

[0041] Referring now also to Figures, other aspects of the disclosure and embodiments of these aspects are discussed.

10 [0042] In case where the number of CSI-ports is high e.g., 8, 16 or 32, in azimuth, a UE gives a base station its best estimate of the beamformer (PMIs are also DFT beams with high resolution in this case). So, in azimuth it is desirable to utilize this information for DL beamforming. However, this information is not available in the elevation and the UE does not provide any info about its elevation beamformer.

15 As such, the base station has to estimate the best precoder in the elevation from the uplink transmission. This is the concept behind mixing the two transmissions in what so-called “Hybrid Transmission”.

[0043] In FD-MIMO, 2D beamformer which is comprised of two beamformers, one in horizontal and one in vertical dimensions as follows:

20 [0044] $W_{2D} = W_h \otimes W_v$

[0045] In transmission modes where there is a codebook report from the UE, the reported codebook could be the horizontal precoder, i.e., $W_h = W_{PMI}$. This is specially a good choice in scenarios where the number of CSI-RS ports are high which provides high number of possible codebooks where UE can select the particular codebook that gives the best SINR.

25

[0046] For elevation beamforming, however, the UE does not report any information to the base station. As such, the base station utilizes the uplink pilot signals such as SRS or DMRS to estimate the channel in the uplink. In 1D GoB approach, the base station has a set of predefined beams (codebooks) as follows:

$$5 \quad [0047] \quad W(\mathbf{k}) = \frac{1}{\sqrt{N}} \begin{bmatrix} e^{j2\pi \cdot 0 \cdot \frac{k}{QN}} \\ e^{j2\pi \cdot 1 \cdot \frac{k}{QN}} \\ \vdots \\ e^{j2\pi \cdot (N-1) \cdot \frac{k}{QN}} \end{bmatrix}$$

[0048] Where $k = 0, 1, \dots, QN - 1$ is the precoder index, N is the number of antennas and Q is an integer oversampling factor. The procedure to find the best beam is that base station will go through the set and picks the one that provides the highest power, i.e.,

$$10 \quad [0049] \quad W_v = \arg \max_k w^H(k) R_v W(k)$$

[0050] where R_v is the vertical covariance of the uplink channel, estimated at the base station and $(\cdot)^H$ indicates the Hermitian. The two-dimensional beam grid of the Hybrid approach is shown in FIG. 1 where in azimuth direction, the PMI dictates the best beam and its vertical GoB algorithm finds the best beam. In Figures 1, n is the number of DFT beams in the codebook and m is the number of DFT beams in 1D GoB.

[0051] FIG. 2 shows the block diagram of a proposed method according to one embodiment of the disclosure.

[0052] Once the DL beamforming precoder is created, reported SINR and reported rank from the UE need to be adjusted. The reason for these adjustments is that the UE reports the SINR and rank based on the DL reference signals and PMIs. Since PMIs only carry horizontal beamforming, the UE is not aware of the potential elevation beamforming and as such, what the UE reports can be an underestimate of

what the UE can receive if the base station uses 2D precoder. In order to correct these estimates, at the base station, BF gain is calculated as follows and it will be added to the reported SINR:

[0053]
$$BF\ gain = \frac{W_{2D}^H R W_{2D}}{W_{UE-estimate}^H R W_{UE-estimate}}$$

5 [0054] Where R is the uplink channel covariance and $W_{UE-estimate} = W_{PMI} \otimes W_{v-CSIRS}$ is the precoder that UE suggested to use in DL which consists of W_{PMI} in azimuth and vertical component of the precoder used to send CSI-RS signal, $W_{v-CSIRS}$.

[0055] Given the updated SINR, the reported rank from the UE might get
 10 increased and, in this case, new PMI needs to be used. The reported PMI could assist in selecting the new PMI in the sense that it reveals the direction and co-phasing information for a smaller number of layers. For instance, if the reported rank from the UE is equal to one, and after performing the Hybrid approach, the rank increased to two, the new PMI can be constructed as follows:

15 [0056] 1-layer reported: $\begin{bmatrix} v_m \\ \varphi_n v_m \end{bmatrix} \Rightarrow$ 2-layer constructed: $\begin{bmatrix} v_m & v_m \\ \varphi_n v_m & -\varphi_n v_m \end{bmatrix}$

[0057] Looking closely to the structure of the PMIs, defined in the standard reveals that in rank-2 codebooks, there are two distinct directions m, m' , and a co-phasing factor, φ_n . To account for the in-balance throughput between two layers, the same approach as the one used in GoB is taken, i.e., CDD. However, since PMI
 20 already contained the co-phasing info, a modified version of CDD will be applied. In particular, in rank-2 DL transmissions, every other sub-band, the columns of the PMI will be swapped as follows:

[0058]
$$W_h = \begin{cases} \begin{bmatrix} v_m & v_{m'} \\ \varphi_n v_m & -\varphi_n v_{m'} \end{bmatrix} & \text{odd sub - bands} \\ \begin{bmatrix} v_{m'} & v_m \\ -\varphi_n v_{m'} & \varphi_n v_m \end{bmatrix} & \text{even sub - bands} \end{cases}$$

[0059] Although the subject matter described herein may be implemented in any appropriate type of system using any suitable components, the embodiments disclosed herein are described in relation to a wireless network, such as the example wireless network illustrated in Figure 3. For simplicity, the wireless network of Figure 3 only depicts network 306, network nodes 360 and 360b, and WDs 310, 310b, and 310c. In practice, a wireless network may further include any additional elements suitable to support communication between wireless devices or between a wireless device and another communication device, such as a landline telephone, a service provider, or any other network node or end device. Of the illustrated components, network node 360 and wireless device (WD) 310 are depicted with additional detail. The wireless network may provide communication and other types of services to one or more wireless devices to facilitate the wireless devices' access to and/or use of the services provided by, or via, the wireless network.

[0060] The wireless network may comprise and/or interface with any type of communication, telecommunication, data, cellular, and/or radio network or other similar type of system. In some embodiments, the wireless network may be configured to operate according to specific standards or other types of predefined rules or procedures. Thus, particular embodiments of the wireless network may implement communication standards, such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), and/or other suitable 2G, 3G, 4G, or 5G standards; wireless local area network (WLAN) standards, such as the IEEE 802.11 standards; and/or any other appropriate wireless communication standard, such as the Worldwide Interoperability for Microwave Access (WiMax), Bluetooth, Z-Wave and/or ZigBee standards.

[0061] Network 306 may comprise one or more backhaul networks, core networks, IP networks, public switched telephone networks (PSTNs), packet data networks, optical networks, wide-area networks (WANs), local area networks (LANs), wireless local area networks (WLANs), wired networks, wireless networks, metropolitan area networks, and other networks to enable communication between devices.

[0062] Network node 360 and WD 310 comprise various components described in more detail below. These components work together in order to provide network node and/or wireless device functionality, such as providing wireless connections in a wireless network. In different embodiments, the wireless network may comprise any number of wired or wireless networks, network nodes, base stations, controllers, wireless devices, relay stations, and/or any other components or systems that may facilitate or participate in the communication of data and/or signals whether via wired or wireless connections.

[0063] As used herein, network node refers to equipment capable, configured, arranged and/or operable to communicate directly or indirectly with a wireless device and/or with other network nodes or equipment in the wireless network to enable and/or provide wireless access to the wireless device and/or to perform other functions (e.g., administration) in the wireless network. Examples of network nodes include, but are not limited to, access points (APs) (e.g., radio access points), base stations (BSs) (e.g., radio base stations, Node Bs, evolved Node Bs (eNBs) and NR NodeBs (gNBs)). Base stations may be categorized based on the amount of coverage they provide (or, stated differently, their transmit power level) and may then also be referred to as femto base stations, pico base stations, micro base stations, or macro base stations. A base station may be a relay node or a relay donor node controlling a

relay. A network node may also include one or more (or all) parts of a distributed radio base station such as centralized digital units and/or remote radio units (RRUs), sometimes referred to as Remote Radio Heads (RRHs). Such remote radio units may or may not be integrated with an antenna as an antenna integrated radio. Parts of a distributed radio base station may also be referred to as nodes in a distributed antenna system (DAS). Yet further examples of network nodes include multi-standard radio (MSR) equipment such as MSR BSs, network controllers such as radio network controllers (RNCs) or base station controllers (BSCs), base transceiver stations (BTSs), transmission points, transmission nodes, multi-cell/multicast coordination entities (MCEs), core network nodes (e.g., MSCs, MMEs), O&M nodes, OSS nodes, SON nodes, positioning nodes (e.g., E-SMLCs), and/or MDTs. As another example, a network node may be a virtual network node as described in more detail below. More generally, however, network nodes may represent any suitable device (or group of devices) capable, configured, arranged, and/or operable to enable and/or provide a wireless device with access to the wireless network or to provide some service to a wireless device that has accessed the wireless network.

[0064] In Figure 3, network node 360 includes processing circuitry 370, device readable medium 380, interface 390, auxiliary equipment 384, power source 386, power circuitry 387, and antenna 362. Although network node 360 illustrated in the example wireless network of Figure 3 may represent a device that includes the illustrated combination of hardware components, other embodiments may comprise network nodes with different combinations of components. It is to be understood that a network node comprises any suitable combination of hardware and/or software needed to perform the tasks, features, functions and methods disclosed herein. Moreover, while the components of network node 360 are depicted as single boxes

located within a larger box, or nested within multiple boxes, in practice, a network node may comprise multiple different physical components that make up a single illustrated component (e.g., device readable medium 380 may comprise multiple separate hard drives as well as multiple RAM modules).

5 [0065] Similarly, network node 360 may be composed of multiple physically separate components (e.g., a NodeB component and a RNC component, or a BTS component and a BSC component, etc.), which may each have their own respective components. In certain scenarios in which network node 360 comprises multiple separate components (e.g., BTS and BSC components), one or more of the separate
10 components may be shared among several network nodes. For example, a single RNC may control multiple NodeB's. In such a scenario, each unique NodeB and RNC pair, may in some instances be considered a single separate network node. In some embodiments, network node 360 may be configured to support multiple radio access technologies (RATs). In such embodiments, some components may be
15 duplicated (e.g., separate device readable medium 380 for the different RATs) and some components may be reused (e.g., the same antenna 362 may be shared by the RATs). Network node 360 may also include multiple sets of the various illustrated components for different wireless technologies integrated into network node 360, such as, for example, GSM, WCDMA, LTE, NR, WiFi, or Bluetooth wireless
20 technologies. These wireless technologies may be integrated into the same or different chip or set of chips and other components within network node 360.

[0066] Processing circuitry 370 is configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being provided by a network node. These operations performed by processing
25 circuitry 370 may include processing information obtained by processing circuitry

370 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored in the network node, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a
5 determination.

[0067] Processing circuitry 370 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software
10 and/or encoded logic operable to provide, either alone or in conjunction with other network node 360 components, such as device readable medium 380, network node 360 functionality. For example, processing circuitry 370 may execute instructions stored in device readable medium 380 or in memory within processing circuitry 370. Such functionality may include providing any of the various wireless features,
15 functions, or benefits discussed herein. In some embodiments, processing circuitry 370 may include a system on a chip (SOC).

[0068] In some embodiments, processing circuitry 370 may include one or more of radio frequency (RF) transceiver circuitry 372 and baseband processing circuitry 374. In some embodiments, radio frequency (RF) transceiver circuitry 372
20 and baseband processing circuitry 374 may be on separate chips (or sets of chips), boards, or units, such as radio units and digital units. In alternative embodiments, part or all of RF transceiver circuitry 372 and baseband processing circuitry 374 may be on the same chip or set of chips, boards, or units.

[0069] In certain embodiments, some or all of the functionality described
25 herein as being provided by a network node, base station, eNB or other such network

device may be performed by processing circuitry 370 executing instructions stored on device readable medium 380 or memory within processing circuitry 370. In alternative embodiments, some or all of the functionality may be provided by processing circuitry 370 without executing instructions stored on a separate or
5 discrete device readable medium, such as in a hard-wired manner. In any of those embodiments, whether executing instructions stored on a device readable storage medium or not, processing circuitry 370 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 370 alone or to other components of network node 360, but are
10 enjoyed by network node 360 as a whole, and/or by end users and the wireless network generally.

[0070] Device readable medium 380 may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid-state memory, remotely mounted memory, magnetic media, optical
15 media, random access memory (RAM), read-only memory (ROM), mass storage media (for example, a hard disk), removable storage media (for example, a flash drive, a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer-executable memory devices that store information, data, and/or instructions that may be used by
20 processing circuitry 370. Device readable medium 380 may store any suitable instructions, data or information, including a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions capable of being executed by processing circuitry 370 and, utilized by network node 360. Device readable medium 380 may be used to store any
25 calculations made by processing circuitry 370 and/or any data received via interface

390. In some embodiments, processing circuitry 370 and device readable medium 380 may be considered to be integrated.

[0071] Interface 390 is used in the wired or wireless communication of signalling and/or data between network node 360, network 306, and/or WDs 310. As illustrated, interface 390 comprises port(s)/terminal(s) 394 to send and receive data, for example to and from network 306 over a wired connection. Interface 390 also includes radio front end circuitry 392 that may be coupled to, or in certain embodiments a part of, antenna 362. Radio front end circuitry 392 comprises filters 398 and amplifiers 396. Radio front end circuitry 392 may be connected to antenna 362 and processing circuitry 370. Radio front end circuitry may be configured to condition signals communicated between antenna 362 and processing circuitry 370. Radio front end circuitry 392 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 392 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 398 and/or amplifiers 396. The radio signal may then be transmitted via antenna 362. Similarly, when receiving data, antenna 362 may collect radio signals which are then converted into digital data by radio front end circuitry 392. The digital data may be passed to processing circuitry 370. In other embodiments, the interface may comprise different components and/or different combinations of components.

[0072] In certain alternative embodiments, network node 360 may not include separate radio front end circuitry 392, instead, processing circuitry 370 may comprise radio front end circuitry and may be connected to antenna 362 without separate radio front end circuitry 392. Similarly, in some embodiments, all or some of RF transceiver circuitry 372 may be considered a part of interface 390. In still other

embodiments, interface 190 may include one or more ports or terminals 194, radio front end circuitry 192, and RF transceiver circuitry 372, as part of a radio unit (not shown), and interface 190 may communicate with baseband processing circuitry 374, which is part of a digital unit (not shown).

5 **[0073]** Antenna 362 may include one or more antennas, or antenna arrays, configured to send and/or receive wireless signals. Antenna 362 may be coupled to radio front end circuitry 190 and may be any type of antenna capable of transmitting and receiving data and/or signals wirelessly. In some embodiments, antenna 362 may comprise one or more omni-directional, sector or panel antennas operable to
10 transmit/receive radio signals between, for example, 2 GHz and 66 GHz. An omni-directional antenna may be used to transmit/receive radio signals in any direction, a sector antenna may be used to transmit/receive radio signals from devices within a particular area, and a panel antenna may be a line of sight antenna used to transmit/receive radio signals in a relatively straight line. In some instances, the use
15 of more than one antenna may be referred to as MIMO. In certain embodiments, antenna 362 may be separate from network node 360 and may be connectable to network node 360 through an interface or port.

[0074] Antenna 362, interface 390, and/or processing circuitry 370 may be configured to perform any receiving operations and/or certain obtaining operations
20 described herein as being performed by a network node. Any information, data and/or signals may be received from a wireless device, another network node and/or any other network equipment. Similarly, antenna 362, interface 390, and/or processing circuitry 370 may be configured to perform any transmitting operations described herein as being performed by a network node. Any information, data

and/or signals may be transmitted to a wireless device, another network node and/or any other network equipment.

[0075] Power circuitry 387 may comprise, or be coupled to, power management circuitry and is configured to supply the components of network node 360 with power for performing the functionality described herein. Power circuitry 387 may receive power from power source 386. Power source 386 and/or power circuitry 387 may be configured to provide power to the various components of network node 360 in a form suitable for the respective components (e.g., at a voltage and current level needed for each respective component). Power source 386 may either be included in, or external to, power circuitry 387 and/or network node 360. For example, network node 360 may be connectable to an external power source (e.g., an electricity outlet) via an input circuitry or interface such as an electrical cable, whereby the external power source supplies power to power circuitry 387. As a further example, power source 386 may comprise a source of power in the form of a battery or battery pack which is connected to, or integrated in, power circuitry 387. The battery may provide backup power should the external power source fail. Other types of power sources, such as photovoltaic devices, may also be used.

[0076] Alternative embodiments of network node 360 may include additional components beyond those shown in Figure 3 that may be responsible for providing certain aspects of the network node's functionality, including any of the functionality described herein and/or any functionality necessary to support the subject matter described herein. For example, network node 360 may include user interface equipment to allow input of information into network node 360 and to allow output of information from network node 360. This may allow a user to perform diagnostic, maintenance, repair, and other administrative functions for network node 360.

[0077] As used herein, wireless device (WD) refers to a device capable, configured, arranged and/or operable to communicate wirelessly with network nodes and/or other wireless devices. Unless otherwise noted, the term WD may be used interchangeably herein with user equipment (UE). Communicating wirelessly may
5 involve transmitting and/or receiving wireless signals using electromagnetic waves, radio waves, infrared waves, and/or other types of signals suitable for conveying information through air. In some embodiments, a WD may be configured to transmit and/or receive information without direct human interaction. For instance, a WD may be designed to transmit information to a network on a predetermined schedule, when
10 triggered by an internal or external event, or in response to requests from the network. Examples of a WD include, but are not limited to, a smart phone, a mobile phone, a cell phone, a voice over IP (VoIP) phone, a wireless local loop phone, a desktop computer, a personal digital assistant (PDA), a wireless cameras, a gaming console or device, a music storage device, a playback appliance, a wearable terminal device, a
15 wireless endpoint, a mobile station, a tablet, a laptop, a laptop-embedded equipment (LEE), a laptop-mounted equipment (LME), a smart device, a wireless customer-premise equipment (CPE), a vehicle-mounted wireless terminal device, etc.. A WD may support device-to-device (D2D) communication, for example by implementing a 3GPP standard for sidelink communication, vehicle-to-vehicle (V2V), vehicle-to-
20 infrastructure (V2I), vehicle-to-everything (V2X) and may in this case be referred to as a D2D communication device. As yet another specific example, in an Internet of Things (IoT) scenario, a WD may represent a machine or other device that performs monitoring and/or measurements, and transmits the results of such monitoring and/or measurements to another WD and/or a network node. The WD may in this case be a
25 machine-to-machine (M2M) device, which may in a 3GPP context be referred to as an

MTC device. As one particular example, the WD may be a UE implementing the 3GPP narrow band internet of things (NB-IoT) standard. Particular examples of such machines or devices are sensors, metering devices such as power meters, industrial machinery, or home or personal appliances (e.g. refrigerators, televisions, etc.)

5 personal wearables (e.g., watches, fitness trackers, etc.). In other scenarios, a WD may represent a vehicle or other equipment that is capable of monitoring and/or reporting on its operational status or other functions associated with its operation. A WD as described above may represent the endpoint of a wireless connection, in which case the device may be referred to as a wireless terminal. Furthermore, a WD as

10 described above may be mobile, in which case it may also be referred to as a mobile device or a mobile terminal.

[0078] As illustrated, wireless device 310 includes antenna 311, interface 314, processing circuitry 320, device readable medium 330, user interface equipment 332, auxiliary equipment 334, power source 336 and power circuitry 337. WD 310 may

15 include multiple sets of one or more of the illustrated components for different wireless technologies supported by WD 310, such as, for example, GSM, WCDMA, LTE, NR, WiFi, WiMAX, or Bluetooth wireless technologies, just to mention a few. These wireless technologies may be integrated into the same or different chips or set of chips as other components within WD 310.

20 **[0079]** Antenna 311 may include one or more antennas or antenna arrays, configured to send and/or receive wireless signals, and is connected to interface 314. In certain alternative embodiments, antenna 311 may be separate from WD 310 and be connectable to WD 310 through an interface or port. Antenna 311, interface 314, and/or processing circuitry 320 may be configured to perform any receiving or

25 transmitting operations described herein as being performed by a WD. Any

information, data and/or signals may be received from a network node and/or another WD. In some embodiments, radio front end circuitry and/or antenna 311 may be considered an interface.

[0080] As illustrated, interface 314 comprises radio front end circuitry 312 and antenna 311. Radio front end circuitry 312 comprise one or more filters 318 and amplifiers 316. Radio front end circuitry 314 is connected to antenna 311 and processing circuitry 320, and is configured to condition signals communicated between antenna 311 and processing circuitry 320. Radio front end circuitry 312 may be coupled to or a part of antenna 311. In some embodiments, WD 310 may not include separate radio front end circuitry 312; rather, processing circuitry 320 may comprise radio front end circuitry and may be connected to antenna 311. Similarly, in some embodiments, some or all of RF transceiver circuitry 322 may be considered a part of interface 314. Radio front end circuitry 312 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 312 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 318 and/or amplifiers 316. The radio signal may then be transmitted via antenna 311. Similarly, when receiving data, antenna 311 may collect radio signals which are then converted into digital data by radio front end circuitry 312. The digital data may be passed to processing circuitry 320. In other embodiments, the interface may comprise different components and/or different combinations of components.

[0081] Processing circuitry 320 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software,

and/or encoded logic operable to provide, either alone or in conjunction with other WD 310 components, such as device readable medium 330, WD 310 functionality. Such functionality may include providing any of the various wireless features or benefits discussed herein. For example, processing circuitry 320 may execute

5 instructions stored in device readable medium 330 or in memory within processing circuitry 320 to provide the functionality disclosed herein.

[0082] As illustrated, processing circuitry 320 includes one or more of RF transceiver circuitry 322, baseband processing circuitry 324, and application processing circuitry 326. In other embodiments, the processing circuitry may

10 comprise different components and/or different combinations of components. In certain embodiments processing circuitry 320 of WD 310 may comprise a SOC. In some embodiments, RF transceiver circuitry 322, baseband processing circuitry 324, and application processing circuitry 326 may be on separate chips or sets of chips. In alternative embodiments, part or all of baseband processing circuitry 324 and

15 application processing circuitry 326 may be combined into one chip or set of chips, and RF transceiver circuitry 322 may be on a separate chip or set of chips. In still alternative embodiments, part or all of RF transceiver circuitry 322 and baseband processing circuitry 324 may be on the same chip or set of chips, and application processing circuitry 326 may be on a separate chip or set of chips. In yet other

20 alternative embodiments, part or all of RF transceiver circuitry 322, baseband processing circuitry 324, and application processing circuitry 326 may be combined in the same chip or set of chips. In some embodiments, RF transceiver circuitry 322 may be a part of interface 314. RF transceiver circuitry 322 may condition RF signals for processing circuitry 320.

[0083] In certain embodiments, some or all of the functionality described herein as being performed by a WD may be provided by processing circuitry 320 executing instructions stored on device readable medium 330, which in certain embodiments may be a computer-readable storage medium. In alternative
5 embodiments, some or all of the functionality may be provided by processing circuitry 320 without executing instructions stored on a separate or discrete device readable storage medium, such as in a hard-wired manner. In any of those particular embodiments, whether executing instructions stored on a device readable storage
10 medium or not, processing circuitry 320 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 320 alone or to other components of WD 310, but are enjoyed by WD 310 as a whole, and/or by end users and the wireless network generally.

[0084] Processing circuitry 320 may be configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations)
15 described herein as being performed by a WD. These operations, as performed by processing circuitry 320, may include processing information obtained by processing circuitry 320 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to
20 information stored by WD 310, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

[0085] Device readable medium 330 may be operable to store a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions capable of being executed by processing circuitry 320.
25 Device readable medium 330 may include computer memory (e.g., Random Access

Memory (RAM) or Read Only Memory (ROM)), mass storage media (e.g., a hard disk), removable storage media (e.g., a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer executable memory devices that store information, data, and/or instructions that may be used by processing circuitry 320. In some embodiments, processing circuitry 320 and device readable medium 330 may be considered to be integrated.

[0086] User interface equipment 332 may provide components that allow for a human user to interact with WD 310. Such interaction may be of many forms, such as visual, audial, tactile, etc. User interface equipment 332 may be operable to produce output to the user and to allow the user to provide input to WD 310. The type of interaction may vary depending on the type of user interface equipment 332 installed in WD 310. For example, if WD 310 is a smart phone, the interaction may be via a touch screen; if WD 310 is a smart meter, the interaction may be through a screen that provides usage (e.g., the number of gallons used) or a speaker that provides an audible alert (e.g., if smoke is detected). User interface equipment 332 may include input interfaces, devices and circuits, and output interfaces, devices and circuits. User interface equipment 332 is configured to allow input of information into WD 310, and is connected to processing circuitry 320 to allow processing circuitry 320 to process the input information. User interface equipment 332 may include, for example, a microphone, a proximity or other sensor, keys/buttons, a touch display, one or more cameras, a USB port, or other input circuitry. User interface equipment 332 is also configured to allow output of information from WD 310, and to allow processing circuitry 320 to output information from WD 310. User interface equipment 332 may include, for example, a speaker, a display, vibrating circuitry, a USB port, a

headphone interface, or other output circuitry. Using one or more input and output interfaces, devices, and circuits, of user interface equipment 332, WD 310 may communicate with end users and/or the wireless network, and allow them to benefit from the functionality described herein.

5 [0087] Auxiliary equipment 334 is operable to provide more specific functionality which may not be generally performed by WDs. This may comprise specialized sensors for doing measurements for various purposes, interfaces for additional types of communication such as wired communications etc. The inclusion and type of components of auxiliary equipment 334 may vary depending on the
10 embodiment and/or scenario.

[0088] Power source 336 may, in some embodiments, be in the form of a battery or battery pack. Other types of power sources, such as an external power source (e.g., an electricity outlet), photovoltaic devices or power cells, may also be used. WD 310 may further comprise power circuitry 337 for delivering power from
15 power source 336 to the various parts of WD 310 which need power from power source 336 to carry out any functionality described or indicated herein. Power circuitry 337 may in certain embodiments comprise power management circuitry. Power circuitry 337 may additionally or alternatively be operable to receive power from an external power source; in which case WD 310 may be connectable to the
20 external power source (such as an electricity outlet) via input circuitry or an interface such as an electrical power cable. Power circuitry 337 may also in certain embodiments be operable to deliver power from an external power source to power source 336. This may be, for example, for the charging of power source 336. Power circuitry 337 may perform any formatting, converting, or other modification to the

power from power source 336 to make the power suitable for the respective components of WD 310 to which power is supplied.

[0089] Figure 4 illustrates one embodiment of a UE in accordance with various aspects described herein. As used herein, a user equipment or UE may not necessarily have a user in the sense of a human user who owns and/or operates the relevant device. Instead, a UE may represent a device that is intended for sale to, or operation by, a human user but which may not, or which may not initially, be associated with a specific human user (e.g., a smart sprinkler controller). Alternatively, a UE may represent a device that is not intended for sale to, or operation by, an end user but which may be associated with or operated for the benefit of a user (e.g., a smart power meter). UE 400 may be any UE identified by the 3rd Generation Partnership Project (3GPP), including a NB-IoT UE, a machine type communication (MTC) UE, and/or an enhanced MTC (eMTC) UE. UE 400, as illustrated in Figure 4, is one example of a WD configured for communication in accordance with one or more communication standards promulgated by the 3rd Generation Partnership Project (3GPP), such as 3GPP's GSM, UMTS, LTE, and/or 5G standards. As mentioned previously, the term WD and UE may be used interchangeably. Accordingly, although Figure 4 is a UE, the components discussed herein are equally applicable to a WD, and vice-versa.

[0090] In Figure 4, UE 400 includes processing circuitry 401 that is operatively coupled to input/output interface 405, radio frequency (RF) interface 409, network connection interface 411, memory 415 including random access memory (RAM) 417, read-only memory (ROM) 419, and storage medium 421 or the like, communication subsystem 431, power source 233, and/or any other component, or any combination thereof. Storage medium 421 includes operating system 423,

application program 425, and data 427. In other embodiments, storage medium 421 may include other similar types of information. Certain UEs may utilize all of the components shown in Figure 4, or only a subset of the components. The level of integration between the components may vary from one UE to another UE. Further, 5 certain UEs may contain multiple instances of a component, such as multiple processors, memories, transceivers, transmitters, receivers, etc.

[0091] In Figure 4, processing circuitry 401 may be configured to process computer instructions and data. Processing circuitry 401 may be configured to implement any sequential state machine operative to execute machine instructions 10 stored as machine-readable computer programs in the memory, such as one or more hardware-implemented state machines (e.g., in discrete logic, FPGA, ASIC, etc.); programmable logic together with appropriate firmware; one or more stored program, general-purpose processors, such as a microprocessor or Digital Signal Processor (DSP), together with appropriate software; or any combination of the above. For 15 example, the processing circuitry 401 may include two central processing units (CPUs). Data may be information in a form suitable for use by a computer.

[0092] In the depicted embodiment, input/output interface 405 may be configured to provide a communication interface to an input device, output device, or input and output device. UE 400 may be configured to use an output device via 20 input/output interface 405. An output device may use the same type of interface port as an input device. For example, a USB port may be used to provide input to and output from UE 400. The output device may be a speaker, a sound card, a video card, a display, a monitor, a printer, an actuator, an emitter, a smartcard, another output device, or any combination thereof. UE 400 may be configured to use an input device 25 via input/output interface 405 to allow a user to capture information into UE 400. The

input device may include a touch-sensitive or presence-sensitive display, a camera (e.g., a digital camera, a digital video camera, a web camera, etc.), a microphone, a sensor, a mouse, a trackball, a directional pad, a trackpad, a scroll wheel, a smartcard, and the like. The presence-sensitive display may include a capacitive or resistive touch sensor to sense input from a user. A sensor may be, for instance, an accelerometer, a gyroscope, a tilt sensor, a force sensor, a magnetometer, an optical sensor, a proximity sensor, another like sensor, or any combination thereof. For example, the input device may be an accelerometer, a magnetometer, a digital camera, a microphone, and an optical sensor.

10 **[0093]** In Figure 4, RF interface 409 may be configured to provide a communication interface to RF components such as a transmitter, a receiver, and an antenna. Network connection interface 411 may be configured to provide a communication interface to network 443a. Network 443a may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network
15 (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 443a may comprise a Wi-Fi network. Network connection interface 411 may be configured to include a receiver and a transmitter interface used to communicate with one or more other devices over a communication network according to one or more
20 communication protocols, such as Ethernet, TCP/IP, SONET, ATM, or the like. Network connection interface 411 may implement receiver and transmitter functionality appropriate to the communication network links (e.g., optical, electrical, and the like). The transmitter and receiver functions may share circuit components, software or firmware, or alternatively may be implemented separately.

[0094] RAM 417 may be configured to interface via bus 402 to processing circuitry 401 to provide storage or caching of data or computer instructions during the execution of software programs such as the operating system, application programs, and device drivers. ROM 419 may be configured to provide computer instructions or data to processing circuitry 401. For example, ROM 419 may be configured to store invariant low-level system code or data for basic system functions such as basic input and output (I/O), startup, or reception of keystrokes from a keyboard that are stored in a non-volatile memory. Storage medium 421 may be configured to include memory such as RAM, ROM, programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, or flash drives. In one example, storage medium 421 may be configured to include operating system 423, application program 425 such as a web browser application, a widget or gadget engine or another application, and data file 227. Storage medium 421 may store, for use by UE 400, any of a variety of various operating systems or combinations of operating systems.

[0095] Storage medium 421 may be configured to include a number of physical drive units, such as redundant array of independent disks (RAID), floppy disk drive, flash memory, USB flash drive, external hard disk drive, thumb drive, pen drive, key drive, high-density digital versatile disc (HD-DVD) optical disc drive, internal hard disk drive, Blu-Ray optical disc drive, holographic digital data storage (HDDS) optical disc drive, external mini-dual in-line memory module (DIMM), synchronous dynamic random access memory (SDRAM), external micro-DIMM SDRAM, smartcard memory such as a subscriber identity module or a removable user identity (SIM/RUIM) module, other memory, or any combination thereof. Storage

medium 421 may allow UE 400 to access computer-executable instructions, application programs or the like, stored on transitory or non-transitory memory media, to off-load data, or to upload data. An article of manufacture, such as one utilizing a communication system may be tangibly embodied in storage medium 421, which may
5 comprise a device readable medium.

[0096] In Figure 4, processing circuitry 401 may be configured to communicate with network 443b using communication subsystem 431. Network 443a and network 443b may be the same network or networks or different network or networks. Communication subsystem 431 may be configured to include one or more
10 transceivers used to communicate with network 443b. For example, communication subsystem 431 may be configured to include one or more transceivers used to communicate with one or more remote transceivers of another device capable of wireless communication such as another WD, UE, or base station of a radio access network (RAN) according to one or more communication protocols, such as IEEE
15 802, CDMA, WCDMA, GSM, LTE, UTRAN, WiMax, or the like. Each transceiver may include transmitter 433 and/or receiver 435 to implement transmitter or receiver functionality, respectively, appropriate to the RAN links (e.g., frequency allocations and the like). Further, transmitter 433 and receiver 435 of each transceiver may share circuit components, software or firmware, or alternatively may be implemented
20 separately.

[0097] In the illustrated embodiment, the communication functions of communication subsystem 431 may include data communication, voice communication, multimedia communication, short-range communications such as Bluetooth, near-field communication, location-based communication such as the use
25 of the global positioning system (GPS) to determine a location, another like

communication function, or any combination thereof. For example, communication subsystem 431 may include cellular communication, Wi-Fi communication, Bluetooth communication, and GPS communication. Network 243b may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 443b may be a cellular network, a Wi-Fi network, and/or a near-field network. Power source 413 may be configured to provide alternating current (AC) or direct current (DC) power to components of UE 400.

10 **[0098]** The features, benefits and/or functions described herein may be implemented in one of the components of UE 400 or partitioned across multiple components of UE 400. Further, the features, benefits, and/or functions described herein may be implemented in any combination of hardware, software or firmware. In one example, communication subsystem 431 may be configured to include any of
15 the components described herein. Further, processing circuitry 401 may be configured to communicate with any of such components over bus 402. In another example, any of such components may be represented by program instructions stored in memory that when executed by processing circuitry 401 perform the corresponding functions described herein. In another example, the functionality of any of such
20 components may be partitioned between processing circuitry 401 and communication subsystem 431. In another example, the non-computationally intensive functions of any of such components may be implemented in software or firmware and the computationally intensive functions may be implemented in hardware.

[0099] Figure 5 is a schematic block diagram illustrating a virtualization
25 environment 500 in which functions implemented by some embodiments may be

virtualized. In the present context, virtualizing means creating virtual versions of apparatuses or devices which may include virtualizing hardware platforms, storage devices and networking resources. As used herein, virtualization can be applied to a node (e.g., a virtualized base station or a virtualized radio access node) or to a device
5 (e.g., a UE, a wireless device or any other type of communication device) or components thereof and relates to an implementation in which at least a portion of the functionality is implemented as one or more virtual components (e.g., via one or more applications, components, functions, virtual machines or containers executing on one or more physical processing nodes in one or more networks).

10 **[00100]** In some embodiments, some or all of the functions described herein may be implemented as virtual components executed by one or more virtual machines implemented in one or more virtual environments 500 hosted by one or more of hardware nodes 530. Further, in embodiments in which the virtual node is not a radio access node or does not require radio connectivity (e.g., a core network node), then
15 the network node may be entirely virtualized.

[00101] The functions may be implemented by one or more applications 520 (which may alternatively be called software instances, virtual appliances, network functions, virtual nodes, virtual network functions, etc.) operative to implement some of the features, functions, and/or benefits of some of the embodiments disclosed
20 herein. Applications 520 are run in virtualization environment 500 which provides hardware 530 comprising processing circuitry 560 and memory 590. Memory 590 contains instructions 595 executable by processing circuitry 560 whereby application 520 is operative to provide one or more of the features, benefits, and/or functions disclosed herein.

[00102] Virtualization environment 500, comprises general-purpose or special-purpose network hardware devices 530 comprising a set of one or more processors or processing circuitry 560, which may be commercial off-the-shelf (COTS) processors, dedicated Application Specific Integrated Circuits (ASICs), or any other type of processing circuitry including digital or analog hardware components or special purpose processors. Each hardware device may comprise memory 590-1 which may be non-persistent memory for temporarily storing instructions 595 or software executed by processing circuitry 560. Each hardware device may comprise one or more network interface controllers (NICs) 570, also known as network interface cards, which include physical network interface 580. Each hardware device may also include non-transitory, persistent, machine-readable storage media 590-2 having stored therein software 595 and/or instructions executable by processing circuitry 560. Software 595 may include any type of software including software for instantiating one or more virtualization layers 550 (also referred to as hypervisors), software to execute virtual machines 540 as well as software allowing it to execute functions, features and/or benefits described in relation with some embodiments described herein.

[00103] Virtual machines 540, comprise virtual processing, virtual memory, virtual networking or interface and virtual storage, and may be run by a corresponding virtualization layer 550 or hypervisor. Different embodiments of the instance of virtual appliance 520 may be implemented on one or more of virtual machines 540, and the implementations may be made in different ways.

[00104] During operation, processing circuitry 560 executes software 595 to instantiate the hypervisor or virtualization layer 550, which may sometimes be referred to as a virtual machine monitor (VMM). Virtualization layer 550 may

present a virtual operating platform that appears like networking hardware to virtual machine 540.

[00105] As shown in Figure 5, hardware 530 may be a standalone network node with generic or specific components. Hardware 530 may comprise antenna 525 and may implement some functions via virtualization. Alternatively, hardware 530 may be part of a larger cluster of hardware (e.g. such as in a data center or customer premise equipment (CPE)) where many hardware nodes work together and are managed via management and orchestration (MANO) 5100, which, among others, oversees lifecycle management of applications 520.

10 **[00106]** Virtualization of the hardware is in some contexts referred to as network function virtualization (NFV). NFV may be used to consolidate many network equipment types onto industry standard high volume server hardware, physical switches, and physical storage, which can be located in data centers, and customer premise equipment.

15 **[00107]** In the context of NFV, virtual machine 540 may be a software implementation of a physical machine that runs programs as if they were executing on a physical, non-virtualized machine. Each of virtual machines 540, and that part of hardware 530 that executes that virtual machine, be it hardware dedicated to that virtual machine and/or hardware shared by that virtual machine with others of the virtual machines 540, forms a separate virtual network elements (VNE).

20 **[00108]** Still in the context of NFV, Virtual Network Function (VNF) is responsible for handling specific network functions that run in one or more virtual machines 540 on top of hardware networking infrastructure 530 and corresponds to application 520 in Figure 5.

[00109] In some embodiments, one or more radio units 5200 that each include one or more transmitters 5220 and one or more receivers 5210 may be coupled to one or more antennas 5225. Radio units 5200 may communicate directly with hardware nodes 530 via one or more appropriate network interfaces and may be used in
5 combination with the virtual components to provide a virtual node with radio capabilities, such as a radio access node or a base station.

[00110] In some embodiments, some signalling can be effected with the use of control system 5230 which may alternatively be used for communication between the hardware nodes 530 and radio units 5200.

10 **[00111]** With reference to FIGURE 6, a communication system in accordance with an embodiment is shown. The illustrated communication system includes telecommunication network 610, such as a 3GPP-type cellular network, which comprises access network 611, such as a radio access network, and core network 614. Access network 611 comprises a plurality of base stations 612a, 612b, 612c, such as
15 NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area 613a, 613b, 613c. Each base station 612a, 612b, 612c is connectable to core network 614 over a wired or wireless connection 615. A first UE 691 located in coverage area 613c is configured to wirelessly connect to, or be paged by, the corresponding base station 612c. A second UE 692 in coverage area 613a is
20 wirelessly connectable to the corresponding base station 612a. While a plurality of UEs 691, 692 are illustrated in this example, the disclosed embodiments are equally applicable to a situation where a sole UE is in the coverage area or where a sole UE is connecting to the corresponding base station 612.

[00112] Telecommunication network 610 is itself connected to host computer
25 630, which may be embodied in the hardware and/or software of a standalone server,

a cloud-implemented server, a distributed server or as processing resources in a server farm. Host computer 630 may be under the ownership or control of a service provider, or may be operated by the service provider or on behalf of the service provider. Connections 621 and 622 between telecommunication network 610 and
5 host computer 630 may extend directly from core network 614 to host computer 630 or may go via an optional intermediate network 620. Intermediate network 620 may be one of, or a combination of more than one of, a public, private or hosted network; intermediate network 620, if any, may be a backbone network or the Internet; in particular, intermediate network 620 may comprise two or more sub-networks (not
10 shown).

[00113] The communication system of Figure 6 as a whole enables connectivity between the connected UEs 691, 692 and host computer 630. The connectivity may be described as an over-the-top (OTT) connection 650. Host computer 630 and the connected UEs 691, 692 are configured to communicate data
15 and/or signalling via OTT connection 650, using access network 611, core network 614, any intermediate network 620 and possible further infrastructure (not shown) as intermediaries. OTT connection 650 may be transparent in the sense that the participating communication devices through which OTT connection 650 passes are unaware of routing of uplink and downlink communications. For example, base
20 station 612 may not or need not be informed about the past routing of an incoming downlink communication with data originating from host computer 630 to be forwarded (e.g., handed over) to a connected UE 691. Similarly, base station 612 need not be aware of the future routing of an outgoing uplink communication originating from the UE 691 towards the host computer 630.

[00114] Example implementations, in accordance with an embodiment, of the UE, base station and host computer discussed in the preceding paragraphs will now be described with reference to Figure 7. In communication system 700, host computer 710 comprises hardware 715 including communication interface 716 configured to set up and maintain a wired or wireless connection with an interface of a different communication device of communication system 700. Host computer 710 further comprises processing circuitry 718, which may have storage and/or processing capabilities. In particular, processing circuitry 718 may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Host computer 710 further comprises software 711, which is stored in or accessible by host computer 710 and executable by processing circuitry 718. Software 711 includes host application 712. Host application 712 may be operable to provide a service to a remote user, such as UE 730 connecting via OTT connection 750 terminating at UE 730 and host computer 710. In providing the service to the remote user, host application 712 may provide user data which is transmitted using OTT connection 750.

[00115] Communication system 700 further includes base station 720 provided in a telecommunication system and comprising hardware 725 enabling it to communicate with host computer 710 and with UE 730. Hardware 725 may include communication interface 726 for setting up and maintaining a wired or wireless connection with an interface of a different communication device of communication system 700, as well as radio interface 727 for setting up and maintaining at least wireless connection 770 with UE 730 located in a coverage area (not shown in Figure 7) served by base station 720. Communication interface 726 may be configured to

facilitate connection 760 to host computer 710. Connection 760 may be direct or it may pass through a core network (not shown in Figure 7) of the telecommunication system and/or through one or more intermediate networks outside the telecommunication system. In the embodiment shown, hardware 725 of base station 5 720 further includes processing circuitry 728, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Base station 720 further has software 721 stored internally or accessible via an external connection.

10 **[00116]** Communication system 700 further includes UE 730 already referred to. Its hardware 735 may include radio interface 737 configured to set up and maintain wireless connection 770 with a base station serving a coverage area in which UE 730 is currently located. Hardware 735 of UE 730 further includes processing circuitry 738, which may comprise one or more programmable processors, 15 application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. UE 730 further comprises software 731, which is stored in or accessible by UE 730 and executable by processing circuitry 738. Software 731 includes client application 732. Client application 732 may be operable to provide a service to a human or non-human user 20 via UE 730, with the support of host computer 710. In host computer 710, an executing host application 712 may communicate with the executing client application 732 via OTT connection 750 terminating at UE 730 and host computer 710. In providing the service to the user, client application 732 may receive request data from host application 712 and provide user data in response to the request data.

OTT connection 750 may transfer both the request data and the user data. Client application 732 may interact with the user to generate the user data that it provides.

[00117] It is noted that host computer 710, base station 720 and UE 730 illustrated in Figure 7 may be similar or identical to host computer 630, one of base stations 612a, 612b, 612c and one of UEs 691, 692 of Figure 6, respectively. This is
5 to say, the inner workings of these entities may be as shown in Figure 7 and independently, the surrounding network topology may be that of Figure 6.

[00118] In Figure 7, OTT connection 750 has been drawn abstractly to illustrate the communication between host computer 710 and UE 730 via base station
10 720, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from UE 730 or from the service provider operating host computer 710, or both. While OTT connection 750 is active, the network infrastructure may further take decisions by which it dynamically changes the routing
15 (e.g., on the basis of load balancing consideration or reconfiguration of the network).

[00119] Wireless connection 770 between UE 730 and base station 720 is in accordance with the teachings of the embodiments described throughout this disclosure. One or more of the various embodiments improve the performance of OTT services provided to UE 730 using OTT connection 750, in which wireless
20 connection 770 forms the last segment. More precisely, the teachings of these embodiments may improve the latency and reliability and thereby provide benefits such as reduced user waiting time, relaxed restriction on file size, better responsiveness, etc.

[00120] A measurement procedure may be provided for the purpose of
25 monitoring data rate, latency and other factors on which the one or more embodiments

improve. There may further be an optional network functionality for reconfiguring OTT connection 750 between host computer 710 and UE 730, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring OTT connection 750 may be implemented in software 711 and hardware 715 of host computer 710 or in software 731 and hardware 735 of UE 730, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which OTT connection 750 passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above, or supplying values of other physical quantities from which software 711, 731 may compute or estimate the monitored quantities. The reconfiguring of OTT connection 750 may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect base station 720, and it may be unknown or imperceptible to base station 720. Such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary UE signalling facilitating host computer 710's measurements of throughput, propagation times, latency and the like. The measurements may be implemented in that software 711 and 731 causes messages to be transmitted, in particular empty or 'dummy' messages, using OTT connection 750 while it monitors propagation times, errors etc.

20 **[00121]** Figure 8 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to Figures 6 and 7. For simplicity of the present disclosure, only drawing references to Figure 8 will be included in this section. In step 810, the host computer provides user data. In substep 811 (which may be optional) of step 810,

25

the host computer provides the user data by executing a host application. In step 820, the host computer initiates a transmission carrying the user data to the UE. In step 830 (which may be optional), the base station transmits to the UE the user data which was carried in the transmission that the host computer initiated, in accordance with the teachings of the embodiments described throughout this disclosure. In step 840 (which may also be optional), the UE executes a client application associated with the host application executed by the host computer.

[00122] Figure 9 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to Figures 6 and 7. For simplicity of the present disclosure, only drawing references to Figure 9 will be included in this section. In step 910 of the method, the host computer provides user data. In an optional substep (not shown) the host computer provides the user data by executing a host application. In step 920, the host computer initiates a transmission carrying the user data to the UE. The transmission may pass via the base station, in accordance with the teachings of the embodiments described throughout this disclosure. In step 930 (which may be optional), the UE receives the user data carried in the transmission.

[00123] Figure 10 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to Figures 6 and 7. For simplicity of the present disclosure, only drawing references to Figure 10 will be included in this section. In step 1010 (which may be optional), the UE receives input data provided by the host computer. Additionally or alternatively, in step 1020, the UE provides user data. In substep 1021

(which may be optional) of step 1020, the UE provides the user data by executing a client application. In substep 1011 (which may be optional) of step 1010, the UE executes a client application which provides the user data in reaction to the received input data provided by the host computer. In providing the user data, the executed client application may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the UE initiates, in substep 1030 (which may be optional), transmission of the user data to the host computer. In step 1040 of the method, the host computer receives the user data transmitted from the UE, in accordance with the teachings of the embodiments described throughout this disclosure.

[00124] Figure 11 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to Figures 6 and 7. For simplicity of the present disclosure, only drawing references to Figure 11 will be included in this section. In step 1110 (which may be optional), in accordance with the teachings of the embodiments described throughout this disclosure, the base station receives user data from the UE. In step 1120 (which may be optional), the base station initiates transmission of the received user data to the host computer. In step 1130 (which may be optional), the host computer receives the user data carried in the transmission initiated by the base station.

[00125] Any appropriate steps, methods, features, functions, or benefits disclosed herein may be performed through one or more functional units or modules of one or more virtual apparatuses. Each virtual apparatus may comprise a number of these functional units. These functional units may be implemented via processing

circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or
5 several types of memory such as read-only memory (ROM), random-access memory (RAM), cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein. In some
10 implementations, the processing circuitry may be used to cause the respective functional unit to perform corresponding functions according one or more embodiments of the present disclosure.

[00126] FIG. 12 is a flow diagram for FD_MIMO in codebook-based transmissions according to some embodiments. In some embodiments, the method
15 1200 of FIG. 12 is performed by a radio node (e.g. a base station or a UE). At step 1202, the radio node performs horizontal beamforming based on a UE reported codebook. At optional step 1204, the radio node optionally, determines an elevation beamformer based on elevation beamforming at radio node (e.g. base station) side, optionally the elevation beamforming being based on an 1D GoB algorithm;
20 optionally, combs one or more horizontal codebooks and one or more vertical codebooks and/or optionally, generates a 2D beamformer for transmissions (downlink or uplink).

[00127] FIG. 13 illustrates a schematic block diagram of an apparatuses 1300, in a wireless network (for example, the wireless network shown in FIG. 3). The
25 apparatus may be implemented in a wireless device or network node (e.g., wireless

device 310 or network node 360 shown in FIG. 3). Apparatus 1300 is operable to carry out the example methods described with reference to FIG. 12 respectively and possibly any other processes or methods disclosed herein. It is also to be understood that the methods of FIG. 12 are not necessarily carried out solely by apparatuses 1300.

5 At least some operations of the method can be performed by one or more other entities.

[00128] Virtual apparatuses 1300 may comprise processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital
10 logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes
15 program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein, in several embodiments. In some implementations, the processing circuitry may be used to cause a horizontal beamforming unit 1302, an optional elevation beamforming unit 1304 and/or any other suitable units of apparatuses 1300 to perform corresponding functions according one or more
20 embodiments of the present disclosure.

[00129] As illustrated in FIG. 13, apparatus 1300 includes a horizontal beamforming unit 1302 configured to perform horizontal beamforming based on a UE reported codebook, and an optional elevation beamforming unit 1304 configured to optionally, determining an elevation beamformer based on elevation beamforming at
25 radio node (e.g. base station) side, optionally the elevation beamforming being based

on an 1D GoB algorithm, and/or optionally, comb one or more horizontal codebooks and one or more vertical codebooks, and/or optionally, generating a 2D beamformer for transmissions (downlink or uplink).

[00130] The term unit may have conventional meaning in the field of

5 electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

10 **[00131]** As will be appreciated by one of skill in the art, the concepts described herein may be embodied as a method, data processing system, computer program product and/or computer storage media storing an executable computer program.

Accordingly, the concepts described herein may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects all generally referred to herein as a “circuit” or “module.” Any
15 process, step, action and/or functionality described herein may be performed by, and/or associated to, a corresponding module, which may be implemented in software and/or firmware and/or hardware. Furthermore, the disclosure may take the form of a computer program product on a tangible computer usable storage medium having
20 computer program code embodied in the medium that can be executed by a computer. Any suitable tangible computer readable medium may be utilized including hard disks, CD-ROMs, electronic storage devices, optical storage devices, or magnetic storage devices.

[00132] Some embodiments are described herein with reference to flowchart
25 illustrations and/or block diagrams of methods, systems and computer program

products. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer (to thereby create a special purpose computer), special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

10 **[00133]** These computer program instructions may also be stored in a computer readable memory or storage medium that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer readable memory produce an article of manufacture including instruction means which implement the function/act specified in the flowchart and/or block diagram block or blocks.

[00134] The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[00135] It is to be understood that the functions/acts noted in the blocks may occur out of the order noted in the operational illustrations. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the

functionality/acts involved. Although some of the diagrams include arrows on communication paths to show a primary direction of communication, it is to be understood that communication may occur in the opposite direction to the depicted arrows.

5 [00136] Computer program code for carrying out operations of the concepts described herein may be written in an object oriented programming language such as Java® or C++. However, the computer program code for carrying out operations of the disclosure may also be written in conventional procedural programming languages, such as the "C" programming language. The program code may execute
10 entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer. In the latter scenario, the remote computer may be connected to the user's computer through a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for
15 example, through the Internet using an Internet Service Provider).

[00137] Many different embodiments have been disclosed herein, in connection with the above description and the drawings. It will be understood that it would be unduly repetitious and obfuscating to literally describe and illustrate every combination and subcombination of these embodiments. Accordingly, all
20 embodiments can be combined in any way and/or combination, and the present specification, including the drawings, shall be construed to constitute a complete written description of all combinations and subcombinations of the embodiments described herein, and of the manner and process of making and using them, and shall support claims to any such combination or sub-combination.

25 [00138] cc

	<u>Abbreviation</u>	<u>Explanation</u>
	1x RTT	CDMA2000 1x Radio Transmission Technology
	3GPP	3rd Generation Partnership Project
	5G	5th Generation
5	ABS	Almost Blank Subframe
	ARQ	Automatic Repeat Request
	AWGN	Additive White Gaussian Noise
	BCCH	Broadcast Control Channel
	BCH	Broadcast Channel
10	CA	Carrier Aggregation
	CC	Carrier Component
	CCCH SDU	Common Control Channel SDU
	CDMA	Code Division Multiplexing Access
	CGI	Cell Global Identifier
15	CIR	Channel Impulse Response
	CP	Cyclic Prefix
	CPICH	Common Pilot Channel
	CPICH E_c/N_0	CPICH Received energy per chip divided by the power density in the band
20	CQI	Channel Quality information
	C-RNTI	Cell RNTI
	CSI	Channel State Information
	DCCH	Dedicated Control Channel
	DL	Downlink
25	DM	Demodulation

	DMRS	Demodulation Reference Signal
	DRX	Discontinuous Reception
	DTX	Discontinuous Transmission
	DTCH	Dedicated Traffic Channel
5	DUT	Device Under Test
	E-CID	Enhanced Cell-ID (positioning method)
	E-SMLC	Evolved-Serving Mobile Location Centre
	ECGI	Evolved CGI
	eNB	E-UTRAN NodeB
10	ePDCCH	enhanced Physical Downlink Control Channel
	E-SMLC	evolved Serving Mobile Location Center
	E-UTRA	Evolved UTRA
	E-UTRAN	Evolved UTRAN
	FDD	Frequency Division Duplex
15	FFS	For Further Study
	GERAN	GSM EDGE Radio Access Network
	gNB	Base station in NR
	GNSS	Global Navigation Satellite System
	GSM	Global System for Mobile communication
20	HARQ	Hybrid Automatic Repeat Request
	HO	Handover
	HSPA	High Speed Packet Access
	HRPD	High Rate Packet Data
	LOS	Line of Sight
25	LPP	LTE Positioning Protocol

	LTE	Long-Term Evolution
	MAC	Medium Access Control
	MBMS	Multimedia Broadcast Multicast Services
	MBSFN	Multimedia Broadcast multicast service Single Frequency
5	Network	
	MBSFN ABS	MBSFN Almost Blank Subframe
	MDT	Minimization of Drive Tests
	MIB	Master Information Block
	MME	Mobility Management Entity
10	MSC	Mobile Switching Center
	NPDCCH	Narrowband Physical Downlink Control Channel
	NR	New Radio
	OCNG	OFDMA Channel Noise Generator
	OFDM	Orthogonal Frequency Division Multiplexing
15	OFDMA	Orthogonal Frequency Division Multiple Access
	OSS	Operations Support System
	OTDOA	Observed Time Difference of Arrival
	O&M	Operation and Maintenance
	PBCH	Physical Broadcast Channel
20	P-CCPCH	Primary Common Control Physical Channel
	PCell	Primary Cell
	PCFICH	Physical Control Format Indicator Channel
	PDCCH	Physical Downlink Control Channel
	PDP	Profile Delay Profile
25	PDSCH	Physical Downlink Shared Channel

	PGW	Packet Gateway
	PHICH	Physical Hybrid-ARQ Indicator Channel
	PLMN	Public Land Mobile Network
	PMI	Precoder Matrix Indicator
5	PRACH	Physical Random Access Channel
	PRS	Positioning Reference Signal
	PSS	Primary Synchronization Signal
	PUCCH	Physical Uplink Control Channel
	PUSCH	Physical Uplink Shared Channel
10	RACH	Random Access Channel
	QAM	Quadrature Amplitude Modulation
	RAN	Radio Access Network
	RAT	Radio Access Technology
	RLM	Radio Link Management
15	RNC	Radio Network Controller
	RNTI	Radio Network Temporary Identifier
	RRC	Radio Resource Control
	RRM	Radio Resource Management
	RS	Reference Signal
20	RSCP	Received Signal Code Power
	RSRP	Reference Symbol Received Power OR Reference Signal Received Power
	RSRQ	Reference Signal Received Quality OR Reference Symbol Received Quality
25	RSSI	Received Signal Strength Indicator

	RSTD	Reference Signal Time Difference
	SCH	Synchronization Channel
	SCell	Secondary Cell
	SDU	Service Data Unit
5	SFN	System Frame Number
	SGW	Serving Gateway
	SI	System Information
	SIB	System Information Block
	SNR	Signal to Noise Ratio
10	SON	Self Optimized Network
	SS	Synchronization Signal
	SSS	Secondary Synchronization Signal
	TDD	Time Division Duplex
	TDOA	Time Difference of Arrival
15	TOA	Time of Arrival
	TSS	Tertiary Synchronization Signal
	TTI	Transmission Time Interval
	UE	User Equipment
	UL	Uplink
20	UMTS	Universal Mobile Telecommunication System
	USIM	Universal Subscriber Identity Module
	UTDOA	Uplink Time Difference of Arrival
	UTRA	Universal Terrestrial Radio Access
	UTRAN	Universal Terrestrial Radio Access Network
25	WCDMA	Wide CDMA

	WLAN	Wide Local Area Network
	AAS	Active Antenna System
	CSI-RS	Channel State Information Reference Signal
	DFT	Discrete Fourier Transform
5	DMRS	Demodulation Reference Signal
	FD-MIMO	Full Dimension MIMO
	GoB	Grid-of-beams
	PMI	Precoding Matrix Indicator
	SRS	Sounding Reference Signal

10

[00139] It will be appreciated by persons skilled in the art that the embodiments described herein are not limited to what has been particularly shown and described herein above. In addition, unless mention was made above to the contrary, it should be noted that all of the accompanying drawings are not to scale. A variety of

15 modifications and variations are possible in light of the above teachings without departing from the scope of the following claims.

What is claimed is:

1. A method performed by a network node (360) to realize FD_MIMO in codebook-based transmissions, the method comprising the steps of:

 combing one or more horizontal codebooks and one or more vertical codebooks;

 generating a 2D beamformer for downlink transmissions based on the combination of the one or more horizontal codebooks and one or more vertical codebooks.
2. The method of claim 1, wherein the one or more horizontal codebooks is based on a wireless device (310) reported codebook.
3. The method of any of claim 1-2, wherein the one or more vertical codebooks is based on elevation beamforming at a base station side.
4. The method of claim 3, wherein the elevation beamforming is based on an 1D grid of beams (GoB) algorithm.
5. The method of claim 1, further comprising performing a column swap of the PMI every other sub-band to adjust a throughput between two layers in rank-2 transmissions.
6. The method of claim 5, wherein the adjustment to the throughput of the two layers being within a predefined range.

7. The method of claims 1-2, wherein the wireless device (310) reported codebook includes at least one of a SINR estimate and a rank estimate.
8. The method of claim 7, further comprising adjusting at least one of the SINR estimate and rank estimate based on a calculated BF gain.
9. A network node (360) comprising:
processing circuitry configured to perform any of the steps of any of the claims 1-8.
10. A computer program comprising instructions which, when executed by at least one processor of a network node (360), causes the network node (101) to carry out the steps of any of the claims 1-8.

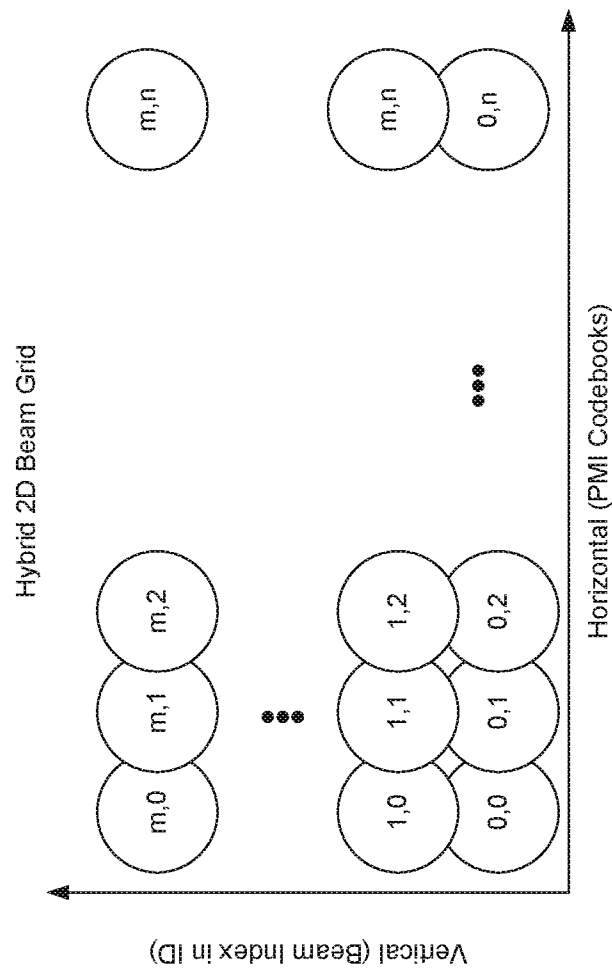


FIG. 1

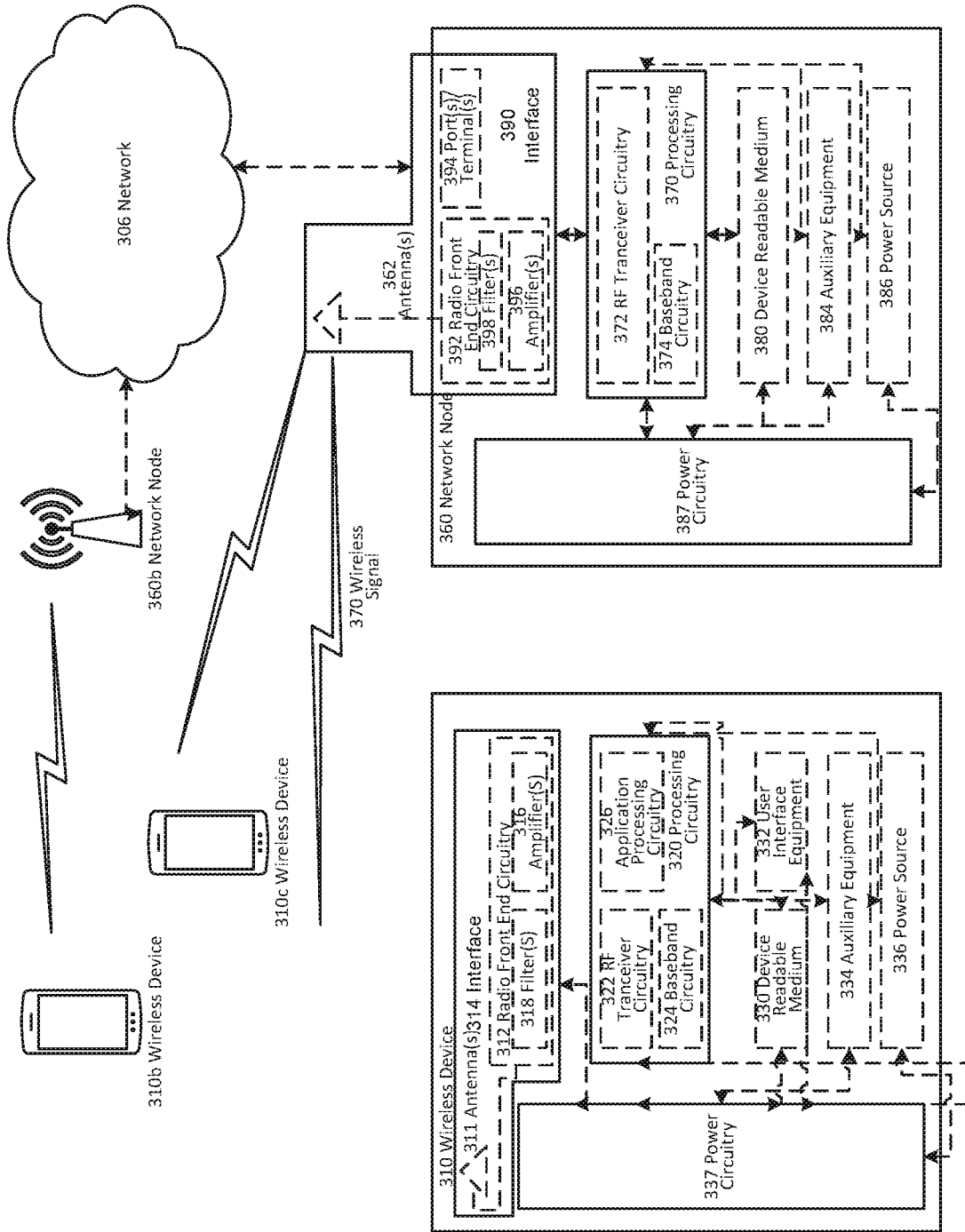


Figure 3

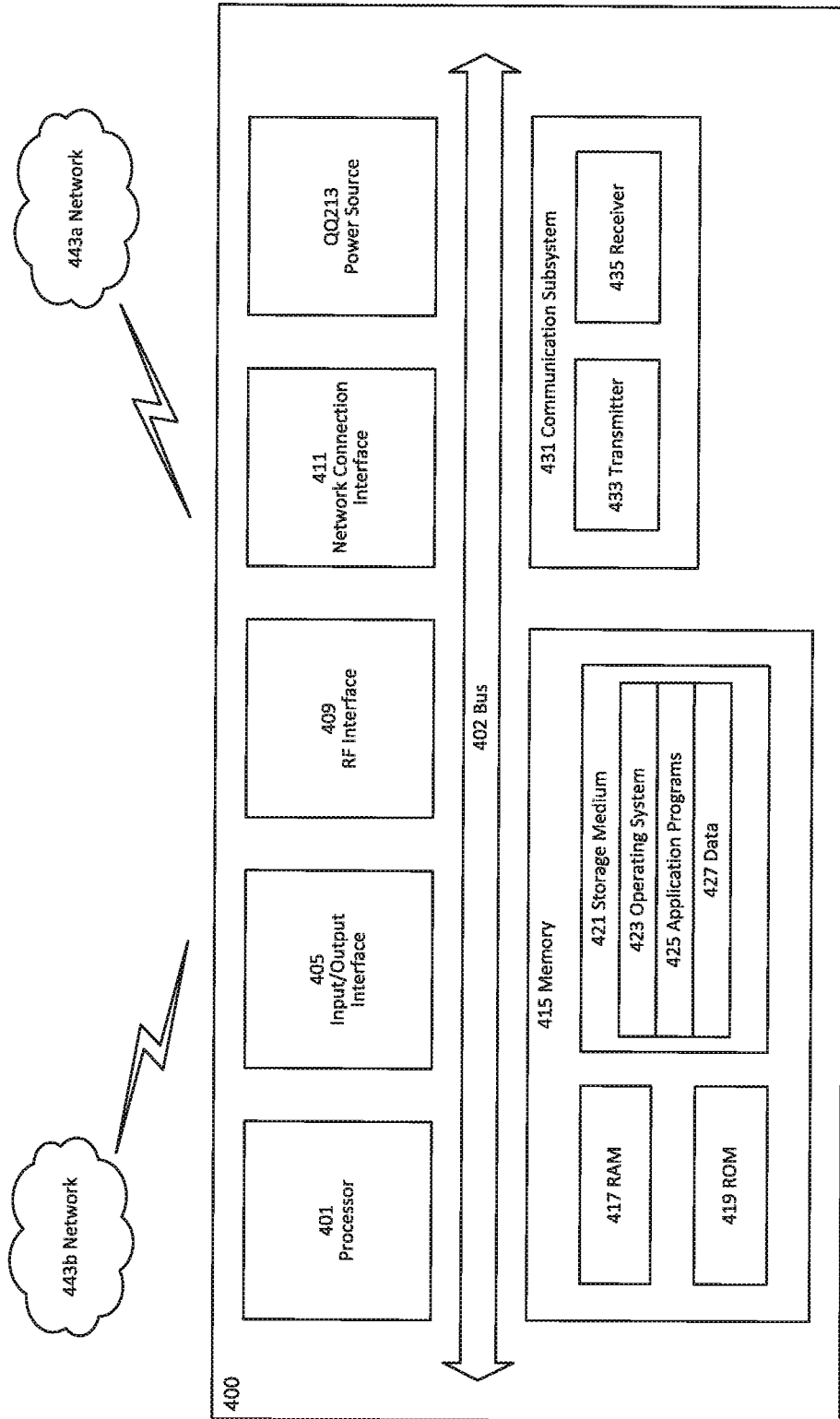


Figure 4

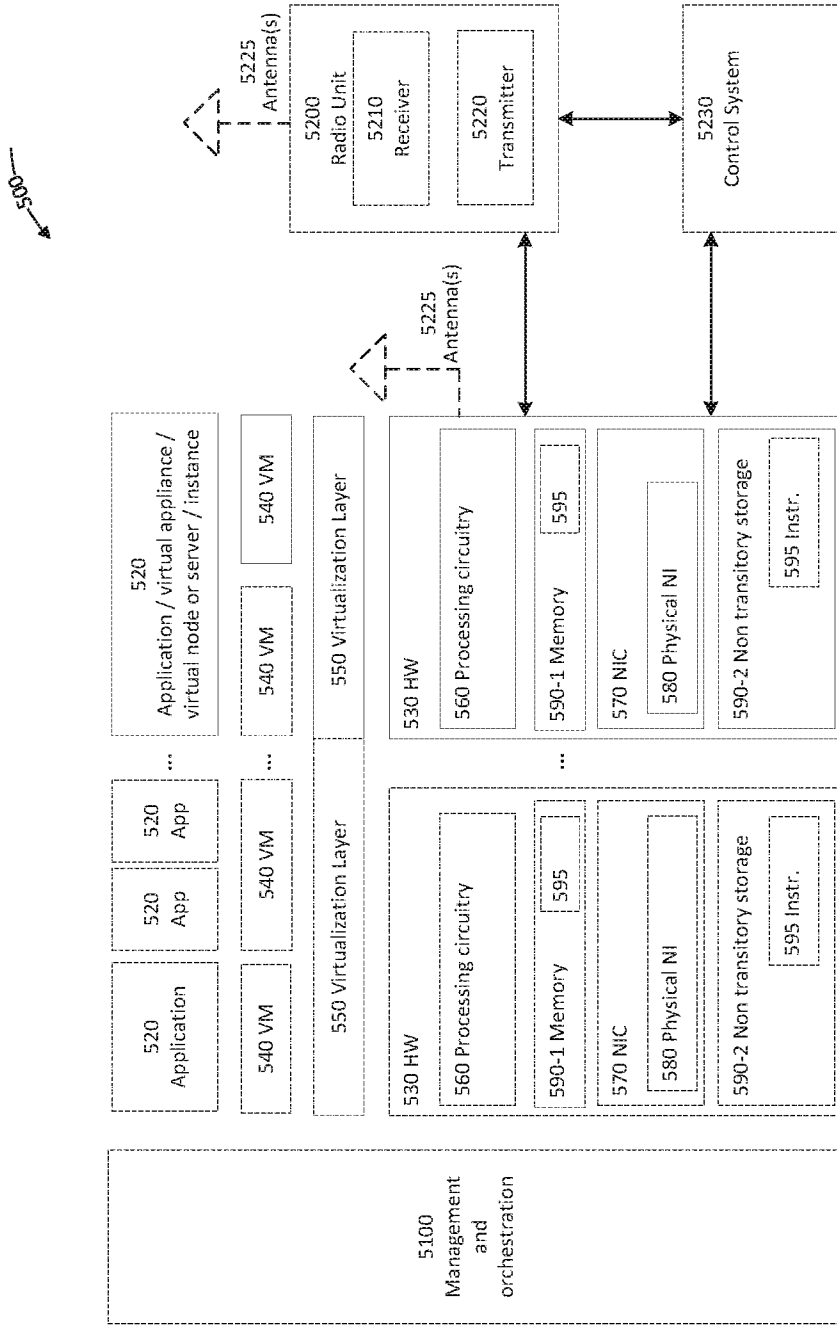


Figure 5

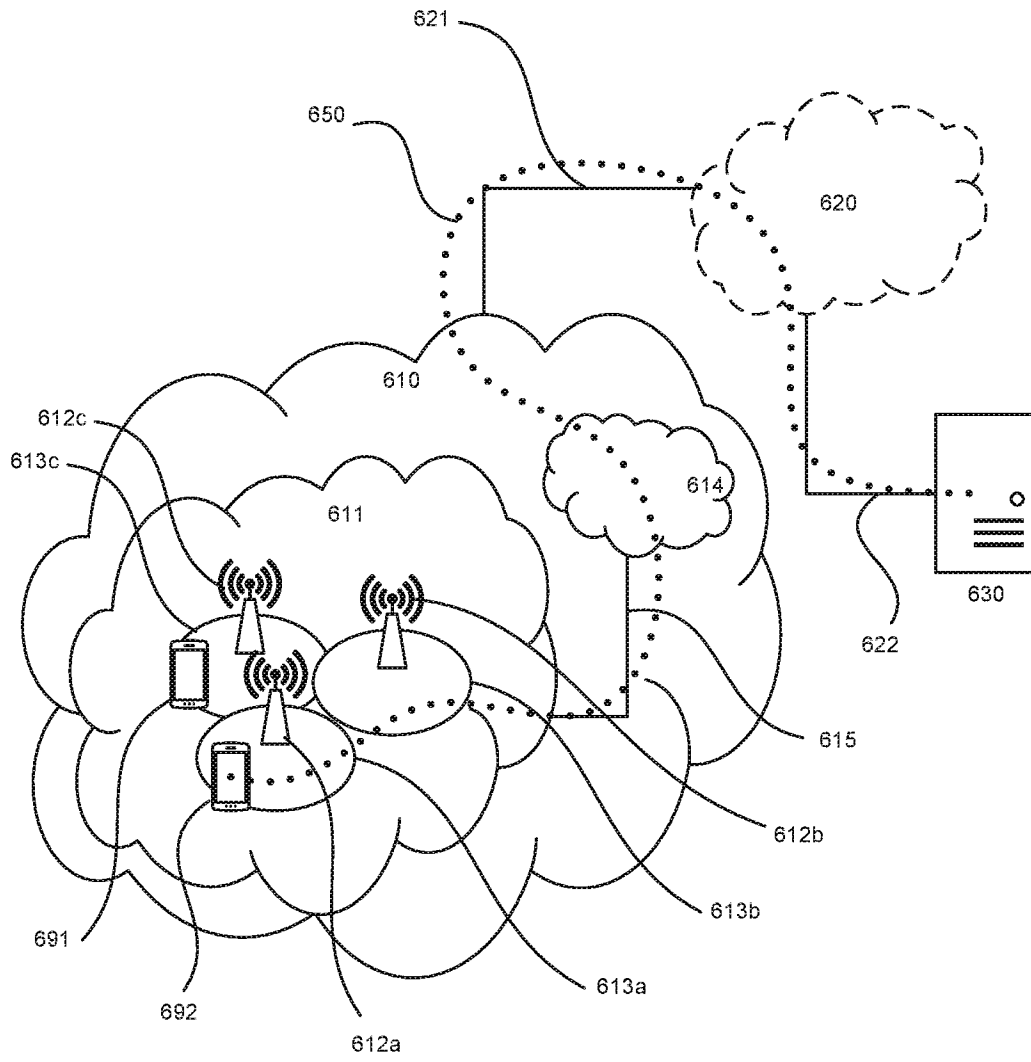


FIG. 6

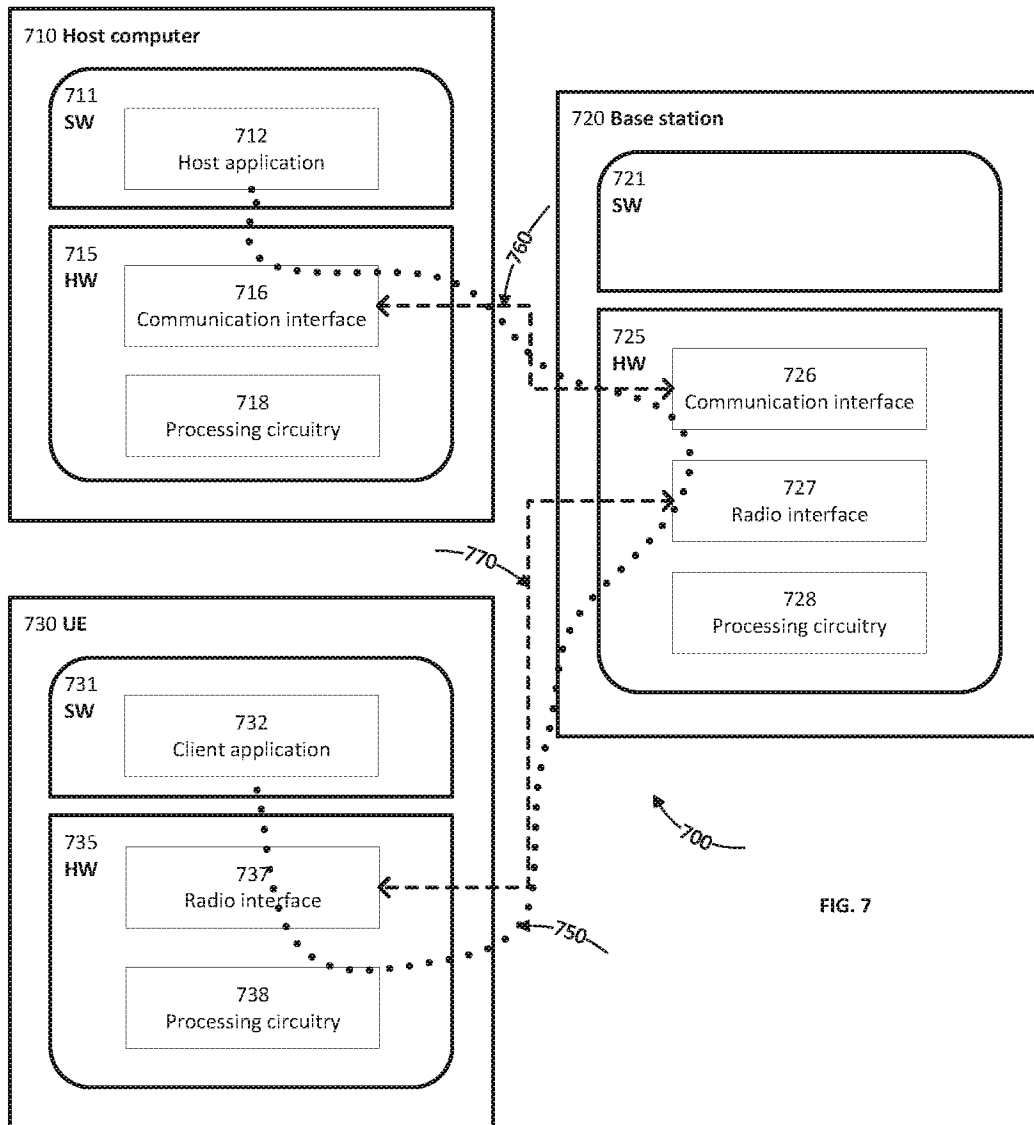


FIG. 7

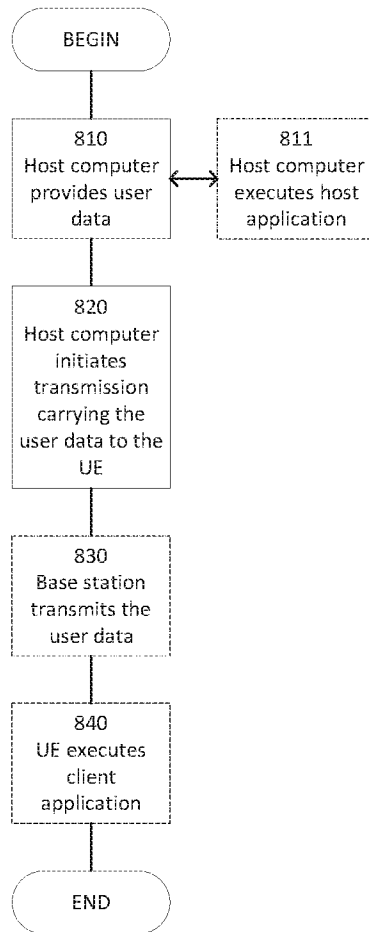


FIG. 8

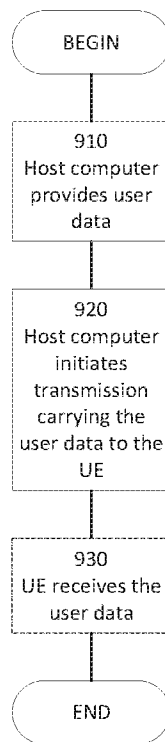


FIG. 9

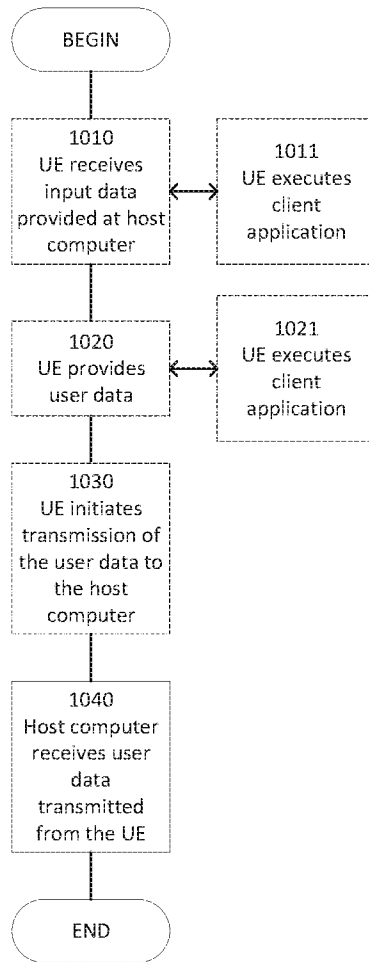


FIG. 10

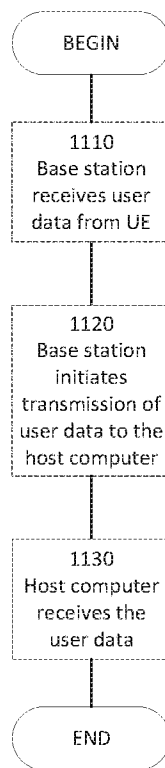


FIG. 11

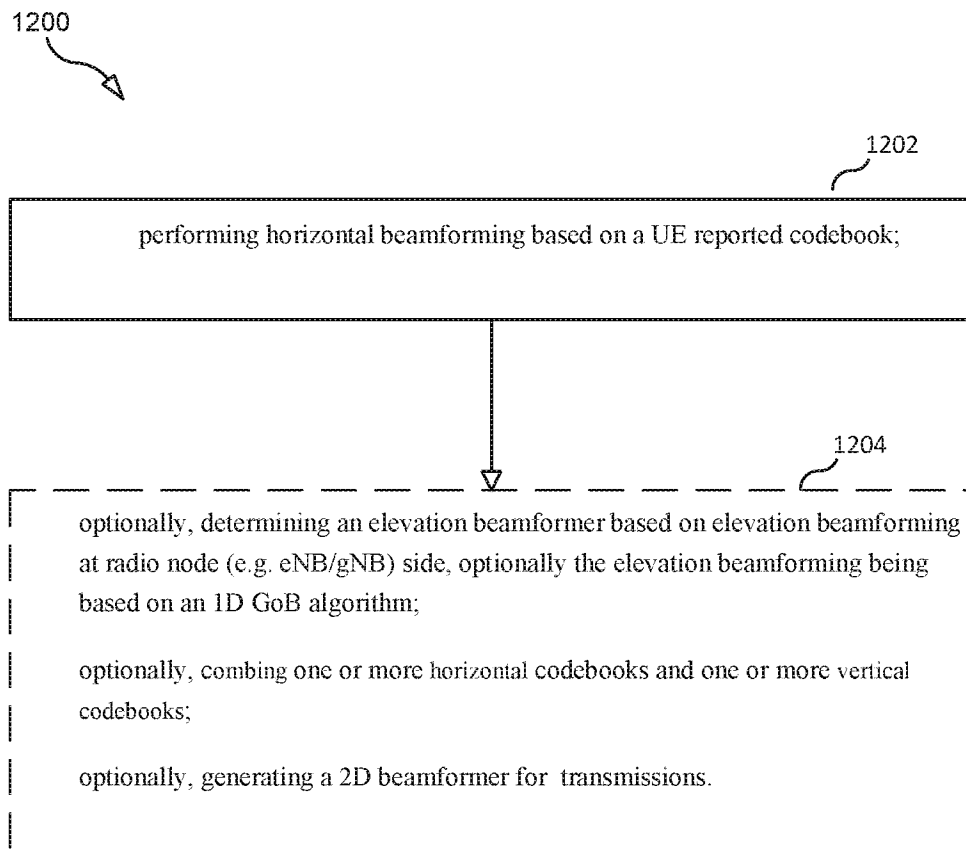


FIG. 12

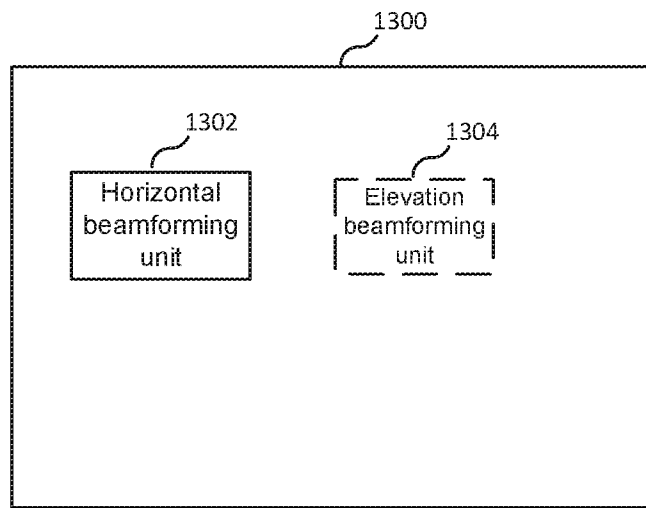


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/058612

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/0456 H04B7/06
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
H04B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017/302345 A1 (KAKISHIMA YUICHI [JP] ET AL) 19 October 2017 (2017-10-19)	1,2,7,9,10
Y	paragraphs [0028] - [0033]; figure 1 paragraphs [0038], [0054]; figures 5,13	5,6,8
X	US 2018/167124 A1 (CHEN RUNHUA [CN] ET AL) 14 June 2018 (2018-06-14)	1-4,7,9,10
Y	paragraphs [0003], [0005], [0064], [0074] - [0075], [0086]	5,6,8
Y	EP 2 413 528 A1 (FUJITSU LTD [JP]) 1 February 2012 (2012-02-01) paragraphs [0065] - [0066]	5,6
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search 27 November 2019	Date of mailing of the international search report 05/12/2019
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Ganis, Alexander
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International application No
PCT/IB2019/058612

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