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(54) **Title:** POSITIONING METHODS, ARCHITECTURES, APPARATUSES AND SYSTEMS FOR LEARNING-BASED NETWORK-USER EQUIPMENT BEAM ALIGNMENT

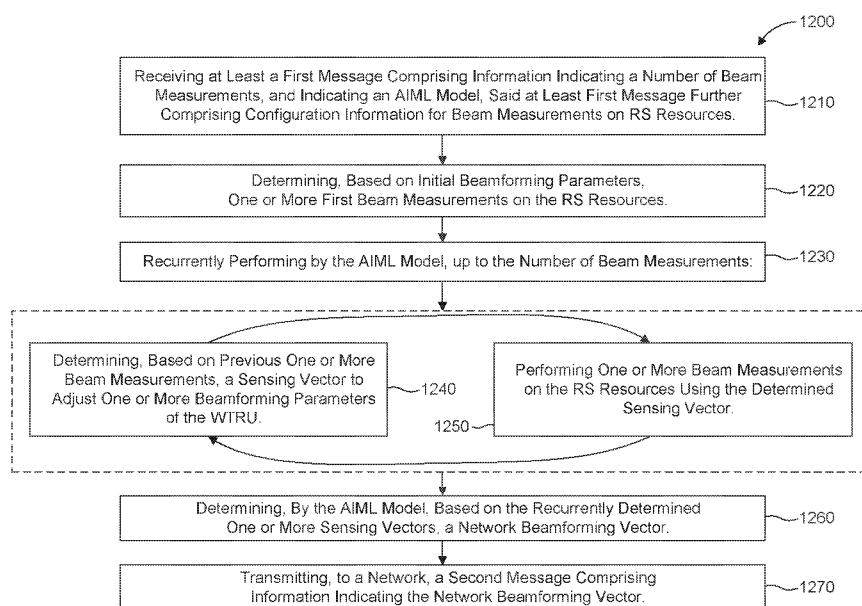


FIG. 12

(57) **Abstract:** In an embodiment, a method, implemented in a WTRU to perform beam alignment, comprises: receiving information indicating beam measurements period, and a recursive AIML model, and initial beam alignment parameters; and comprising information indicating configuration on reference signals, RS, resources for beam measurements. Recurrently, during the beam measurement period, the method comprises: determining, by the recursive AIML model, a data-driven sensing vector to adjust WTRU spatial filter parameters based on previous beam alignment parameters and previous beam measurements; and performing beam measurement on RS, to generate current beam alignment parameters. The method comprises determining a combining vector for adjustment of WTRU spatial filter parameter and a network beam forming vector based on the recurrently determined sensing vectors; transmitting, to the

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network, information indicating the network beamforming vector; and receiving data from the network using the adjusted WTRU spatial filter parameter.

POSITIONING METHODS, ARCHITECTURES, APPARATUSES AND SYSTEMS FOR LEARNING-BASED NETWORK-USER EQUIPMENT BEAM ALIGNMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of EP Patent Application No. 23181773.5 filed June 27th, 2023, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present disclosure is generally directed to the fields of communications, software and encoding, including, for example, to methods, architectures, apparatuses, systems directed to learning-based user equipment sensing beam alignment. More particularly, the present disclosure relates to methods including configuration, training, inference and feedback aspects on the network and user equipment sensing and beam alignment controllers.

BACKGROUND

[0003] The need for highly directional transmissions using beamforming techniques to overcome the large pathloss at higher frequencies (such as FR2 and sub-THz/THz) may require systems operating at these frequencies to use large antenna arrays and use highly directive beamforming. The highly directive beamforming requires modifications to legacy initial access techniques to achieve beam alignment with pencil beams.

[0004] In 3GPP systems today, codebook-based exhaustive search method for beam alignment is used where network and user equipment sweep all beams repeatedly while user equipment performs beam measurement on reference signal resources to find the best beams with the highest received signal strength, and reporting to the network. For systems with pencil beams, such as FR2 and sub-THz/THz, this technique may cause significant latency.

[0005] There is a need to improve methods for beam alignment.

SUMMARY

[0006] In an embodiment, a method, implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise: receiving a first message comprising information indicating beam measurements period, a recursive AIML model, and initial beam alignment parameters; receiving a second message comprising information indicating configuration on reference signals, RS, resources for beam measurements. The method may recurrently comprise during the beam measurement period: determining, by the recursive AIML model, a data-driven sensing vector to adjust WTRU spatial filter parameters based on previous beam alignment parameters; performing beam measurement on RS, to generate current beam alignment

parameters. The method may further comprise: determining a combining vector for final adjustment of WTRU spatial filter parameter and a network beam forming vector based on the recurrently determined sensing vectors; transmitting, to the network, a second message comprising information indicating the network beamforming vector; and receiving data from the network using the final adjusted WTRU spatial filter parameter.

[0007] In another embodiment, a method, implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise receiving a first message comprising information indicating a maximum number of sensing steps, a recursive AIML model, and initial beam alignment parameters; receiving a second message comprising information indicating configuration on reference signals, RS, resources for beam measurements. On condition that a stopping criterion is not satisfied, the method may recurrently comprise: determining, by the recursive AIML model, a data-driven sensing vector to adjust WTRU spatial filter parameters based on previous beam alignment parameters; determining a combining vector and a network beam index based on previous beam alignment parameters; performing beam measurement on RS, to generate current beam alignment parameters; and determining the stopping criterion based on the determined combining vector. The method may further comprise: transmitting, to the network, a second message comprising information indicating the last determined network beam index; adjusting WTRU spatial filter parameters based on the last determined combining vector; and receiving data from the network using the adjusted WTRU spatial filter parameters.

[0008] In another embodiment, a method implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise a step of receiving at least a first message comprising information indicating a number of beam measurements, and indicating an artificial intelligence and machine learning (AIML) model, said at least first message further comprising configuration information for beam measurements on reference signals (RS) resources. In an alternative, the WTRU may receive a first message comprising information indicating a number of beam measurements, and indicating an Artificial Intelligence and Machine Learning (AIML) model, and the WTRU may receive a second message comprising configuration information for beam measurements on reference signals (RS) resources. The method may comprise a step wherein of determining, based on initial beamforming parameters, one or more first beam measurements on the RS resources. The method may further comprise a step of recurrently performing, by the AIML model, up to the number of beam measurements the following steps: (i) determining, based on previous one or more beam measurements, a sensing vector to adjust one or more beamforming parameters of the WTRU, and (ii) performing one or more beam measurements on the RS resources using the determined sensing vector. The method may comprise a step of determining,

by the AIML model, based on the recurrently determined one or more sensing vectors, a network beamforming vector, and a step of transmitting, to a network, a second message comprising information indicating the network beamforming vector.

[0009] The method may comprise a step of determining, by the AIML model, based on the recurrently determined one or more sensing vectors, a combining vector for adjustment of the one or more beamforming parameters of the WTRU.

[0010] The method may comprise a step of receiving data from the network using the adjusted one or more beamforming parameters.

[0011] Prior receiving data from the network using the adjusted one or more beamforming parameters, the method may comprise a step of receiving, from the network, a new RS resource, determining channel measurements on the new RS resource; and transmitting to the network, a channel state information report comprising the determined channel measurements.

[0012] The adjustment of the one or more beamforming parameters of the WTRU may be a final adjustment. The one or more beamforming parameters may comprise one or more WTRU spatial filter parameters. The information indicating configuration on reference signals (RS) resources for beam measurements may be received via downlink control information or radio resource control signaling. The indication of the number of beam measurements may comprise a number of sensing steps. The indication of the number of beam measurements may comprise a sensing window. Performing beam measurements on the RS resources may comprise any of determining L1-RSRP, SINR, and network beam index. Beam measurements may be omitted in case of beam measurements are below a threshold value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more detailed understanding may be had from the detailed description below, given by way of example in conjunction with drawings appended hereto. Figures in such drawings, like the detailed description, are examples. As such, the Figures (FIGs.) and the detailed description are not to be considered limiting, and other equally effective examples are possible and likely. Furthermore, like reference numerals ("ref.") in the FIGs. indicate like elements, and wherein:

[0014] FIG. 1A is a system diagram illustrating an example communications system;

[0015] FIG. 1B is a system diagram illustrating an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A;

[0016] FIG. 1C is a system diagram illustrating an example radio access network (RAN) and an example core network (CN) that may be used within the communications system illustrated in FIG. 1A;

[0017] FIG. 1D is a system diagram illustrating a further example RAN and a further example CN that may be used within the communications system illustrated in FIG. 1A;

[0018] FIG. 2 is a block diagram illustrating an example of a recurrent neural network;

[0019] FIG. 3 is a block diagram illustrating an example of an unrolled depiction of recurrent neural network;

[0020] FIG. 4 is a block diagram illustrating an example of system model of the network and a WTRU beam alignment controllers;

[0021] FIG. 5 is a schematic view of an example of a recursive system model for training and inference of a NW-WTRU beam alignment;

[0022] FIG. 6 is a flow chart diagram illustrating an example of a NW-WTRU beam alignment method according to an embodiment;

[0023] FIG. 7 is a schematic view of an example of a recursive system model for the training and inference of the WTRU-side beam alignment with early stopping;

[0024] FIG. 8 is a schematic view of an example of a trainable recursive neural network of Fig.7;

[0025] FIG. 9 is a flow chart diagram illustrating an example of a NW-WTRU beam alignment method according to another embodiment.

[0026] FIG. 10 is a flow chart diagram illustrating another example of a NW-WTRU beam alignment method according to another embodiment.

[0027] FIG. 11 is another flow chart diagram illustrating another example of a NW-WTRU beam alignment method according to another embodiment.

[0028] FIG. 12 is another flow chart diagram illustrating another example of a NW-WTRU beam alignment method according to another embodiment.

DETAILED DESCRIPTION

[0029] In the following detailed description, numerous specific details are set forth to provide a thorough understanding of embodiments and/or examples disclosed herein. However, it will be understood that such embodiments and examples may be practiced without some or all of the specific details set forth herein. In other instances, well-known methods, procedures, components and circuits have not been described in detail, so as not to obscure the following description. Further, embodiments and examples not specifically described herein may be practiced in lieu of, or in combination with, the embodiments and other examples described, disclosed or otherwise provided explicitly, implicitly and/or inherently (collectively "provided") herein. Although various embodiments are described and/or claimed herein in which an apparatus, system, device, etc. and/or any element thereof carries out an operation, process, algorithm, function, etc. and/or any portion thereof, it is to be understood that any embodiments described and/or claimed herein

assume that any apparatus, system, device, etc. and/or any element thereof is configured to carry out any operation, process, algorithm, function, etc. and/or any portion thereof.

[0030] Hereinafter, 'a' and 'an' and similar phrases are to be interpreted as 'one or more' and 'at least one'. Similarly, any term which ends with the suffix '(s)' is to be interpreted as 'one or more' and 'at least one'. The term 'may' is to be interpreted as 'may, for example'.

[0031] A sign, symbol, or mark of forward slash '/' is to be interpreted as 'and/or' unless particularly mentioned otherwise, where for example, 'A/B' may imply 'A and/or B'.

[0032] The methods, apparatuses and systems provided herein are well-suited for communications involving both wired and wireless networks. An overview of various types of wireless devices and infrastructure is provided with respect to FIGs. 1A-1D, where various elements of the network may utilize, perform, be arranged in accordance with and/or be adapted and/or configured for the methods, apparatuses and systems provided herein.

[0033] FIG. 1A is a system diagram illustrating an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), zero-tail (ZT) unique-word (UW) discrete Fourier transform (DFT) spread OFDM (ZT UW DTS-s OFDM), unique word OFDM (UW-OFDM), resource block-filtered OFDM, filter bank multicarrier (FBMC), and the like.

[0034] As shown in FIG. 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104/113, a core network (CN) 106/115, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d, any of which may be referred to as a "station" and/or a "STA", may be configured to transmit and/or receive wireless signals and may include (or be) a user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a subscription-based unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, a hotspot or Mi-

Fi device, an Internet of Things (IoT) device, a watch or other wearable, a head-mounted display (HMD), a vehicle, a drone, a medical device and applications (e.g., remote surgery), an industrial device and applications (e.g., a robot and/or other wireless devices operating in an industrial and/or an automated processing chain contexts), a consumer electronics device, a device operating on commercial and/or industrial wireless networks, and the like. Any of the WTRUs 102a, 102b, 102c and 102d may be interchangeably referred to as a UE.

[0035] The communications systems 100 may also include a base station 114a and/or a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d, e.g., to facilitate access to one or more communication networks, such as the CN 106/115, the Internet 110, and/or the networks 112. By way of example, the base stations 114a, 114b may be any of a base transceiver station (BTS), a Node-B (NB), an eNode-B (eNB), a Home Node-B (HNB), a Home eNode-B (HeNB), a gNode-B (gNB), a NR Node-B (NR NB), a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0036] The base station 114a may be part of the RAN 104/113, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals on one or more carrier frequencies, which may be referred to as a cell (not shown). These frequencies may be in licensed spectrum, unlicensed spectrum, or a combination of licensed and unlicensed spectrum. A cell may provide coverage for a wireless service to a specific geographical area that may be relatively fixed or that may change over time. The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in an embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In an embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and may utilize multiple transceivers for each or any sector of the cell. For example, beamforming may be used to transmit and/or receive signals in desired spatial directions.

[0037] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 116, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, centimeter wave, micrometer wave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 116 may be established using any suitable radio access technology (RAT).

[0038] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104/113 and the WTRUs 102a, 102b, 102c may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface 116 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink Packet Access (HSDPA) and/or High-Speed Uplink Packet Access (HSUPA).

[0039] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface 116 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A) and/or LTE-Advanced Pro (LTE-A Pro).

[0040] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as NR Radio Access, which may establish the air interface 116 using New Radio (NR).

[0041] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement multiple radio access technologies. For example, the base station 114a and the WTRUs 102a, 102b, 102c may implement LTE radio access and NR radio access together, for instance using dual connectivity (DC) principles. Thus, the air interface utilized by WTRUs 102a, 102b, 102c may be characterized by multiple types of radio access technologies and/or transmissions sent to/from multiple types of base stations (e.g., an eNB and a gNB).

[0042] In an embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (Wi-Fi)), IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

[0043] The base station 114b in FIG. 1A may be a wireless router, Home Node-B, Home eNode-B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, an industrial facility, an air corridor (e.g., for use by drones), a roadway, and the like. In an embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In an embodiment, the

base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In an embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, LTE-A Pro, NR, etc.) to establish any of a small cell, picocell or femtocell. As shown in FIG. 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the CN 106/115.

[0044] The RAN 104/113 may be in communication with the CN 106/115, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. The data may have varying quality of service (QoS) requirements, such as differing throughput requirements, latency requirements, error tolerance requirements, reliability requirements, data throughput requirements, mobility requirements, and the like. The CN 106/115 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. 1A, it will be appreciated that the RAN 104/113 and/or the CN 106/115 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104/113 or a different RAT. For example, in addition to being connected to the RAN 104/113, which may be utilizing an NR radio technology, the CN 106/115 may also be in communication with another RAN (not shown) employing any of a GSM, UMTS, CDMA 2000, WiMAX, E-UTRA, or Wi-Fi radio technology.

[0045] The CN 106/115 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and/or the internet protocol (IP) in the TCP/IP internet protocol suite. The networks 112 may include wired and/or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another CN connected to one or more RANs, which may employ the same RAT as the RAN 104/114 or a different RAT.

[0046] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities (e.g., the WTRUs 102a, 102b, 102c, 102d may include multiple transceivers for communicating with different wireless networks over different wireless links). For example, the WTRU 102c shown in FIG. 1A may be configured to communicate with

the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0047] FIG. 1B is a system diagram illustrating an example WTRU 102. As shown in FIG. 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, non-removable memory 130, removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and/or other elements/peripherals 138, among others. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0048] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While FIG. 1B depicts the processor 118 and the transceiver 120 as separate components, it will be appreciated that the processor 118 and the transceiver 120 may be integrated together, e.g., in an electronic package or chip.

[0049] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station 114a) over the air interface 116. For example, in an embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In an embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In an embodiment, the transmit/receive element 122 may be configured to transmit and/or receive both RF and light signals. It will be appreciated that the transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0050] Although the transmit/receive element 122 is depicted in FIG. 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. For example, the WTRU 102 may employ MIMO technology. Thus, in an embodiment, the WTRU 102 may include two or more transmit/receive elements 122 (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface 116.

[0051] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as NR and IEEE 802.11, for example.

[0052] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in, memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0053] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), etc.), solar cells, fuel cells, and the like.

[0054] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset 136, the WTRU 102 may receive location information over the air interface 116 from a base station (e.g., base stations 114a, 114b) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0055] The processor 118 may further be coupled to other elements/peripherals 138, which may include one or more software and/or hardware modules/units that provide additional features, functionality and/or wired or wireless connectivity. For example, the elements/peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (e.g., for

photographs and/or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, a virtual reality and/or augmented reality (VR/AR) device, an activity tracker, and the like. The elements/peripherals 138 may include one or more sensors, the sensors may be one or more of a gyroscope, an accelerometer, a hall effect sensor, a magnetometer, an orientation sensor, a proximity sensor, a temperature sensor, a time sensor; a geolocation sensor; an altimeter, a light sensor, a touch sensor, a magnetometer, a barometer, a gesture sensor, a biometric sensor, and/or a humidity sensor.

[0056] The WTRU 102 may include a full duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for both the uplink (e.g., for transmission) and downlink (e.g., for reception) may be concurrent and/or simultaneous. The full duplex radio may include an interference management unit to reduce and or substantially eliminate self-interference via either hardware (e.g., a choke) or signal processing via a processor (e.g., a separate processor (not shown) or via processor 118). In an embodiment, the WTRU 102 may include a half-duplex radio for which transmission and reception of some or all of the signals (e.g., associated with particular subframes for either the uplink (e.g., for transmission) or the downlink (e.g., for reception)).

[0057] FIG. 1C is a system diagram illustrating the RAN 104 and the CN 106 according to an embodiment. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 116. The RAN 104 may also be in communication with the CN 106.

[0058] The RAN 104 may include eNode-Bs 160a, 160b, 160c, though it will be appreciated that the RAN 104 may include any number of eNode-Bs while remaining consistent with an embodiment. The eNode-Bs 160a, 160b, 160c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In an embodiment, the eNode-Bs 160a, 160b, 160c may implement MIMO technology. Thus, the eNode-B 160a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0059] Each of the eNode-Bs 160a, 160b, and 160c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink (UL) and/or downlink (DL), and the like. As shown in FIG. 1C, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0060] The CN 106 shown in FIG. 1C may include a mobility management entity (MME) 162, a serving gateway (SGW) 164, and a packet data network (PDN) gateway (PGW) 166. While each of the foregoing elements are depicted as part of the CN 106, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the CN operator.

[0061] The MME 162 may be connected to each of the eNode-Bs 160a, 160b, and 160c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 162 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The MME 162 may provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM and/or WCDMA.

[0062] The SGW 164 may be connected to each of the eNode-Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The SGW 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The SGW 164 may perform other functions, such as anchoring user planes during inter-eNode-B handovers, triggering paging when DL data is available for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0063] The SGW 164 may be connected to the PGW 166, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0064] The CN 106 may facilitate communications with other networks. For example, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the CN 106 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 106 and the PSTN 108. In addition, the CN 106 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers.

[0065] Although the WTRU is described in FIGs. 1A-1D as a wireless terminal, it is contemplated that in certain representative embodiments that such a terminal may use (e.g., temporarily or permanently) wired communication interfaces with the communication network.

[0066] In representative embodiments, the other network 112 may be a WLAN.

[0067] A WLAN in infrastructure basic service set (BSS) mode may have an access point (AP) for the BSS and one or more stations (STAs) associated with the AP. The AP may have an access

or an interface to a distribution system (DS) or another type of wired/wireless network that carries traffic into and/or out of the BSS. Traffic to STAs that originates from outside the BSS may arrive through the AP and may be delivered to the STAs. Traffic originating from STAs to destinations outside the BSS may be sent to the AP to be delivered to respective destinations. Traffic between STAs within the BSS may be sent through the AP, for example, where the source STA may send traffic to the AP and the AP may deliver the traffic to the destination STA. The traffic between STAs within a BSS may be considered and/or referred to as peer-to-peer traffic. The peer-to-peer traffic may be sent between (e.g., directly between) the source and destination STAs with a direct link setup (DLS). In certain representative embodiments, the DLS may use an 802.11e DLS or an 802.11z tunneled DLS (TDLS). A WLAN using an Independent BSS (IBSS) mode may not have an AP, and the STAs (e.g., all of the STAs) within or using the IBSS may communicate directly with each other. The IBSS mode of communication may sometimes be referred to herein as an "ad-hoc" mode of communication.

[0068] When using the 802.11ac infrastructure mode of operation or a similar mode of operations, the AP may transmit a beacon on a fixed channel, such as a primary channel. The primary channel may be a fixed width (e.g., 20 MHz wide bandwidth) or a dynamically set width via signalling. The primary channel may be the operating channel of the BSS and may be used by the STAs to establish a connection with the AP. In certain representative embodiments, Carrier sense multiple access with collision avoidance (CSMA/CA) may be implemented, for example in 802.11 systems. For CSMA/CA, the STAs (e.g., every STA), including the AP, may sense the primary channel. If the primary channel is sensed/detected and/or determined to be busy by a particular STA, the particular STA may back off. One STA (e.g., only one station) may transmit at any given time in a given BSS.

[0069] High throughput (HT) STAs may use a 40 MHz wide channel for communication, for example, via a combination of the primary 20 MHz channel with an adjacent or nonadjacent 20 MHz channel to form a 40 MHz wide channel.

[0070] Very high throughput (VHT) STAs may support 20 MHz, 40 MHz, 80 MHz, and/or 160 MHz wide channels. The 40 MHz, and/or 80 MHz, channels may be formed by combining contiguous 20 MHz channels. A 160 MHz channel may be formed by combining 8 contiguous 20 MHz channels, or by combining two non-contiguous 80 MHz channels, which may be referred to as an 80+80 configuration. For the 80+80 configuration, the data, after channel encoding, may be passed through a segment parser that may divide the data into two streams. Inverse fast fourier transform (IFFT) processing, and time domain processing, may be done on each stream separately. The streams may be mapped on to the two 80 MHz channels, and the data may be transmitted by

a transmitting STA. At the receiver of the receiving STA, the above-described operation for the 80+80 configuration may be reversed, and the combined data may be sent to a medium access control (MAC) layer, entity, etc.

[0071] Sub 1 GHz modes of operation are supported by 802.11af and 802.11ah. The channel operating bandwidths, and carriers, are reduced in 802.11af and 802.11ah relative to those used in 802.11n, and 802.11ac. 802.11af supports 5 MHz, 10 MHz and 20 MHz bandwidths in the TV white space (TVWS) spectrum, and 802.11ah supports 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz bandwidths using non-TVWS spectrum. According to a representative embodiment, 802.11ah may support meter type control/machine-type communications (MTC), such as MTC devices in a macro coverage area. MTC devices may have certain capabilities, for example, limited capabilities including support for (e.g., only support for) certain and/or limited bandwidths. The MTC devices may include a battery with a battery life above a threshold (e.g., to maintain a very long battery life).

[0072] WLAN systems, which may support multiple channels, and channel bandwidths, such as 802.11n, 802.11ac, 802.11af, and 802.11ah, include a channel which may be designated as the primary channel. The primary channel may have a bandwidth equal to the largest common operating bandwidth supported by all STAs in the BSS. The bandwidth of the primary channel may be set and/or limited by a STA, from among all STAs in operating in a BSS, which supports the smallest bandwidth operating mode. In the example of 802.11ah, the primary channel may be 1 MHz wide for STAs (e.g., MTC type devices) that support (e.g., only support) a 1 MHz mode, even if the AP, and other STAs in the BSS support 2 MHz, 4 MHz, 8 MHz, 16 MHz, and/or other channel bandwidth operating modes. Carrier sensing and/or network allocation vector (NAV) settings may depend on the status of the primary channel. If the primary channel is busy, for example, due to a STA (which supports only a 1 MHz operating mode), transmitting to the AP, the entire available frequency bands may be considered busy even though a majority of the frequency bands remains idle and may be available.

[0073] In the United States, the available frequency bands, which may be used by 802.11ah, are from 902 MHz to 928 MHz. In Korea, the available frequency bands are from 917.5 MHz to 923.5 MHz. In Japan, the available frequency bands are from 916.5 MHz to 927.5 MHz. The total bandwidth available for 802.11ah is 6 MHz to 26 MHz depending on the country code.

[0074] FIG. 1D is a system diagram illustrating the RAN 113 and the CN 115 according to an embodiment. As noted above, the RAN 113 may employ an NR radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 113 may also be in communication with the CN 115.

[0075] The RAN 113 may include gNBs 180a, 180b, 180c, though it will be appreciated that the RAN 113 may include any number of gNBs while remaining consistent with an embodiment. The gNBs 180a, 180b, 180c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In an embodiment, the gNBs 180a, 180b, 180c may implement MIMO technology. For example, gNBs 180a, 180b may utilize beamforming to transmit signals to and/or receive signals from the WTRUs 102a, 102b, 102c. Thus, the gNB 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. In an embodiment, the gNBs 180a, 180b, 180c may implement carrier aggregation technology. For example, the gNB 180a may transmit multiple component carriers to the WTRU 102a (not shown). A subset of these component carriers may be on unlicensed spectrum while the remaining component carriers may be on licensed spectrum. In an embodiment, the gNBs 180a, 180b, 180c may implement Coordinated Multi-Point (CoMP) technology. For example, WTRU 102a may receive coordinated transmissions from gNB 180a and gNB 180b (and/or gNB 180c).

[0076] The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using transmissions associated with a scalable numerology. For example, OFDM symbol spacing and/or OFDM subcarrier spacing may vary for different transmissions, different cells, and/or different portions of the wireless transmission spectrum. The WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using subframe or transmission time intervals (TTIs) of various or scalable lengths (e.g., including a varying number of OFDM symbols and/or lasting varying lengths of absolute time).

[0077] The gNBs 180a, 180b, 180c may be configured to communicate with the WTRUs 102a, 102b, 102c in a standalone configuration and/or a non-standalone configuration. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c without also accessing other RANs (e.g., such as eNode-Bs 160a, 160b, 160c). In the standalone configuration, WTRUs 102a, 102b, 102c may utilize one or more of gNBs 180a, 180b, 180c as a mobility anchor point. In the standalone configuration, WTRUs 102a, 102b, 102c may communicate with gNBs 180a, 180b, 180c using signals in an unlicensed band. In a non-standalone configuration WTRUs 102a, 102b, 102c may communicate with/connect to gNBs 180a, 180b, 180c while also communicating with/connecting to another RAN such as eNode-Bs 160a, 160b, 160c. For example, WTRUs 102a, 102b, 102c may implement DC principles to communicate with one or more gNBs 180a, 180b, 180c and one or more eNode-Bs 160a, 160b, 160c substantially simultaneously. In the non-standalone configuration, eNode-Bs 160a, 160b, 160c may serve as a

mobility anchor for WTRUs 102a, 102b, 102c and gNBs 180a, 180b, 180c may provide additional coverage and/or throughput for servicing WTRUs 102a, 102b, 102c.

[0078] Each of the gNBs 180a, 180b, 180c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the UL and/or DL, support of network slicing, dual connectivity, interworking between NR and E-UTRA, routing of user plane data towards user plane functions (UPFs) 184a, 184b, routing of control plane information towards access and mobility management functions (AMFs) 182a, 182b, and the like. As shown in FIG. 1D, the gNBs 180a, 180b, 180c may communicate with one another over an Xn interface.

[0079] The CN 115 shown in FIG. 1D may include at least one AMF 182a, 182b, at least one UPF 184a, 184b, at least one session management function (SMF) 183a, 183b, and at least one Data Network (DN) 185a, 185b. While each of the foregoing elements are depicted as part of the CN 115, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the CN operator.

[0080] The AMF 182a, 182b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N2 interface and may serve as a control node. For example, the AMF 182a, 182b may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, support for network slicing (e.g., handling of different protocol data unit (PDU) sessions with different requirements), selecting a particular SMF 183a, 183b, management of the registration area, termination of NAS signalling, mobility management, and the like. Network slicing may be used by the AMF 182a, 182b, e.g., to customize CN support for WTRUs 102a, 102b, 102c based on the types of services being utilized WTRUs 102a, 102b, 102c. For example, different network slices may be established for different use cases such as services relying on ultra-reliable low latency (URLLC) access, services relying on enhanced massive mobile broadband (eMBB) access, services for MTC access, and/or the like. The AMF 162 may provide a control plane function for switching between the RAN 113 and other RANs (not shown) that employ other radio technologies, such as LTE, LTE-A, LTE-A Pro, and/or non-3GPP access technologies such as Wi-Fi.

[0081] The SMF 183a, 183b may be connected to an AMF 182a, 182b in the CN 115 via an N11 interface. The SMF 183a, 183b may also be connected to a UPF 184a, 184b in the CN 115 via an N4 interface. The SMF 183a, 183b may select and control the UPF 184a, 184b and configure the routing of traffic through the UPF 184a, 184b. The SMF 183a, 183b may perform other functions, such as managing and allocating UE IP address, managing PDU sessions, controlling policy

enforcement and QoS, providing downlink data notifications, and the like. A PDU session type may be IP-based, non-IP based, Ethernet-based, and the like.

[0082] The UPF 184a, 184b may be connected to one or more of the gNBs 180a, 180b, 180c in the RAN 113 via an N3 interface, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, e.g., to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices. The UPF 184a, 184b may perform other functions, such as routing and forwarding packets, enforcing user plane policies, supporting multi-homed PDU sessions, handling user plane QoS, buffering downlink packets, providing mobility anchoring, and the like.

[0083] The CN 115 may facilitate communications with other networks. For example, the CN 115 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the CN 115 and the PSTN 108. In addition, the CN 115 may provide the WTRUs 102a, 102b, 102c with access to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers. In an embodiment, the WTRUs 102a, 102b, 102c may be connected to a local Data Network (DN) 185a, 185b through the UPF 184a, 184b via the N3 interface to the UPF 184a, 184b and an N6 interface between the UPF 184a, 184b and the DN 185a, 185b.

[0084] In view of FIGs. 1A-1D, and the corresponding description of FIGs. 1A-1D, one or more, or all, of the functions described herein with regard to any of: WTRUs 102a-d, base stations 114a-b, eNode-Bs 160a-c, MME 162, SGW 164, PGW 166, gNBs 180a-c, AMFs 182a-b, UPFs 184a-b, SMFs 183a-b, DNs 185a-b, and/or any other element(s)/device(s) described herein, may be performed by one or more emulation elements/devices (not shown). The emulation devices may be one or more devices configured to emulate one or more, or all, of the functions described herein. For example, the emulation devices may be used to test other devices and/or to simulate network and/or WTRU functions.

[0085] The emulation devices may be designed to implement one or more tests of other devices in a lab environment and/or in an operator network environment. For example, the one or more emulation devices may perform the one or more, or all, functions while being fully or partially implemented and/or deployed as part of a wired and/or wireless communication network in order to test other devices within the communication network. The one or more emulation devices may perform the one or more, or all, functions while being temporarily implemented/deployed as part of a wired and/or wireless communication network. The emulation device (e.g., a network node) may be directly coupled to another device for purposes of testing and/or may performing testing using over-the-air wireless communications.

[0086] The one or more emulation devices may perform the one or more, including all, functions while not being implemented/deployed as part of a network node (e.g., wired and/or wireless communication network). For example, the emulation devices may be utilized in a testing scenario in a testing laboratory and/or a non-deployed (e.g., testing) wired and/or wireless communication network in order to implement testing of one or more components. The one or more emulation devices may be test equipment. Direct RF coupling and/or wireless communications via RF circuitry (e.g., which may include one or more antennas) may be used by the emulation devices to transmit and/or receive data.

[0087] In RAN#94-e meeting of 3GPP, RAN study item on Artificial Intelligence (AI)/Machine Learning (ML) for NR air interface was agreed to establish a general framework for enhancing air interface using AI/ML with a focus on three use cases, namely, channel state information (CSI) feedback, beam management, and positioning. The objective of the beam management study aims at decreasing the number of codebook-based (e.g., preconfigured) network (NW) side and WTRU side beam sweeps by leveraging AI/ML techniques.

[0088] Recurrent neural networks (RNN) may be a class of neural networks for uncovering complex relationships between temporal components in an input sequence. RNNs may consist of an input layer, an output layer and one (or more) hidden layers, where the hidden layers may use memory of previous states to perform prediction. Referring to Fig. 2, a representation of a RNN is shown. A state $\mathbf{s}_t$ is recurrently feedback as input to the neural network RNN, together with $\mathbf{x}_t$ to obtain output $\mathbf{y}_t$. Referring to Fig. 3, an unrolled depiction of RNN is shown to illustrate the interaction between the components for T recurrences.

[0089] Beam establishment procedures (e.g., codebook-based) relying on pre-configured sets of beams may cause high latency as they require measuring of a large number of beams (i.e., RS resources) at the WTRU. In addition, these procedures may be sub-optimal since the beams in these codebooks may be fixed that may cause lower L1-RSRP compared to ideal (genie-aided) beam and hence do not account for the dynamics of a given WTRU and its environment. An opportunity therefore may lie in deriving methods to enable beam alignment with alternative codebook-free (i.e., non-pre-configured) beams to help reduce the beam measurement latency and increase L1-RSRP. The below description address the following list of issues: How to enable data-driven (codebook-free/non-pre-configured) WTRU and network beam patterns at the WTRU with optimal physical layer-reference signal received power (L1-RSRP) and lower number of measurements, and feedback the beam pattern(s) to the network (NW)? How to leverage a learning-based framework to obtain codebook-free beam patterns and define enablers including configuration, training, inference, and reporting?

[0090] For systems with beam based access, methods for a WTRU to perform beam measurements on RS resources may be performed by means of: i) determining recurrently a set of sensing vectors (e.g., WTRU Rx spatial filters); ii) using these sensing vectors to determine a final combining vector (e.g., WTRU Rx spatial filter); iii) using the final combining vector to determine a NW beam pattern (e.g., NW Tx spatial filter), e.g., using artificial intelligence and machine learning (AIML) techniques; iv) reporting (feeding back) the NW beam pattern(s) to the NW for beam alignment. The methods may include configuration, training, inference and feedback aspects of the NW and WTRU sensing and beam alignment controllers.

[0091] A WTRU may transmit or receive a physical channel or a reference signal according to at least one spatial domain filter. The term “beam” or “beam pattern” may be used to refer to a spatial domain filter. Beamforming and Tx spatial filter may be used interchangeably to denote the formation of the beam at NW or WTRU. In the examples and embodiments described herein sensing vector and combining vector may be used to denote the receive spatial filter at WTRU or at NW.

[0092] The WTRU may transmit a physical channel or signal using the same spatial domain filter as the spatial domain filter used for receiving a reference signal (RS) (such as CSI-RS) or a synchronization signal block (SS block). The WTRU transmission may be referred to as “target”, and the received RS or SS block may be referred to as “reference” or “source”. In such case, the WTRU may be said to transmit the target physical channel or signal according to a spatial relation with a reference to such RS or SS block.

[0093] During the sensing stage, WTRU may adjust the receive spatial filter parameters based on the sensing vector to perform beam measurement on RS resources. After the sensing stage during data transmission, WTRU may adjust the receive spatial filter parameters based on the combining vector for data transmission. Spatial filter parameters may denote the complex coefficients of antenna elements.

[0094] The WTRU may transmit a first physical channel or signal according to the same spatial domain filter as the spatial domain filter used for transmitting a second physical channel or signal. The first and second transmissions may be referred to as “target” and “reference” (or “source”), respectively. In such case, the WTRU may be said to transmit the first (target) physical channel or signal according to a spatial relation with a reference to the second (reference) physical channel or signal.

[0095] A spatial relation may be implicit, configured by radio resource control (RRC) or signaled by Medium Access Control control element (MAC CE) or by downlink control information (DCI). For example, a WTRU may implicitly transmit physical uplink shared channel (PUSCH) and

demodulation reference signal (DM-RS) of PUSCH according to the same spatial domain filter as an sound reference signal (SRS) indicated by an SRS resource indicator (SRI) indicated in DCI or configured by RRC. In another example, a spatial relation may be configured by RRC for an SRS resource indicator (SRI) or signaled by MAC CE for a physical uplink control channel (PUCCH). Such spatial relation may also be referred to as a “beam indication”.

[0096] The WTRU may receive a first (target) downlink channel or signal according to the same spatial domain filter or spatial reception parameter as a second (reference) downlink channel or signal. For example, such association may exist between a physical channel such as physical downlink control channel (PDCCH) or physical downlink shared channel (PDSCH) and its respective DM-RS. At least when the first and second signals are reference signals, such association may exist when the WTRU is configured with a quasi-colocation (QCL) assumption type D between corresponding antenna ports. Such association may be configured as a transmission configuration indicator (TCI) state. A WTRU may be indicated an association between a CSI-RS or SS block and a DM-RS by an index to a set of TCI states configured by RRC and/or signaled by MAC CE. Such indication may also be referred to as a “beam indication”.

[0097] A unified TCI (e.g., a common TCI, a common beam, a common RS, etc.) may refer to a beam/RS to be (simultaneously) used for multiple physical channels/signals. The term “TCI” may at least comprise a TCI state that includes at least one source RS to provide a reference (e.g., WTRU assumption) for determining QCL and/or spatial filter.

[0098] The WTRU may be configured with a first mode for unified TCI where an indicated unified TCI (e.g., the first unified TCI or the second unified TCI) may be applicable for either downlink (e.g., based on the first unified TCI) or uplink (e.g., based on the second unified TCI).

[0099] The WTRU may be configured with a second mode for unified TCI where an indicated unified TCI (e.g., the third unified TCI) may be applicable for both downlink and uplink (e.g., based on the third unified TCI).

[0100] The WTRU may determine a TCI state applicable to a transmission or reception by first determining a unified TCI state instance applicable to this transmission or reception, then determining a TCI state corresponding to the unified TCI state instance. A transmission may consist of at least PUCCH, PUSCH, SRS. A reception may consist of at least PDCCH, PDSCH, CSI-RS. A unified TCI state instance may also be referred to TCI state group, TCI state process, unified TCI pool, a group of TCI states, a set of time-domain instances/stamps/slots/symbols, and/or a set of frequency-domain instances/resource blocks (RBs)/subbands, etc.

[0101] Hereafter, unified TCI may be interchangeably used with one or more of unified TCI-states, unified TCI instance, TCI, and TCI-state.

[0102] Hereafter, a transmission and reception point (TRP), may be interchangeably used with one or more of transmission point (TP), reception point (RP), radio remote head (RRH), distributed antenna (DA), base station (BS), a sector (of a BS), and a cell (e.g., a geographical cell area served by a BS). Hereafter, Multi-TRP may be interchangeably used with one or more of MTRP, M-TRP, and multiple TRPs.

[0103] A WTRU may be configured with (or may receive configuration of) one or more TRPs to which the WTRU may transmit and/or from which the WTRU may receive. The WTRU may be configured with one or more TRPs for one or more cells. A cell may be a serving cell, or a secondary cell.

[0104] A WTRU may be configured with at least one RS for the purpose of channel measurement. This RS may be denoted as a channel measurement resource (CMR) and may comprise a CSI-RS, SSB, or other downlink RS transmitted from a TRP to a WTRU. A CMR may be configured or associated with a TCI state. A WTRU may be configured with a CMR group where CMRs transmitted from the same TRP may be configured. Each group may be identified by a CMR group index (e.g., group 1). A WTRU may be configured with one CMR group per TRP, and the WTRU may receive a linkage between one CMR group index and another CMR group index, or between one RS index from one CMR group and another RS index from another group.

[0105] A WTRU may be configured with (or receive configuration of) one or more pathloss (PL) reference groups (e.g., sets) and/or one or more SRS groups, SRS resource indicator (SRI) or SRS resource sets. A PL reference group may correspond to or may be associated with a TRP. A PL reference group may include, identify, correspond to or be associated with one or more TCI states, SRIs, reference signal sets (e.g. CSI-RS set, SRI sets), CORESET index, and or reference signals (e.g. CSI-RS, SSB).

[0106] A WTRU may receive a configuration (e.g., any configuration described herein). The configuration may be received from a gNB or TRP. For example, the WTRU may receive configuration of one or more TRPs, one or more PL reference groups and/or one or more SRI sets. A WTRU may implicitly determine an association between a RS set/group and a TRP. E.g., if the WTRU is configured with two SRS resource sets, then the WTRU may determine to transmit to TRP1 with SRS in the first resource set, and to TRP2 with SRS in the second resource set. The configuration may be via RRC signaling.

[0107] In the examples and embodiments described herein, TRP, PL reference group, SRI group, and SRI set may be used interchangeably.

[0108] A WTRU may report a subset of channel state information (CSI) components, where CSI components may correspond to at least a CSI-RS resource indicator (CRI), a SSB resource indicator (SSBRI), an indication of a panel used for reception at the WTRU (such as a panel identity or group identity), measurements such as L1-RSRP, L1-signal to interference noise ratio (SINR) taken from SSB or CSI-RS (e.g., cri-RSRP, cri-SINR, ssb-Index-RSRP, ssb-Index-SINR), and other channel state information such as at least rank indicator (RI), channel quality indicator (CQI), precoding matrix indicator (PMI), layer index (LI), and/or the like.

[0109] Hereafter, a signal may be interchangeably used with one or more of following: sounding reference signal (SRS), channel state information – reference signal (CSI-RS), demodulation reference signal (DM-RS), phase tracking reference signal (PT-RS), and synchronization signal block (SSB).

[0110] Hereafter, a channel may be interchangeably used with one or more of following: physical downlink control channel (PDCCH), physical downlink shared channel (PDSCH), physical uplink control channel (PUCCH), physical uplink shared channel (PUSCH), and physical random access channel (PRACH).

[0111] Hereafter, downlink reception may be used interchangeably with Rx occasion, PDCCH, PDSCH, and SSB reception.

[0112] Hereafter, uplink transmission may be used interchangeably with Tx occasion, PUCCH, PUSCH, PRACH, and SRS transmission.

[0113] Hereafter, RS may be interchangeably used with one or more of RS resource, RS resource set, RS port and RS port group.

[0114] Hereafter, RS may be interchangeably used with one or more of SSB, CSI-RS, SRS and DM-RS.

[0115] Hereafter, time instance may be interchangeably used with slot, symbol, and subframe.

[0116] Referring to Fig. 4, a structure of the network (e.g., base station, BS) and a WTRU beam alignment controller is shown. The shown system model may be described using the formula:

$$y_t = \mathbf{w}_t^H \mathbf{H} \mathbf{f}_t + \mathbf{w}_t^H \mathbf{n}_t \quad (1)$$

wherein y_t denotes a complex received symbol at the base station, $\mathbf{H}$ denotes complex channel coefficients of size $N_{RX} \times N_{TX}$, $\mathbf{w}_t$ denotes the N_{RX} dimensional complex combining vector, $\mathbf{f}_t$ denotes N_{TX} dimensional complex beamforming vector and $\mathbf{n}_t \sim \mathcal{CN}(0, \sigma_n^2 \mathbf{I}_{N_{RX}})$ denotes the complex noise vector, all for timestep t . The received signal-to-noise ratio after combining for a given $\mathbf{w}_t$ and $\mathbf{f}_t$ is given as:

$$\text{SNR} = \frac{\|\mathbf{w}_t^H \mathbf{H} \mathbf{f}_t\|^2}{\|\mathbf{w}_t^H \mathbf{n}_t\|^2} \quad (2)$$

[0117] Given that the SNR is above a threshold, the beam ID (e.g., RS resource index) may be recovered at the WTRU as x_t . The WTRU may receive RS for the measurement of channel. The WTRU may be pre-configured with the resources to receive RS for beam measurement, or the WTRU may receive configurations on the RS resources vis DCI or RRC signaling.

[0118] In an embodiment, a NW-WTRU joint beam alignment may be performed with sensing and learned feedback. Referring to Fig. 5, a recursive system model for training and inference of a NW-WTRU beam alignment is shown. The embodiment is based on a recursive AIML model.

[0119] Referring to Fig. 5, a WTRU beam alignment (BA) controller and a NW BA controller may be used. The NW BA controller may perform beam sweep followed by a trainable feedforward neural network (FNN), whereas WTRU BA controller may be composed of a trainable RNN model. The recursive AIML model may take as input y_{t-1} (metric for measured beam, e.g., L1-RSRP), x_{t-1} (beam index) and s_{t-1} and then may output a sensing vector w_t and a state vector s_t . The previous output state vector at time $t - 1$, i.e., s_{t-1} , may be the recursive input to the model to compute next outputs and s_t at time t . The embodiment may be trained to learn the best and final WTRU combining vector w_{T-1} (e.g., Rx spatial filter parameters) at time step $T - 1$ after $T - 1$ sensing steps and NW beamforming vector f_t (e.g., Tx spatial filter parameters) between $0 \leq t \leq T - 2$. For $t \leq T - 2$, the WTRU may perform beam measurement on RS resources using sensing vector w_t (i.e., Rx spatial filter or beam pattern) with the codebook-based NW beamforming vector f_t (i.e., beam pattern). At time $t = T - 2$, the WTRU may perform the last sensing step and may compute a vector m_f representing the compressed NW beamforming vector (i.e., beam pattern) to be feedback to the NW. Having received the vector m_f , the NW may compute the non-codebook-based beamforming vector f_{T-1} to be used in subsequent data transmissions for $t \geq T - 1$. At time $t = T - 1$, the WTRU may compute final combining vector w_{T-1} (i.e., Rx spatial filter parameters) to be used in subsequent data transmissions for $t \geq T - 1$.

[0120] The embodiment may be trained to find RNN parameters of WTRU BA controller and FNN parameters of NW BA controller so that at $t = T - 1$ the beamforming gain may be maximized with WTRU combining vector w_{T-1} and NW beamforming vector f_{T-1} . As an example the embodiment may comprise a training stage to optimize the following objective function and constraints.

$$\max_{\theta_1, \theta_2, \theta_3, \theta_4} \frac{\|w_{T-1}^H H f_{T-1}\|^2}{\|H\|_2}$$

s. t.:

$$\begin{aligned} w_t &= f_{R, \theta_1}(y_{<t}, x_{<t}, w_{<t}) \quad \forall t \\ m_f &= f_{R, \theta_2}(y_{<T-2}, x_{<T-2}, w_{<T-2}) \end{aligned}$$

$$\begin{aligned}\mathbf{f}_{T-1} &= f_{R,\theta_3}(\mathbf{m}_f) \\ \mathbf{f}_t &= \mathbf{F}_{\theta_4}[(t+i) \bmod N_{\text{CB}}] \text{ for } t < T-1 \\ \|\mathbf{w}_t\|_2^2 &= 1 \forall t \\ \|\mathbf{f}_t\|_2^2 &= 1 \forall t\end{aligned}$$

wherein $f_{R,\theta_1}(\cdot)$ denotes an RNN AIML model that outputs $\mathbf{w}_t$ at the WTRU controller and θ_1 denotes the corresponding learnable parameters, $f_{R,\theta_2}(\cdot)$ denotes an FNN AIML model that outputs $\mathbf{m}_f$ at the WTRU controller and θ_2 denotes the corresponding learnable parameters, $f_{R,\theta_3}(\cdot)$ denotes an FNN AIML model that outputs the NW beam $\mathbf{f}_{T-1}$ at the NW controller and θ_3 denotes the corresponding learnable parameters, and $\mathbf{F}_{\theta_4}$ denotes the learnable NW codebook that outputs the NW beamforming vectors $\mathbf{f}_t$ at the NW controller. In another option, the NW codebook can be fixed (e.g., not trainable).

[0121] Below are configuration for WTRU-NW beam alignment.

[0122] A WTRU may be configured with the number of sensing steps (e.g., T-1) to be used for beam alignment. At each sensing step, the WTRU may use sensing vector computed by the AIML model.

[0123] A WTRU may be configured with an AIML model for beam alignment. The configuration may comprise of the indication of model parameters or the model ID. In case of model ID, the WTRU may have a set of pre-configured AIML models.

[0124] A WTRU may be configured to receive RS resources (e.g., SSB, CSI-RS, etc.) from the NW. The configured resources may be used to measure receive signal strength such as L1-RSRP, and index of the resources. Beam measurement related values such a L1-RSRP and beam index may be input to the AIML model.

[0125] A WTRU may be configured with the size of feedback to be reported to NW for the NW to set-up the codebook-free NW beamforming vector. The size of feedback may be used by the WTRU to determine the output size of AIML model for example by means of quantization.

[0126] Following the configurations on the beam alignment controller, the WTRU may wait for a triggering of a mechanism to start beam measurements. As an example, the beam alignment mechanism may be triggered by the start of an initial connection establishment process. As another example, the beam alignment mechanism may be triggered by handover to a new cell where the WTRU moves. As another example, the mechanism may be triggered after the detection of a beam failure. As another example, the WTRU may wait for an indication from the NW to start the beam alignment mechanism. As another example, a timeout trigger may be set to trigger the beam alignment process periodically or a-periodically. As another example, measurements in the

previous measurement window may trigger another beam alignment procedure based on pre-configured parameters or thresholds.

[0127] Below is an example of methods for NW-WTRU beam alignment with learned feedback.

[0128] The WTRU may load the configured recursive AIML model and parameters to be used for beam measurements during T-1 sensing steps and activates the AIML model. Before the first beam measurement on RS resources, the WTRU may input the initialization parameters (e.g., y_{-1}, x_{-1} in Fig. 5) to the recursive AIML model. After the initialization step, the WTRU may compute the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_0$, using the AIML model. Having computed the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_0$, the WTRU may adjust the Rx spatial filter parameters accordingly.

[0129] The WTRU may receive the configured RS resources (beamformed with $\mathbf{f}_0$) for beam measurement. Then, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_0$ and obtains y_0 and x_0 . If the beam measurement metric y_0 (L1-RSRP, SINR etc.) is below a certain threshold, the WTRU may omit the measurement (e.g., WTRU may assume $y_0 = 0$ and $x_0 = \emptyset$).

[0130] The measured metrics y_0 and x_0 and the previous state vector $\mathbf{s}_0$ may be used as inputs to the AIML model to recursively determine the next sensing vector $\mathbf{w}_1$ and state vector $\mathbf{s}_1$. Then, the Rx spatial filter parameters for beam measurement are adjusted based on the new sensing vector $\mathbf{w}_1$.

[0131] The WTRU may receive the configured RS resources (beamformed with $\mathbf{f}_1$) for beam measurement. Then, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_1$ and obtains y_1 and x_1 . If the beam measurement metric y_1 (L1-RSRP, SINR etc.) is below a certain threshold, the WTRU may omit the measurement (e.g., WTRU may assume $y_1 = 0$ and $x_1 = \emptyset$).

[0132] The WTRU may recursively input $y_{t-1}, x_{t-1}, \mathbf{s}_{t-1}$ to the AIML model, may compute sensing vector $\mathbf{w}_t$ and state vector $\mathbf{s}_t$, and may perform beam measurement by adjusting the Rx spatial filter parameters based on $\mathbf{w}_t$ to obtain y_t, x_t . The recursive beam measurement process may continue until $t = T - 2$, i.e., until end of sensing stage.

[0133] The WTRU may stop the beam measurement process after the configured number of sensing steps is reached or at the end of measurement window. At $t = T - 2$, the WTRU may adjust the Rx spatial filter parameters based on the sensing vector $\mathbf{w}_{T-2}$ and performs final beam measurement on RS resources (beamformed with beamforming vector $\mathbf{f}_{T-2}$). The WTRU may

obtain y_{T-2} , x_{T-2} , $\mathbf{s}_{T-2}$. Then the WTRU may input y_{T-2} , x_{T-2} , $\mathbf{s}_{T-2}$ to the AIML model and may compute the codebook-free (i.e., non-preconfigured) combining vector $\mathbf{w}_{T-1}$. The combining vector may be the final vector that will be used to adjust Rx spatial filter parameters for data transmissions. In addition, at $t = T - 2$, the AIML model at WTRU may compute another output $\mathbf{m}_f$ (i.e., the learned feedback) which is a compressed representation of the best codebook-free NW beamforming vector $\mathbf{f}_{T-1}$. The WTRU may feedback the learned feedback $\mathbf{m}_f$ to the NW.

[0134] After the WTRU sends the feedback $\mathbf{m}_f$ to the NW, the WTRU may adjust the Rx spatial filter parameters based on the final combining vector $\mathbf{w}_{T-1}$. Then, the WTRU may receive a new RS resource beamformed with the codebook-free NW beamforming vector $\mathbf{f}_{T-1}$. The WTRU may perform beam measurement of the new RS resource and may feedback the CSI report to the NW. After the feedback on CSI report, the WTRU receives a new DCI indicating a new TCI state for the new beam created by the beamforming vector $\mathbf{f}_{T-1}$. Then the WTRU may start receiving data transmission using the Rx spatial filter parameters based on combining vector $\mathbf{w}_{T-1}$ from the NW beamformed with codebook-free NW beamforming vector $\mathbf{f}_{T-1}$.

[0135] At the end of the $T - 1$ sensing steps, the WTRU BA controller may compute the compressed representation of NW beamforming vector $\mathbf{m}_f$. Then the WTRU may feed back the compressed representation of NW beamforming vector $\mathbf{m}_f$ to the NW. The WTRU may initiate a RACH procedure at $t = T - 2$ using the resources indicated within the NW beam with the highest L1-RSRP. Then, after connected state, the WTRU may send the learned feedback $\mathbf{m}_f$ using PUCCH or PUSCH as a new message feedback message.

[0136] In case the WTRU is already in connected state at the beginning of the procedures, the WTRU may feedback the compressed representation of NW beamforming vector $\mathbf{m}_f$ via PUCCH or PUSCH.

[0137] The number of sensing steps (e.g., beam measurement with sensing vectors) in the NW-WTRU beam alignment procedures may be reduced by enabling an early sensing method. At each sensing step the model may generate new learned feedback (e.g., compressed NW beamforming vector, $\mathbf{m}_{FB}$) and combining vector. Based on the convergence in combining vector and the NW beamforming vector, the WTRU may stop sensing and feedback the learned feedback before $T - 1$ sensing steps.

[0138] Referring to Fig. 6, an example of a flow chart illustrating a method 600 of NW-WTRU beam alignment according to an embodiment is shown.

[0139] At step 610, the WTRU may be configured with a number T of sensing steps, a recursive AIML model and initialization parameters. Considering step 600 is performed for $t=0$ (see Fig. 5). The WTRU may compute the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_0$,

using the recursive AIML model. Having computed the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_0$, the WTRU may adjust the Rx spatial filter parameters accordingly.

[0140] At step 620, the WTRU may receive, from the NW, configured RS resources for beam measurement at a time t . Then, at step 630, as an initial measurement, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_0$ and obtains y_0 and x_0 . If the beam measurement metric y_0 (L1-RSRP, SINR etc.) is below a certain threshold, according to step 635, the WTRU may omit the measurement (e.g., WTRU may assume $y_0 = 0$ and $x_0 = \emptyset$) and wait until the beam measurement metric (L1-RSRP, SINR etc.) become above the certain threshold.

[0141] In case the beam measurement metric (L1-RSRP, SINR etc.) is above the certain threshold, and in case $t < T - 2$ (step 640), according to step 645, the measured metrics may be used as inputs to the AIML model to recursively compute/determine the next sensing vector and state vector. Then, the Rx spatial filter parameters for beam measurement are adjusted based on the new sensing vector.

[0142] In the iteration illustrated by the loop steps 620, 630, 640, and 645 it has to be considered that the WTRU may recursively input $y_{t-1}, x_{t-1}, \mathbf{s}_{t-1}$ to the AIML model, may compute (step 645) sensing vector $\mathbf{w}_t$ and state vector $\mathbf{s}_t$, and performs beam measurement (step 620) by adjusting the Rx spatial filter parameters based on $\mathbf{w}_t$ to obtain y_t, x_t . The recursive beam measurement process may continue until $t = T - 2$, until end of sensing stage.

[0143] At $t = T - 2$, the WTRU may adjust the Rx spatial filter parameters based on the sensing vector $\mathbf{w}_{T-2}$ and performs final beam measurement on RS resources (beamformed with beamforming vector $\mathbf{f}_{T-2}$). The WTRU may obtain $y_{T-2}, x_{T-2}, \mathbf{s}_{T-2}$. At step 650 ($t = T - 2$), the AIML model at WTRU may compute a compressed representation of the best codebook-free NW beamforming vector $\mathbf{m}_f$ and, at step 660, the WTRU may feedback/transmit, to the NW, the compressed representation of the best codebook-free NW beamforming vector $\mathbf{m}_f$. At step 670, at $t = T-1$, the WTRU may input $y_{T-2}, x_{T-2}, \mathbf{s}_{T-2}$ to the recursive AIML model and may compute the codebook-free (i.e., non-preconfigured) combining vector $\mathbf{w}_{T-1}$. The combining vector may be the final vector that will be used to adjust Rx spatial filter parameters for data transmissions.

[0144] At step 680, the WTRU may receives a new DCI indicating a new TCI state for the new beam created by the beamforming vector $\mathbf{f}_{T-1}$. Then, at step 690, the WTRU may start receiving data transmission using the Rx spatial filter parameters based on combining vector $\mathbf{w}_{T-1}$ from the NW beamformed with codebook-free NW beamforming vector $\mathbf{f}_{T-1}$.

[0145] According to the above embodiments, wherein a NW-WTRU joint beam alignment may be performed with sensing and learned feedback, a WTRU may (i) recurrently computing codebook-free (non-pre-configured) sensing vectors to be used for adjusting Rx spatial filter parameters for beam measurement on RS resources for fixed T sensing steps (or fixed measurement window), (ii) computing codebook-free (non-pre-configured) combining vector (to be used to adjust the Rx spatial filter parameters after sensing phase) and a compressed codebook-free NW beamforming vector (to be used to adjust Tx spatial filter parameters at NW) at the end of T sensing steps, (iii) feedback the compressed NW beamforming vector to NW, (iv) adjusting the Rx spatial filter parameters based on the combining vector to receive data.

[0146] More particularly, the WTRU may be configured with any of: a number of sensing (measurement) steps; a sensing (measurement) window; the RS resources that can be used for sensing; a one-sided AIML model for NW-WTRU beam alignment, which may include model-ID; and a payload size for the feedback on NW beamforming vector.

[0147] In addition, the WTRU may be triggered to perform beam measurement using sensing vectors based one any of the following: initial connection establishment; handover to another cell; beam failure; indication by the NW; timeout trigger; and measurements in the previous window.

[0148] After a trigger on beam measurement, the WTRU may perform any of: loading and activating the AIML-model for NW-WTRU beam alignment; inputting the initialization parameters to the AIML model according to configuration of AIML model; computing an initial codebook-free (i.e., non-pre-configured) sensing vector using the AIML model; adjusting the Rx spatial filter parameters based on initial sensing vector; receiving RS resources for beam measurement; performing beam measurement (e.g., computing L1-RSRP, SINR, NW beam index etc.) on configured RS resource; omitting the beam measurement in case the current beam measurement (e.g., L1-RSRP, SINR etc.) is below a certain threshold; inputting the previous beam measurement (e.g., L1-RSRP), AIML model state vector and the NW beam index (i.e., RS resource index) to the AIML-based model; computing a new codebook-free (i.e., non-pre-configured) sensing vector (e.g., Rx spatial filter parameters to be used for beam measurement on next RS resource) and updated state vector as the output the AIML model; adjusting the Rx spatial filter parameters based on the new sensing vector; receiving RS resources for beam measurement; performing beam measurement (e.g., computing L1-RSRP, SINR, NW beam index etc.) on configured RS resources; omitting the beam measurement in case the current beam measurement (e.g., L1-RSRP, SINR etc.) is below a certain threshold; and recurrently computing a new sensing vector, receiving new RS and performing beam measurement until a stopping criterion is reached.

[0149] The WTRU stopping the beam measurement process after the configured number of sensing steps or end of measurement window is reached may perform any of: inputting the final beam measurement (e.g., L1-RSRP) and the NW beam index (i.e., RS resource index) to the WTRU-side AIML-based model; computing the final codebook-free (i.e., non-pre-configured) combining vector using the AIML model; computing a compressed codebook-free NW beamforming vector using the AIML model to be used by NW to adjust Tx spatial filter parameters; and feedback compressed codebook-free NW beamforming vector to NW.

[0150] The WTRU after the feedback on NW beamforming vector may perform any of: adjusting the Rx spatial filter parameters based on final combining vector; receiving a new RS resource beamformed with the codebook-free NW beamforming vector; perform channel measurement on the new RS resource; feedback CSI to NW based on the measurement; receiving DCI indicating a new TCI state; and receiving data transmission from the NW beamformed with codebook-free NW beamforming vector.

[0151] Below is an example of methods for WTRU-side data-driven beam alignment with early stopping. Referring to Fig. 7, a recursive system model for training and inference of the WTRU-side beam alignment with early stopping is shown. The embodiment is based on a recursive AIML model. Referring to Fig. 7, a WTRU sensing and beam alignment (BA) controller and a NW BA controller may be used.

[0152] In this embodiment, NW BA controller may perform traditional beam sweep, whereas WTRU BA controller may be composed of a trainable RNN model, T_RNN. The recursive AIML model may take as input y_{t-1} (metric for measured beam, e.g., L1-RSRP), x_{t-1} (beam index) and $\mathbf{s}_{t-1}$ and then may output a sensing vector $\mathbf{w}_{s,t}$ (e.g., Rx spatial filter parameters for beam measurement), a combining vector $\mathbf{w}_{g,t}$ (e.g., estimation of best Rx spatial filter or beam pattern to be used for downlink data) and a state vector $\mathbf{s}_t$. The previous output state vector at time $t - 1$, e.g., $\mathbf{s}_{t-1}$, may be the recursive input to the model to compute next outputs and $\mathbf{s}_t$ at time t . The embodiment may be trained to learn a new combining vector $\mathbf{w}_{g,t}$ and estimation of the best BS beamforming vector index i^* at each time step $t \leq T - 2$ using the sensing vector $\mathbf{w}_{s,t}$. At time $t = T - 2$, the WTRU may perform last sensing step using $\mathbf{w}_{s,T-2}$ and may compute the estimated best NW beam index i^* . The final combining vector $\mathbf{w}_{g,T-1}$ may be obtained at step $t = T - 1$.

[0153] The embodiment may be trained to find RNN and FNN parameters of WTRU BA controller so that at each t the beamforming gain may be maximized with WTRU combining vector $\mathbf{w}_{g,t}$ and the predicted best NW beamforming vector $\mathbf{F}[i_t^*]$ (e.g., beam pattern) at time each

sensing t to enable early stopping in case of detection of convergence in the combining vector $\mathbf{w}_{g,t}$ and beamforming vector index i_t^* .

[0154] Referring to Fig. 8, an example of a trainable recursive neural network (T-RNN) is shown. The T-RNN may comprise a RNN component that may output sensing vector $\mathbf{w}_{s,t}$ may may take as input y_{t-1} (metric for measured beam, e.g., L1-RSRP), x_{t-1} (beam index), a previous output state vector at time $t-1$, e.g., $\mathbf{s}_{t-1}$, and a current output state vector at time t , e.g., $\mathbf{s}_t$. The T-RNN may comprise a first FNN that may output a combining vector $\mathbf{w}_{g,t}$ (e.g., estimation of best Rx spatial filter or beam pattern to be used for downlink data). The T-RNN may comprise a second FNN that may output $\mathbf{z}_t$ representative of the beamforming vector index i_t^* .

[0155] Referring to Fig. 7 and Fig. 8, the embodiment may include a training statge to optimize the following objective function and constraints:

$$\max_{\theta_1, \theta_{2a}} \frac{\|\mathbf{w}_{g,t}^H \mathbf{H} \mathbf{f}_t\|^2}{\|\mathbf{H}\|_2}$$

$$\min_{\theta_1, \theta_{2b}} - \sum_{c=1}^{N_{CB}} u_c \log(z_{\text{soft},t,c})$$

$s. t.:$

$$\mathbf{w}_{s,t} = f_{R,\theta_1}(s_t) \forall t$$

$$\mathbf{w}_{g,t} = f_{R,\theta_{2a}}(s_t) \forall t$$

$$\mathbf{z}_t = f_{R,\theta_{2b}}(s_t) \forall t$$

$$\mathbf{f}_t = \mathbf{F}[(t+i) \bmod N_{CB}] \text{ for } t < T-1$$

$$\mathbf{f}_{T-1} = \mathbf{F}_{i^*}$$

$$\mathbf{z}_{\text{soft},t} = \frac{\exp(\mathbf{z}_t)}{\sum_{k=1}^{N_{CB}} \exp(z_{k,t})}$$

$$i_t^* = \max_i \left(\|z_{\text{soft},t,i}\|_2 \right) \forall t$$

$$\|\mathbf{w}_{\text{sensing},t}\|_2^2 = 1 \forall t$$

$$\|\mathbf{w}_{\text{gain},t}\|_2^2 = 1 \forall t$$

$$\|\mathbf{f}_t\|_2^2 = 1 \forall t$$

where $f_{R,\theta_1}(\cdot)$ denotes RNN that outputs $\mathbf{w}_{s,t}$ at the WTRU controller and θ_1 denotes the corresponding learnable parameters, $f_{R,\theta_{2a}}(\cdot)$ denotes the FNN that outputs $\mathbf{w}_{g,t}$ at the WTRU controller and θ_{2a} denotes the corresponding learnable parameters, $f_{R,\theta_{2b}}(\cdot)$ denotes the FNN that outputs $\mathbf{z}_t$ at the WTRU controller and θ_{2b} denotes the corresponding learnable parameters.

[0156] The WTRU may be configured for beam alignment with early stopping according to any of the following configuration: (i) the WTRU may be configured with the maximum number of sensing steps (e.g., T-1) to be used for beam alignment; at each sensing step the WTRU may use sensing vector computed by the AIML model; (ii) the WTRU may be configured with an AIML model for beam alignment; the configuration may comprise of the indication of model parameters or the model ID. In case of model ID, the WTRU may have a set of pre-configured AIML models; (iii) the WTRU may be configured to receive RS resources (e.g., SSB, CSI-RS, etc.) from the NW; the configured resources may be used to measure receive signal strength such as L1-RSRP, and index of the resources; beam measurement related values such a L1-RSRP and beam index may be input to the AIML model; (iv) the WTRU may be configured with an early stopping indicator for reduced latency beam alignment; when the WTRU is configured with an early stopping, the WTRU may compute estimate of best WTRU combining vector and NW beam index at every sensing step.

[0157] Following the configurations on the beam alignment controller, the WTRU may wait for the triggering of the mechanism to start beam measurements. As an example, the beam alignment mechanism may be triggered by the start of an initial connection establishment process. As another example, the beam alignment mechanism may be triggered by handover to a new cell where the WTRU moves. As another example, the mechanism may be triggered after the detection of a beam failure. As another example, the WTRU may wait for an indication from the NW to start the beam alignment mechanism. As another example, a timeout trigger may be set to trigger the beam alignment process periodically or a-periodically. As another example, measurements in the previous measurement window may trigger another beam alignment procedure based on pre-configured parameters or thresholds.

[0158] Below is an example of methods for WTRU beam alignment with early stopping.

[0159] The WTRU may load the configured recursive AIML model and parameters to be used for beam measurements during T-1 sensing steps and may activate the AIML model. Before the first beam measurement on RS resources, the WTRU may input the initialization parameters (e.g., y_{-1}, x_{-1} in Fig. 7) to the recursive AIML model. After the initialization step, the WTRU may compute the initial codebook-free (i.e., non-preconfigured) sensing vector $\mathbf{w}_{s,0}$ using the AIML

model. Having computed the initial codebook-free (i.e., non-preconfigured) sensing vector $\mathbf{w}_{s,0}$, the WTRU may adjust the Rx spatial filter parameters accordingly.

[0160] The WTRU may receive the configured RS resources (beamformed with $\mathbf{f}_0$) for beam measurement. Then, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_{s,0}$ and may obtain y_0 and x_0 . If the beam measurement metric y_0 (L1-RSRP, SINR etc.) is below a certain threshold, the WTRU may omit the measurement (e.g., WTRU may assume $y_0 = 0$ and $x_0 = \emptyset$).

[0161] The measured metrics y_0 and x_0 and the previous state vector $\mathbf{s}_0$ may be used as inputs to the AIML model to recursively determine the next sensing vector $\mathbf{w}_{s,1}$, estimate of the best combining vector $\mathbf{w}_{g,1}$, estimate of the best NW beam index i_1^* , and state vector $\mathbf{s}_1$. Then, the Rx spatial filter parameters for beam measurement may be adjusted based on the new sensing vector $\mathbf{w}_{s,1}$. The WTRU may receive the configured RS resources (beamformed with $\mathbf{f}_1$) for beam measurement. Then, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_{s,1}$ and may obtain/determine y_1 and x_1 . If the beam measurement metric y_1 (L1-RSRP, SINR etc.) is below a certain threshold, the WTRU may omit the measurement (e.g., UE may assume $y_1 = 0$ and $x_1 = \emptyset$).

[0162] The WTRU may recursively input $y_{t-1}, x_{t-1}, \mathbf{s}_{t-1}$ to the AIML model, and as output of the model computes sensing vector $\mathbf{w}_{s,t}$, estimate of the best combining vector $\mathbf{w}_{g,t}$, estimate of the best NW beam index i_t^* , and state vector $\mathbf{s}_t$, and then may perform beam measurement by adjusting the Rx spatial filter parameters based on $\mathbf{w}_t$ to obtain y_t, x_t .

[0163] The WTRU may stop the beam measurement process at time $t = t_s$ based on stopping criterion. For example, if at any time $t = t_s < T - 2$, if the absolute difference between current and previous WTRU combining vectors are below a threshold, i.e., $\|\mathbf{w}_{g,t_s} - \mathbf{w}_{g,t_s-1}\|_2 < \text{Thr}_w$, then the sensing may stop at $t = t_s$. At $t = t_s$, the WTRU may compute $y_{t_s}, x_{t_s}, \mathbf{s}_{t_s}$ as the output of the AIML model. Then, $y_{t_s}, x_{t_s}, \mathbf{s}_{t_s}$ may be input to the model and the WTRU may compute the final combining vector $\mathbf{w}_{g,t_s+1}$ and final NW beam index $i_{t_s}^*$. The WTRU may feed back the final NW beam index $i_{t_s}^*$ to the NW. At $t = t_s + 1$, the WTRU may adjust the Rx spatial filter parameters based on the final WTRU combining vector $\mathbf{w}_{g,t_s+1}$ and the NW may adjust Tx spatial filter parameters based on the beamforming vector $\mathbf{f}_{T-1} = \mathbf{F}[i_{t_s}^*]$. For all $t \geq t_s + 1$, the WTRU

may use the combining vector $\mathbf{w}_{g,t_s+1}$ and NW may use the beamforming vector $\mathbf{f}_{t_s+1} = \mathbf{F}[i_{t_s}^*]$, until a new beam alignment process is triggered.

[0164] As another example, the WTRU may stop sensing when the maximum sensing steps has been reached at $t = T - 2$. The WTRU may obtain $y_{T-2}, x_{T-2}, \mathbf{s}_{T-2}$ and then the WTRU may input $y_{T-2}, x_{T-2}, \mathbf{s}_{T-2}$ to the AIML model and computes the codebook-free (e.g., non-preconfigured) combining vector $\mathbf{w}_{g,T-1}$ and final NW beam index i_{T-1}^* . The WTRU may feed back final NW beam index i_{T-1}^* to the NW. At $t = T - 1$, the WTRU may adjust the Rx spatial filter parameters based on the final WTRU combining vector $\mathbf{w}_{g,T-1}$ and the NW may adjust Tx spatial filter parameters based on the beamforming vector $\mathbf{f}_{T-1} = \mathbf{F}[i_{T-1}^*]$. For all $t \geq T - 1$, the WTRU may use the combining vector $\mathbf{w}_{g,T-1}$ and NW may use the beamforming vector $\mathbf{f}_{T-1} = \mathbf{F}[i_{T-1}^*]$, until a new beam alignment process is triggered.

[0165] Referring to Fig. 9, an example of a low chart illustrating a method 600 of NW-WTRU beam alignment according to another embodiment is shown.

[0166] At step 900, the WTRU may be configured with a (e.g., maximum) number T of sensing steps, a recursive AIML model and initialization parameters. Considering step 900 is performed for $t=0$ (see Fig. 7) as initialization step. The WTRU may compute the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_{s,0}$, using the recursive AIML model. Having computed the initial codebook-free (e.g., non-preconfigured) sensing vector $\mathbf{w}_{s,0}$, the WTRU may adjust the Rx spatial filter parameters accordingly.

[0167] At step 920, the WTRU may receive, from the NW, configured RS resources for beam measurement at a time t. Then, at step 930, as an initial measurement, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_{s,0}$ and obtains y_0 and x_0 . If the beam measurement metric y_0 (L1-RSRP, SINR etc.) is below a certain threshold, according to step 935, the WTRU may omit the measurement (e.g., WTRU may assume $y_0 = 0$ and $x_0 = \emptyset$) and wait until the beam measurement metric (L1-RSRP, SINR etc.) become above the certain threshold.

[0168] In case the beam measurement metric (L1-RSRP, SINR etc.) is above the certain threshold, and in case t is not equal to $T - 2$ (step 940), according to step 950, the measured metrics y_0 and x_0 and the previous state vector $\mathbf{s}_0$ may be used as inputs to the AIML model to recursively determine/compute the next sensing vector $\mathbf{w}_{s,1}$, estimate of the best combining vector $\mathbf{w}_{g,1}$, estimate of the best NW beam index i_1^* , and state vector $\mathbf{s}_1$. Then, the Rx spatial filter parameters for beam measurement are adjusted based on the new sensing vector.

[0169] According to step 960, if the absolute difference between current and previous WTRU combining vectors are above a threshold, e.g., $\|\mathbf{w}_{g,1} - \mathbf{w}_{g,0}\|_2 > \text{Thr}_w$, the WTRU may receive, at step 920 the configured RS resources (beamformed with $\mathbf{f}_1$) for another beam measurement. Then, according to step 930, the WTRU may perform beam measurement (e.g., computes L1-RSRP, SINR, NW beam index etc.) on the RS resources with the RX spatial filter parameters adjusted based on the sensing vector $\mathbf{w}_{s,1}$ and may obtain/determine y_1 and x_1 . If the beam measurement metric y_1 (L1-RSRP, SINR etc.) is below a certain threshold, the WTRU may omit the measurement (e.g., WTRU may assume $y_1 = 0$ and $x_1 = \emptyset$).

[0170] In the iteration illustrated by the loop steps 920, 930, 940, 950, 960 and 935 it has to be considered that the WTRU may recursively input $y_{t-1}, x_{t-1}, \mathbf{s}_{t-1}$ to the AIML model, and as output of the model computes sensing vector $\mathbf{w}_{s,t}$, estimate of the best combining vector $\mathbf{w}_{g,t}$, estimate of the best NW beam index i_t^* , and state vector $\mathbf{s}_t$, and then may perform beam measurement by adjusting the Rx spatial filter parameters based on $\mathbf{w}_t$ to obtain y_t, x_t .

[0171] The WTRU may stop the beam measurement process at time $t = t_s$ based on stopping criterion. For example, if at any time $t = t_s < T - 2$, if the absolute difference between current and previous WTRU combining vectors are below a threshold, e.g., $\|\mathbf{w}_{g,t_s} - \mathbf{w}_{g,t_s-1}\|_2 < \text{Thr}_w$, according to step 970, the sensing may stop at $t = t_s$. At $t = t_s$, the WTRU may compute/determine $y_{t_s}, x_{t_s}, \mathbf{s}_{t_s}$ as the output of the AIML model. Then, $y_{t_s}, x_{t_s}, \mathbf{s}_{t_s}$ may be input to the model and the WTRU may compute the final combining vector $\mathbf{w}_{g,t_s+1}$ and final NW beam index $i_{t_s}^*$. According to step 980, the WTRU may feed back the final NW beam index $i_{t_s}^*$ to the NW. At $t = t_s + 1$, the WTRU may adjust the Rx spatial filter parameters based on the final WTRU combining vector $\mathbf{w}_{g,t_s+1}$ and the NW may adjust Tx spatial filter parameters based on the beamforming vector $\mathbf{f}_{T-1} = \mathbf{F}[i_{t_s}^*]$. According to step 990, for all $t \geq t_s + 1$, the WTRU may use the combining vector $\mathbf{w}_{g,t_s+1}$ and NW may use the beamforming vector $\mathbf{f}_{t_s+1} = \mathbf{F}[i_{t_s}^*]$, until a new beam alignment process is triggered.

[0172] According to the above embodiments, wherein beam alignment is data-driven on the WTRU side with early stopping, the WTRU (i) may recurrently compute a codebook-free (e.g., non-pre-configured) sensing vector to adjust Rx spatial filter parameters, using sensing vector to perform beam measurement on RS resources, estimate the best WTRU codebook-free combining vector (to be used during data transmission) and estimate of best NW beam index (e.g., RS resource index) at each sensing step, (ii) early stop the sensing process upon detection of convergence in the estimate of best combining vector, (iii) feedback the estimate of best NW beam index, (iv) adjust the Rx spatial filter parameters based on the combining vector to receive data.

[0173] More particularly, the WTRU may be configured any of: (i) the maximum number of sensing (measurement) steps; (ii) a sensing (measurement) window; (iii) the RS resources that can be used for sensing; and (iv) a one-sided AIML model for early stopping beam alignment, which may include model-ID.

[0174] In addition, the WTRU may be triggered to perform beam measurement using sensing vectors based one any of the following: initial connection establishment; handover to another cell; beam failure; indication by the NW; timeout trigger; measurements in the previous window; and measurements in the previous sensing step.

[0175] After a trigger on beam measurement, the WTRU may perform any of: loading and activating the AIML-model for beam alignment; inputting the initialization parameters to the AIML model according to configuration of AIML model; computing an initial codebook-free (i.e., non-pre-configured) sensing vector (i.e., Rx spatial filter parameters to be used for beam measurement on next RS resource) using the AIML model; adjusting the Rx spatial filter parameters based on initial sensing vector; receiving RS resources for beam measurement; performing beam measurement (e.g., computing L1-RSRP, SINR, NW beam index etc.) on configured RS resources; omitting the beam measurement in case the current beam measurement (e.g., L1-RSRP, SINR etc.) is below a certain threshold; inputting the previous beam measurement (e.g., L1-RSRP), AIML model state vector and the NW beam index (i.e., RS resource index) to the AIML-based model; computing: (i) new codebook-free (i.e., non-pre-configured) sensing vector (e.g., Rx spatial filter parameters to be used for beam measurement on next RS resource), (ii) new estimate of the best codebook-free (i.e., non-pre-configured) combining vector (e.g., Rx spatial filter parameters to be used for data transmission after the sensing phase), (iii) an estimate of the best NW beam index (i.e., RS resource index); adjusting the Rx spatial filter parameters based on the new sensing vector; receiving RS resources for beam measurement; performing beam measurement (e.g., computing L1-RSRP, SINR, NW beam index etc.) on configured RS resources.; omitting the beam measurement in case the current beam measurement (e.g., L1-RSRP, SINR etc.) is below a certain threshold; recurrently computing a new sensing vector, new combining vector, an estimate of the best NW beam index, receiving new RS and performing beam measurement until a stopping criterion is reached; WTRU early stopping the beam measurement process, if the distance between current estimate of the best combining vector (i.e., Rx spatial filter parameters) and the previous is below a certain threshold; and WTRU stopping the beam measurement process if the configured maximum number of sensing steps reached

[0176] After the WTRU decides to stop the beam measurement process, the WRU may decide the current estimate of the best combining vector (e.g., Rx spatial filter) as the final combining

vector; and may decide the current best estimate of the NW beam index (e.g., RS resource index) as the final estimate of the NW-side beam index. Then, WTRU may feedback the final estimate of the NW-side beam index (e.g., RS resource index) to the NW.

[0177] After the feedback, the WTRU may adjust the Rx spatial filter parameters based on final combining vector and may receive data transmission from the NW beamformed with the final estimate of the NW beam index.

[0178] Referring to Fig. 10, in another embodiment, a method 1000, implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise a step of receiving 1010 a first message comprising information indicating beam measurements period, a recursive AIML model, and initial beam alignment parameters. The indication of beam measurements period may be a sensing/measurement window or a fixed number of sensing/measurement step. The method may further comprise a step of receiving 1020 a second message comprising information indicating configuration on reference signals, RS, resources for beam measurements. The method may comprise recurrent steps for AIML learning, such that during the beam measurement period, the method may recurrently: determining 1030, by the recursive AIML model, a data-driven sensing vector to adjust WTRU spatial filter parameters based on previous beam alignment parameters and previous beam measurements; and performing 1040 beam measurement on RS, to generate current beam alignment parameters. Then, the method may comprise a step of determining 1050 a combining vector for final adjustment of WTRU spatial filter parameter and a network beam forming vector based on the recurrently determined sensing vectors. The method may comprise a step of transmitting 1060, to the network, a second message comprising information indicating the network beamforming vector; and a step of receiving 1070 data from the network using the final adjusted WTRU spatial filter parameter.

[0179] Referring to Fig. 11, in another embodiment, a method 1100, implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise a step of receiving 1110 a first message comprising information indicating a maximum number of sensing steps, a recursive AIML model, and initial beam alignment parameters. The method may further comprise a step of receiving 1120 a second message comprising information indicating configuration on reference signals, RS, resources for beam measurements. On condition that a stopping criterion is not satisfied, the method may further recurrently comprise steps of: determining 1130, by the recursive AIML model, a data-driven sensing vector to adjust WTRU spatial filter parameters based on previous beam alignment parameters; determining 1140 a combining vector and a network beam index based on previous beam alignment parameters and previous beam measurements; performing 1150 beam measurement on RS, to generate current beam alignment parameters; and

determining 1160 the stopping criterion based on the determined combining vector. The stopping criterion may be satisfied if the distance between current estimate of the combining vector and the previous is below a certain threshold. The method may further comprise a step of transmitting 1170, to the network, a second message comprising information indicating the last determined network beam index. The method may further comprise a step of adjusting 1180 WTRU spatial filter parameters based on the last determined combining vector; and a step of receiving 1190 data from the network using the adjusted WTRU spatial filter parameters.

[0180] Referring to FIG. 12, in another embodiment, a method 1200, implemented in a wireless transmit/receive unit, WTRU, to perform beam alignment, may comprise a step of receiving 1210 at least a first message comprising information indicating a number of beam measurements, and indicating an artificial intelligence and machine learning (AIML) model, said at least first message further comprising configuration information for beam measurements on reference signals (RS) resources. In an alternative, the WTRU may receive a first message comprising information indicating a number of beam measurements, and indicating an Artificial Intelligence and Machine Learning (AIML) model, and the WTRU may receive a second message comprising configuration information for beam measurements on reference signals (RS) resources. The method 1200 may comprise another step wherein the WTRU may determine 1220, based on initial beamforming parameters, one or more first beam measurements on the RS resources. The method 1200 may further comprise a step wherein the WTRU may recurrently perform 1230 by the AIML model, up to the number of beam measurements the following steps: (i) determining 1240, based on previous one or more beam measurements, a sensing vector to adjust one or more beamforming parameters of the WTRU, and (ii) performing 1250 one or more beam measurements on the RS resources using the determined sensing vector. The method 1200 may comprise a step wherein the WTRU may determine 1260, by the AIML model, based on the recurrently determined one or more sensing vectors, a network beamforming vector, and a step wherein the WTRU may transmit 1270, to a network, a second message comprising information indicating the network beamforming vector.

[0181] The method 1200 may comprise a step wherein the WTRU may determine, by the AIML model, based on the recurrently determined one or more sensing vectors, a combining vector for adjustment of the one or more beamforming parameters of the WTRU.

[0182] The method 1200 may comprise a step wherein the WTRU may receive data from the network using the adjusted one or more beamforming parameters.

[0183] Prior receiving data from the network using the adjusted one or more beamforming parameters, the method 1200 may comprise a step wherein the WTRU may receive, from the

network, a new RS resource, may determine channel measurements on the new RS resource; and may transmit to the network, a channel state information report comprising the determined channel measurements.

[0184] The adjustment of the one or more beamforming parameters of the WTRU may be a final adjustment. The one or more beamforming parameters may comprise one or more WTRU spatial filter parameters. The information indicating configuration on reference signals (RS) resources for beam measurements may be received via downlink control information or radio resource control signaling. The indication of the number of beam measurements may comprise a number of sensing steps. The indication of the number of beam measurements may comprise a sensing window. Performing beam measurements on the RS resources may comprise any of determining L1-RSRP, SINR, and network beam index. Beam measurements may be omitted in case of beam measurements are below a threshold value.

[0185] Conclusion

[0186] Although features and elements are provided above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations may be made without departing from its spirit and scope, as will be apparent to those skilled in the art. No element, act, or instruction used in the description of the present application should be construed as critical or essential to the invention unless explicitly provided as such. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods or systems.

[0187] The foregoing embodiments are discussed, for simplicity, with regard to the terminology and structure of infrared capable devices, i.e., infrared emitters and receivers. However, the embodiments discussed are not limited to these systems but may be applied to other systems that use other forms of electromagnetic waves or non-electromagnetic waves such as acoustic waves.

[0188] It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the term "video" or the term "imagery" may mean any of a snapshot, single image and/or multiple images displayed

over a time basis. As another example, when referred to herein, the terms "user equipment" and its abbreviation "UE", the term "remote" and/or the terms "head mounted display" or its abbreviation "HMD" may mean or include (i) a wireless transmit and/or receive unit (WTRU); (ii) any of a number of embodiments of a WTRU; (iii) a wireless-capable and/or wired-capable (e.g., tetherable) device configured with, inter alia, some or all structures and functionality of a WTRU; (iii) a wireless-capable and/or wired-capable device configured with less than all structures and functionality of a WTRU; or (iv) the like. Details of an example WTRU, which may be representative of any WTRU recited herein, are provided herein with respect to FIGs. 1A-1D. As another example, various disclosed embodiments herein *supra* and *infra* are described as utilizing a head mounted display. Those skilled in the art will recognize that a device other than the head mounted display may be utilized and some or all of the disclosure and various disclosed embodiments can be modified accordingly without undue experimentation. Examples of such other device may include a drone or other device configured to stream information for providing the adapted reality experience.

[0189] In addition, the methods provided herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

[0190] Variations of the method, apparatus and system provided above are possible without departing from the scope of the invention. In view of the wide variety of embodiments that can be applied, it should be understood that the illustrated embodiments are examples only, and should not be taken as limiting the scope of the following claims. For instance, the embodiments provided herein include handheld devices, which may include or be utilized with any appropriate voltage source, such as a battery and the like, providing any appropriate voltage.

[0191] Moreover, in the embodiments provided above, processing platforms, computing systems, controllers, and other devices that include processors are noted. These devices may include at least one Central Processing Unit ("CPU") and memory. In accordance with the practices of persons skilled in the art of computer programming, reference to acts and symbolic

representations of operations or instructions may be performed by the various CPUs and memories. Such acts and operations or instructions may be referred to as being "executed," "computer executed" or "CPU executed."

[0192] One of ordinary skill in the art will appreciate that the acts and symbolically represented operations or instructions include the manipulation of electrical signals by the CPU. An electrical system represents data bits that can cause a resulting transformation or reduction of the electrical signals and the maintenance of data bits at memory locations in a memory system to thereby reconfigure or otherwise alter the CPU's operation, as well as other processing of signals. The memory locations where data bits are maintained are physical locations that have particular electrical, magnetic, optical, or organic properties corresponding to or representative of the data bits. It should be understood that the embodiments are not limited to the above-mentioned platforms or CPUs and that other platforms and CPUs may support the provided methods.

[0193] The data bits may also be maintained on a computer readable medium including magnetic disks, optical disks, and any other volatile (e.g., Random Access Memory (RAM)) or non-volatile (e.g., Read-Only Memory (ROM)) mass storage system readable by the CPU. The computer readable medium may include cooperating or interconnected computer readable medium, which exist exclusively on the processing system or are distributed among multiple interconnected processing systems that may be local or remote to the processing system. It should be understood that the embodiments are not limited to the above-mentioned memories and that other platforms and memories may support the provided methods.

[0194] In an illustrative embodiment, any of the operations, processes, etc. described herein may be implemented as computer-readable instructions stored on a computer-readable medium. The computer-readable instructions may be executed by a processor of a mobile unit, a network element, and/or any other computing device.

[0195] There is little distinction left between hardware and software implementations of aspects of systems. The use of hardware or software is generally (but not always, in that in certain contexts the choice between hardware and software may become significant) a design choice representing cost versus efficiency tradeoffs. There may be various vehicles by which processes and/or systems and/or other technologies described herein may be effected (e.g., hardware, software, and/or firmware), and the preferred vehicle may vary with the context in which the processes and/or systems and/or other technologies are deployed. For example, if an implementer determines that speed and accuracy are paramount, the implementer may opt for a mainly hardware and/or firmware vehicle. If flexibility is paramount, the implementer may opt for a mainly software

implementation. Alternatively, the implementer may opt for some combination of hardware, software, and/or firmware.

[0196] The foregoing detailed description has set forth various embodiments of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples include one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, or examples may be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In an embodiment, several portions of the subject matter described herein may be implemented via Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs), digital signal processors (DSPs), and/or other integrated formats. However, those skilled in the art will recognize that some aspects of the embodiments disclosed herein, in whole or in part, may be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein may be distributed as a program product in a variety of forms, and that an illustrative embodiment of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution. Examples of a signal bearing medium include, but are not limited to, the following: a recordable type medium such as a floppy disk, a hard disk drive, a CD, a DVD, a digital tape, a computer memory, etc., and a transmission type medium such as a digital and/or an analog communication medium (e.g., a fiber optic cable, a waveguide, a wired communications link, a wireless communication link, etc.).

[0197] Those skilled in the art will recognize that it is common within the art to describe devices and/or processes in the fashion set forth herein, and thereafter use engineering practices to integrate such described devices and/or processes into data processing systems. That is, at least a portion of the devices and/or processes described herein may be integrated into a data processing system via a reasonable amount of experimentation. Those having skill in the art will recognize that a typical data processing system may generally include one or more of a system unit housing, a video display device, a memory such as volatile and non-volatile memory, processors such as microprocessors and digital signal processors, computational entities such as operating systems,

drivers, graphical user interfaces, and applications programs, one or more interaction devices, such as a touch pad or screen, and/or control systems including feedback loops and control motors (e.g., feedback for sensing position and/or velocity, control motors for moving and/or adjusting components and/or quantities). A typical data processing system may be implemented utilizing any suitable commercially available components, such as those typically found in data computing/communication and/or network computing/communication systems.

[0198] The herein described subject matter sometimes illustrates different components included within, or connected with, different other components. It is to be understood that such depicted architectures are merely examples, and that in fact many other architectures may be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality may be achieved. Hence, any two components herein combined to achieve a particular functionality may be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated may also be viewed as being "operably connected", or "operably coupled", to each other to achieve the desired functionality, and any two components capable of being so associated may also be viewed as being "operably couplable" to each other to achieve the desired functionality. Specific examples of operably couplable include but are not limited to physically mateable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interacting and/or logically interactable components.

[0199] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0200] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, where only one item is intended, the term "single" or similar language may be used. As an aid to understanding, the following appended claims and/or the descriptions herein may include usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However,

the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim including such introduced claim recitation to embodiments including only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should be interpreted to mean "at least one" or "one or more"). The same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B." Further, the terms "any of" followed by a listing of a plurality of items and/or a plurality of categories of items, as used herein, are intended to include "any of," "any combination of," "any multiple of," and/or "any combination of multiples of" the items and/or the categories of items, individually or in conjunction with other items and/or other categories of items. Moreover, as used herein, the term "set" is intended to include any number of items, including zero. Additionally, as used herein, the term "number" is intended to include any number, including zero. And the term "multiple", as used herein, is intended to be synonymous with "a plurality".

[0201] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0202] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein may be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as "up to," "at least," "greater than," "less than," and the like includes the number recited and refers to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0203] Moreover, the claims should not be read as limited to the provided order or elements unless stated to that effect. In addition, use of the terms "means for" in any claim is intended to invoke 35 U.S.C. §112, ¶ 6 or means-plus-function claim format, and any claim without the terms "means for" is not so intended.

CLAIMS

1. A method, implemented in a wireless transmit/receive unit (WTRU), the method comprising:

receiving at least a first message comprising information indicating a number of beam measurements, and indicating an Artificial Intelligence and Machine Learning (AIML) model, said at least first message further comprising configuration information for beam measurements on reference signals (RS) resources;

determining, based on initial beamforming parameters, one or more first beam measurements on the RS resources;

recurrently performing by the AIML model, up to the number of beam measurements:

determining, based on previous one or more beam measurements, a sensing vector to adjust one or more beamforming parameters of the WTRU;

performing one or more beam measurements on the RS resources using the determined sensing vector;

determining, by the AIML model, based on the recurrently determined one or more sensing vectors, a network beamforming vector; and

transmitting, to a network, a second message comprising information indicating the network beamforming vector.

2. The method of claim 1 comprising determining, by the AIML model, based on the recurrently determined one or more sensing vectors, a combining vector for adjustment of the one or more beamforming parameters of the WTRU.

3. The method of claim 2 comprising:

receiving data from the network using the adjusted one or more beamforming parameters.

4. The method of claim 3, wherein prior receiving data from the network using the adjusted one or more beamforming parameters, the method comprising:

receiving, from the network, a new RS resource;

determining channel measurements on the new RS resource; and

transmitting to the network, a channel state information report comprising the determined channel measurements.

5. The method of any of the claims 2 to 4, wherein the adjustment of the one or more beamforming parameters of the WTRU is a final adjustment.
6. The method of any of the preceding claims, wherein the one or more beamforming parameters comprises one or more WTRU spatial filter parameters.
7. The method of any of the preceding claims, wherein the information indicating configuration on reference signals (RS) resources for beam measurements is received via downlink control information or radio resource control signaling.
8. The method of any of the preceding claims, wherein the indication of the number of beam measurements comprises a number of sensing steps.
9. The method of any of the preceding claims, wherein the indication of the number of beam measurements comprises a sensing window.
10. The method of any of the preceding claims, wherein performing beam measurements on the RS resources comprises any of determining L1-RSRP, SINR, and network beam index.
11. The method of any of the preceding claims, wherein beam measurements are omitted in case of beam measurements are below a threshold value.
12. A wireless transmit/receive unit (WTRU) comprising circuitry, including a transmitter, a receiver, a processor and memory, configured to:

receive at least a first message comprising information indicating a number of beam measurements, and indicating an Artificial Intelligence and Machine Learning (AIML) model, said at least first message further comprising configuration information for beam measurements on reference signals (RS) resources;

determine, based on initial beamforming parameters, one or more first beam measurements on the RS resources;

recurrently perform by the AIML model, up to the number of beam measurements:

determine, based on previous one or more beam measurements, a sensing vector to adjust one or more beamforming parameters of the WTRU;

perform one or more beam measurements on the RS resources using the determined sensing vector;

determine, by the AIML model, based on the recurrently determined one or more sensing vectors, a network beamforming vector; and

transmit, to a network, a second message comprising information indicating the network beamforming vector.

13. The WTRU of claim 12 comprising determining, by the AIML model, based on the recurrently determined one or more sensing vectors, a combining vector for adjustment of the one or more beamforming parameters of the WTRU.

14. The WTRU of claim 13 configured to:

receive data from the network using the adjusted one or more beamforming parameters.

15. The WTRU of claim 14 configured to, prior to receive data from the network using the adjusted one or more beamforming parameters:

receive, from the network, a new RS resource;

determine channel measurements on the new RS resource; and

transmit to the network, a channel state information report comprising the determined channel measurements.

16. The WTRU of any of the claims 13 to 15, wherein the adjustment of the one or more beamforming parameters of the WTRU is a final adjustment.

17. The WTRU of any of claims 12 to 16, wherein the one or more beamforming parameters comprises one or more WTRU spatial filter parameters.

18. The WTRU of any of claims 12 to 17, wherein the information indicating configuration on reference signals (RS) resources for beam measurements is received via downlink control information or radio resource control signaling.

19. The WTRU of any of claims 12 to 18, wherein the indication of the number of beam measurements comprises a number of sensing steps.

20. The WTRU of any of claims 12 to 19, wherein the indication of a number of beam measurements comprises a sensing window.

21. The WTRU of any of claims 12 to 20, wherein performing beam measurements on the RS resources comprises any of determining L1-RSRP, SINR, and network beam index.

22. The WTRU of any of claims 12 to 21, wherein beam measurements is omitted in case of beam measurements are below a threshold value.

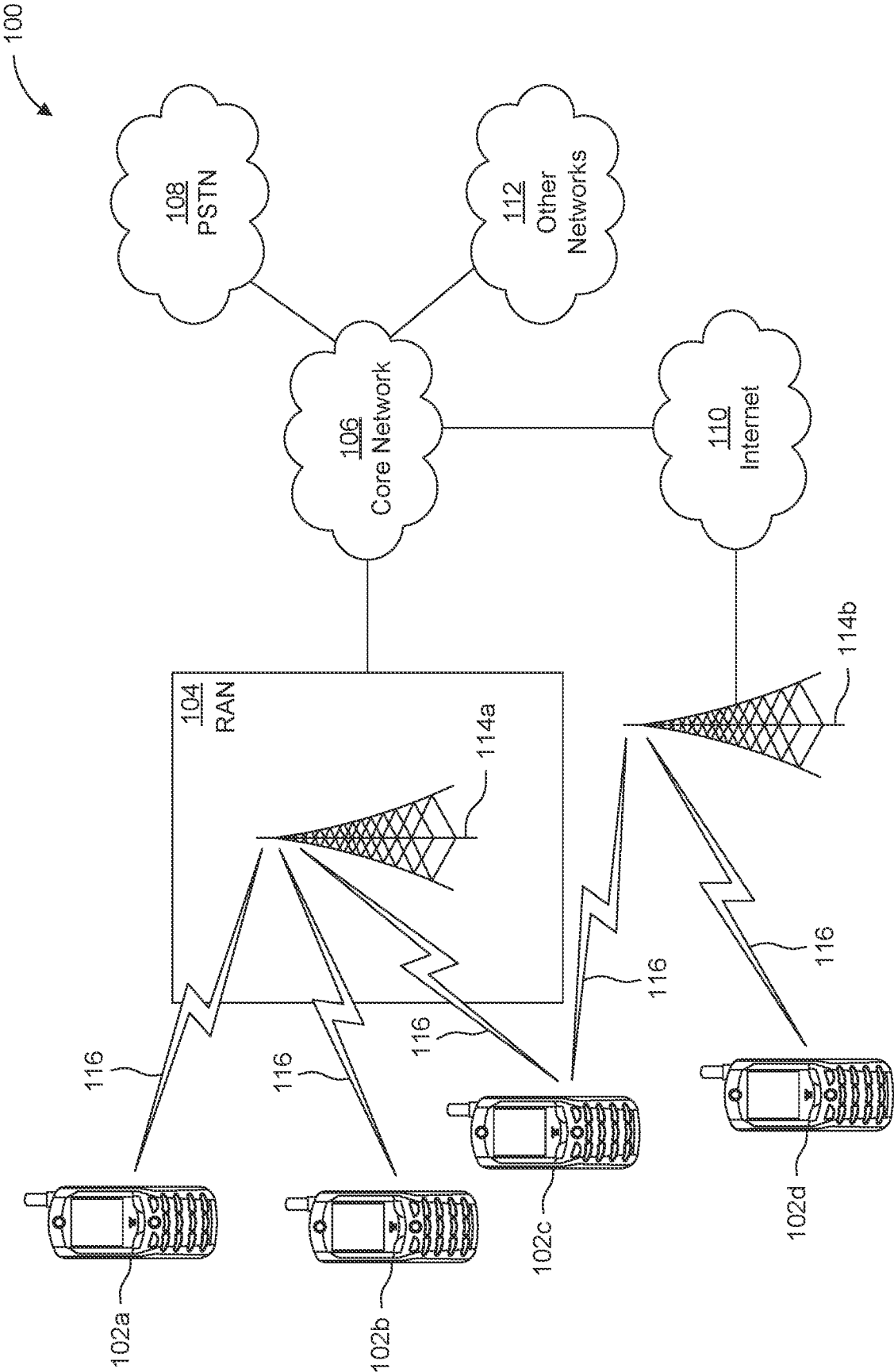


FIG. 1A

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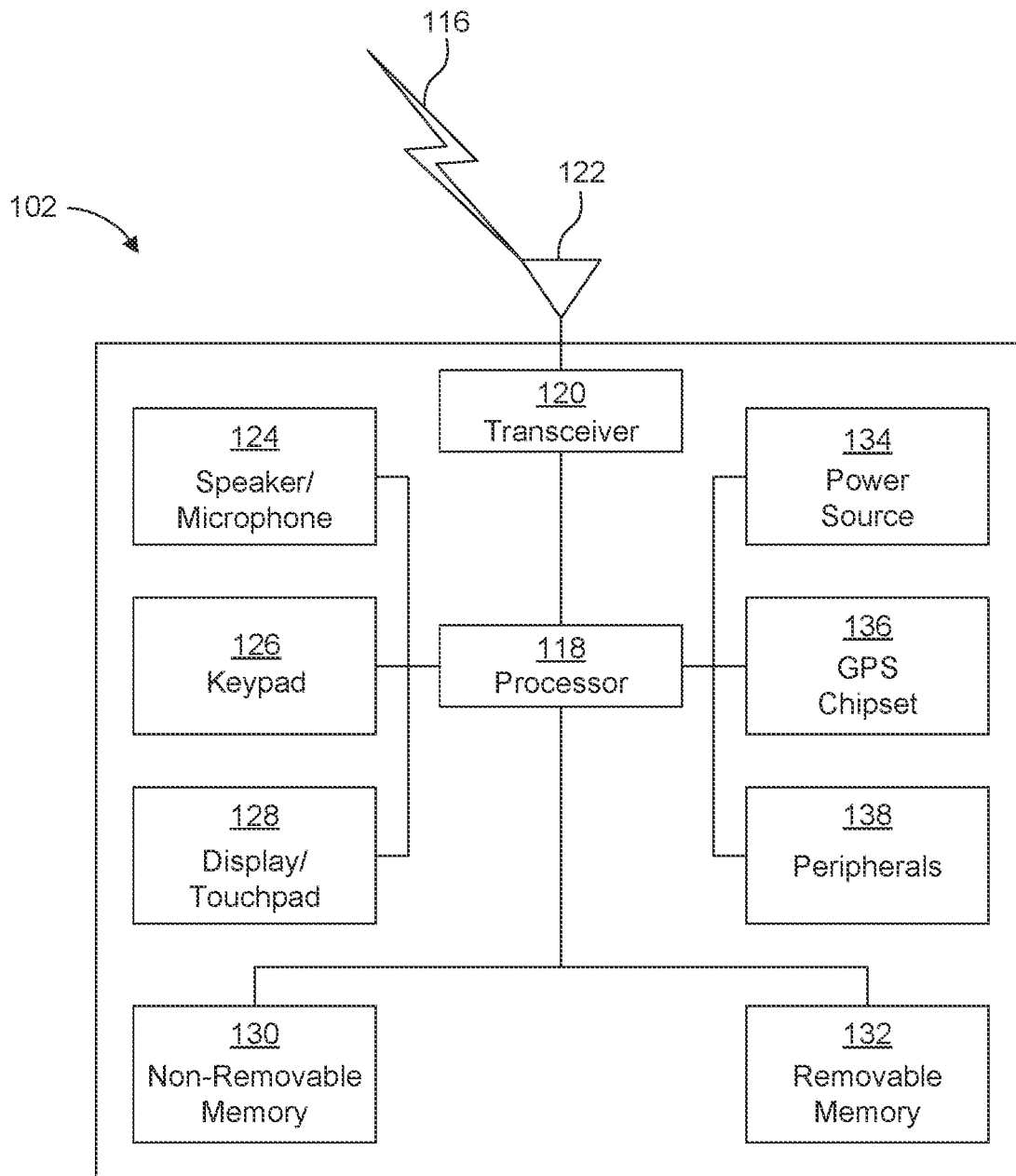


FIG. 1B

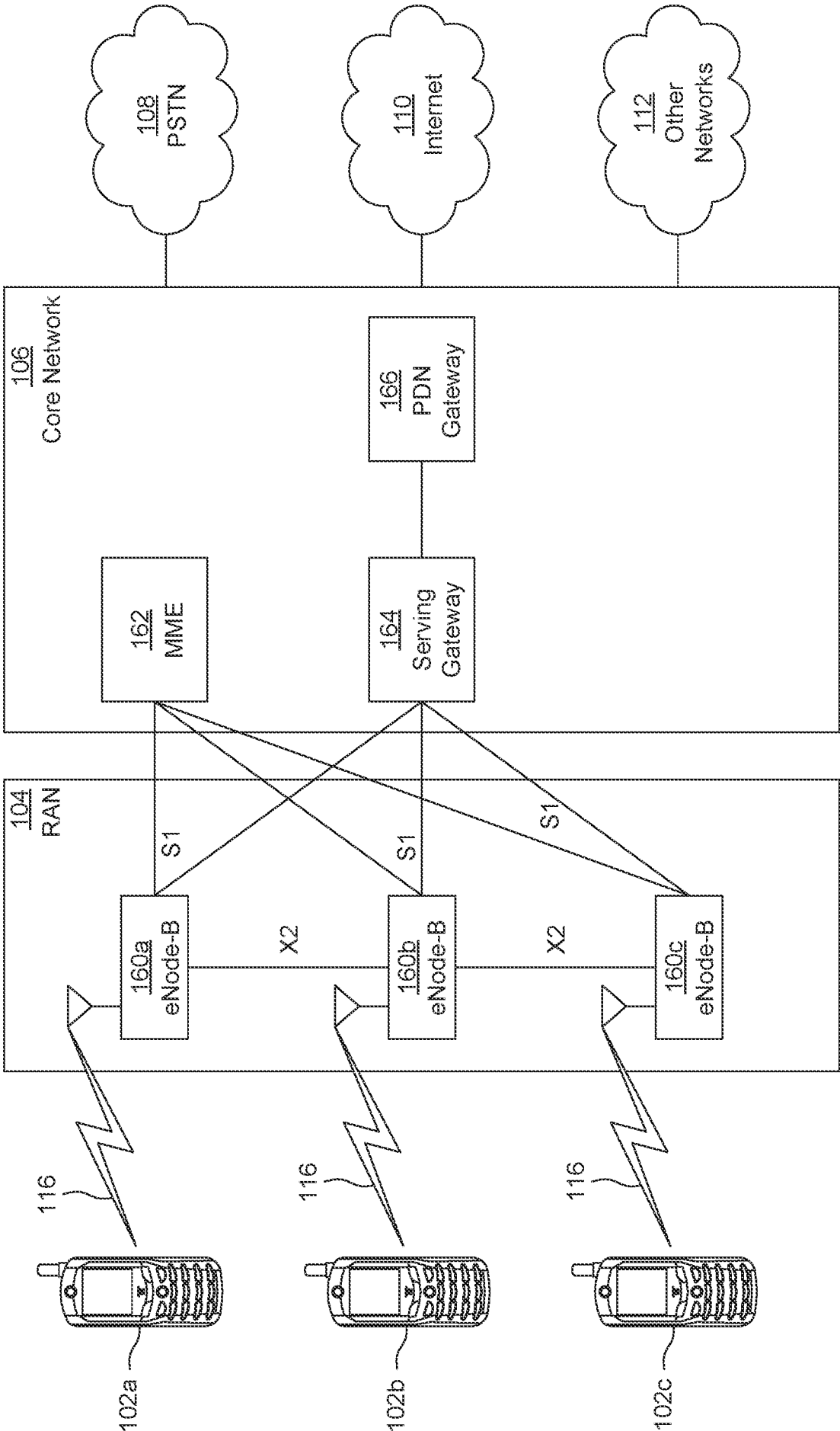


FIG. 1C

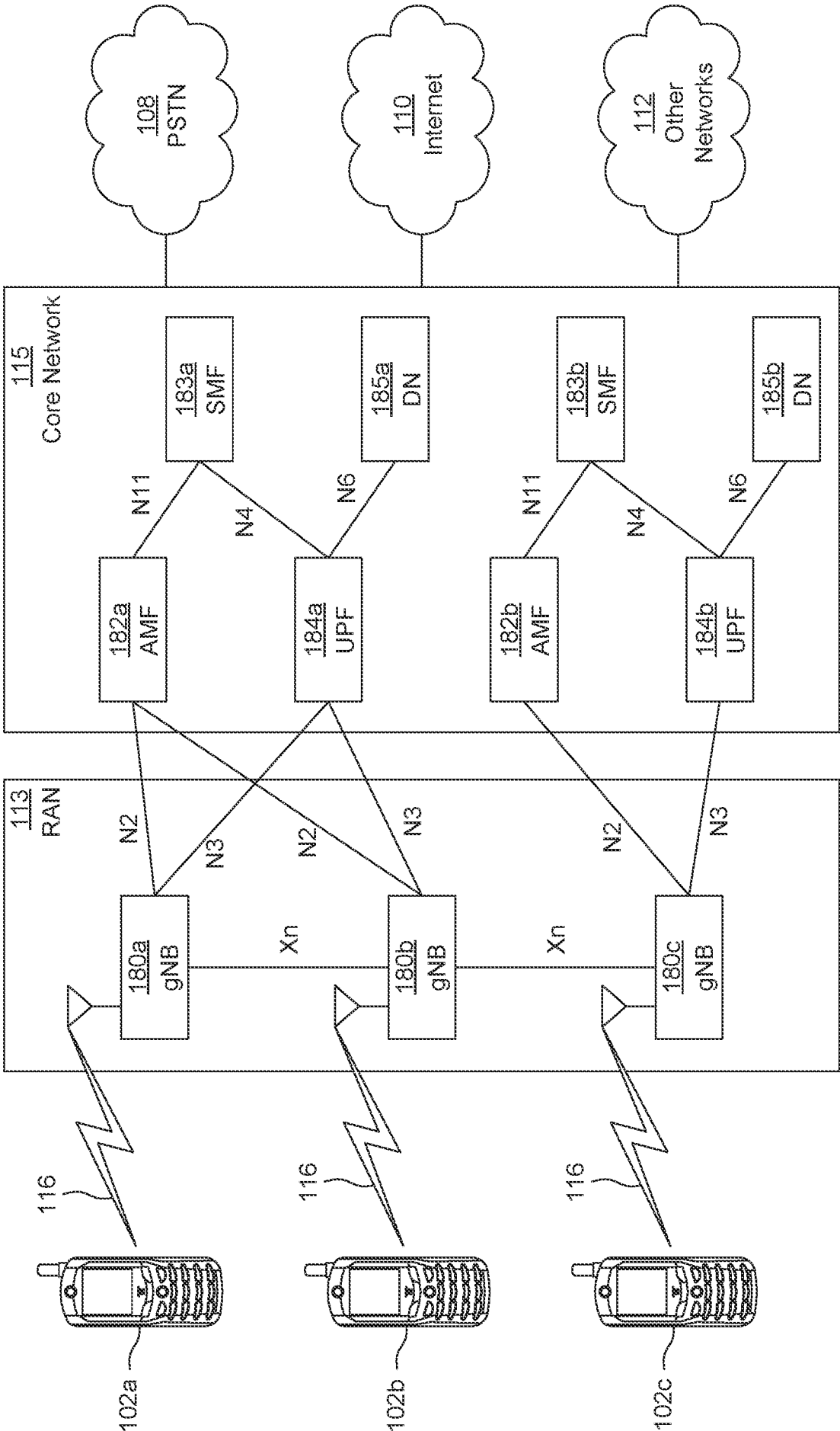


FIG. 1D

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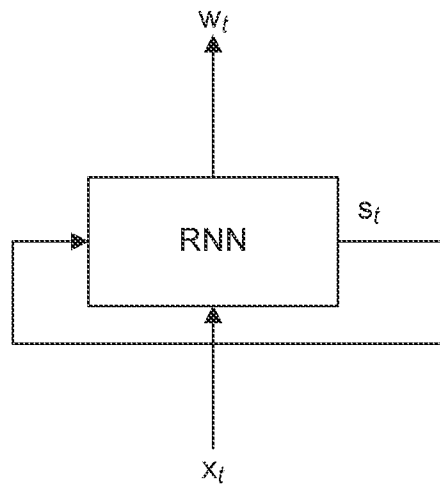


FIG. 2

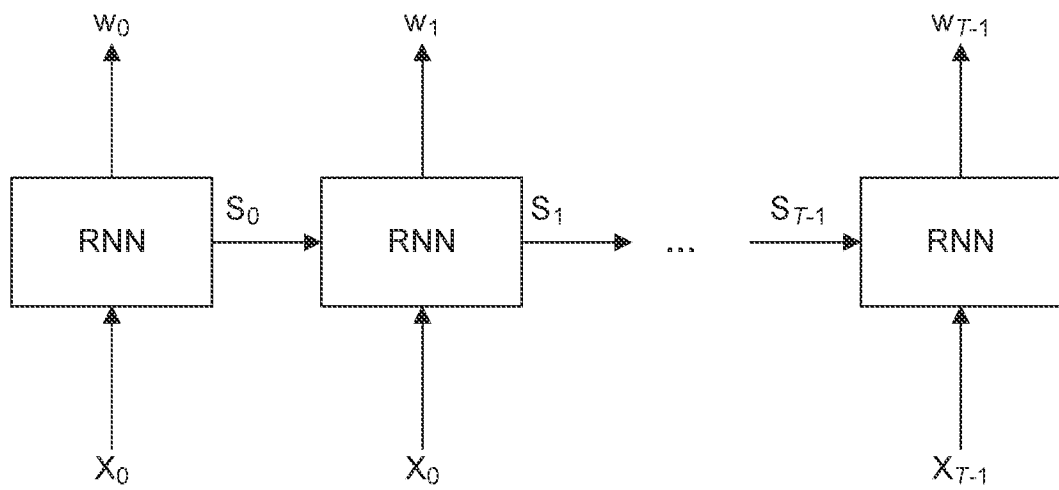


FIG. 3

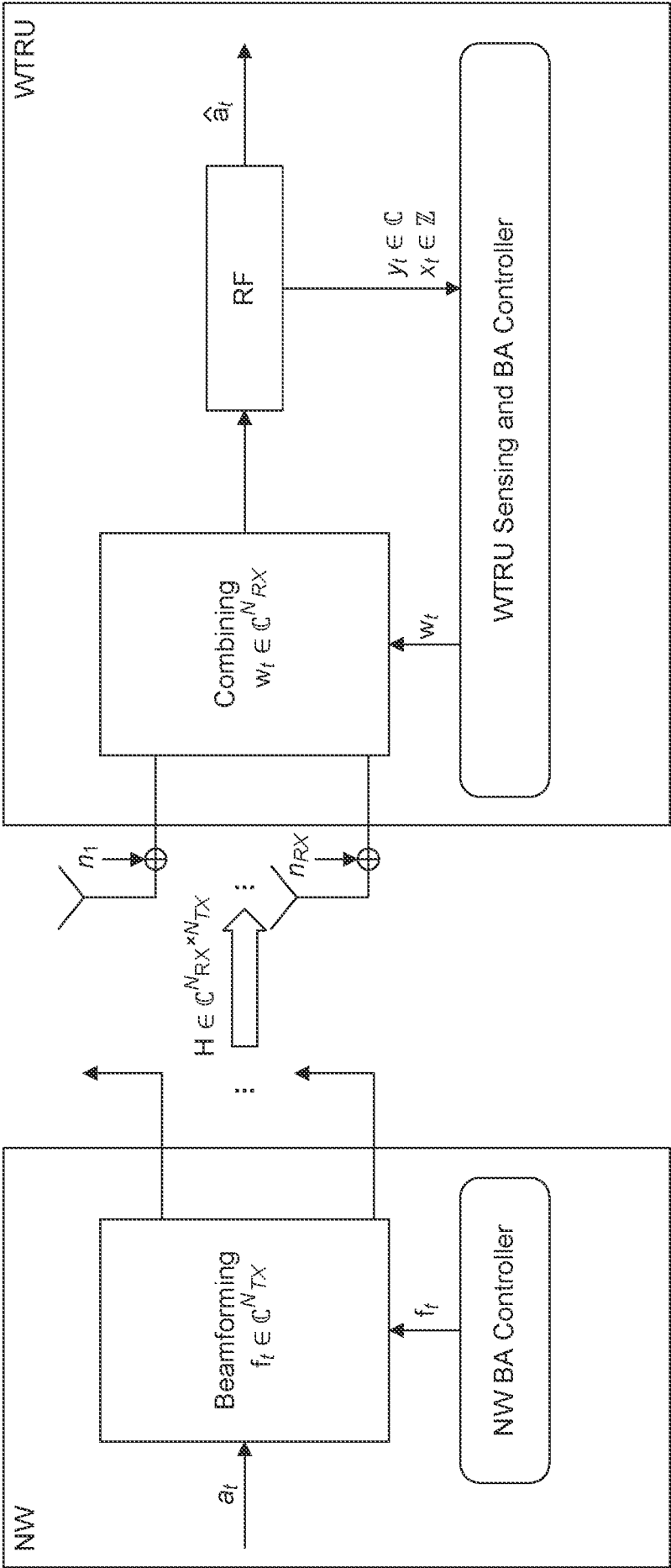
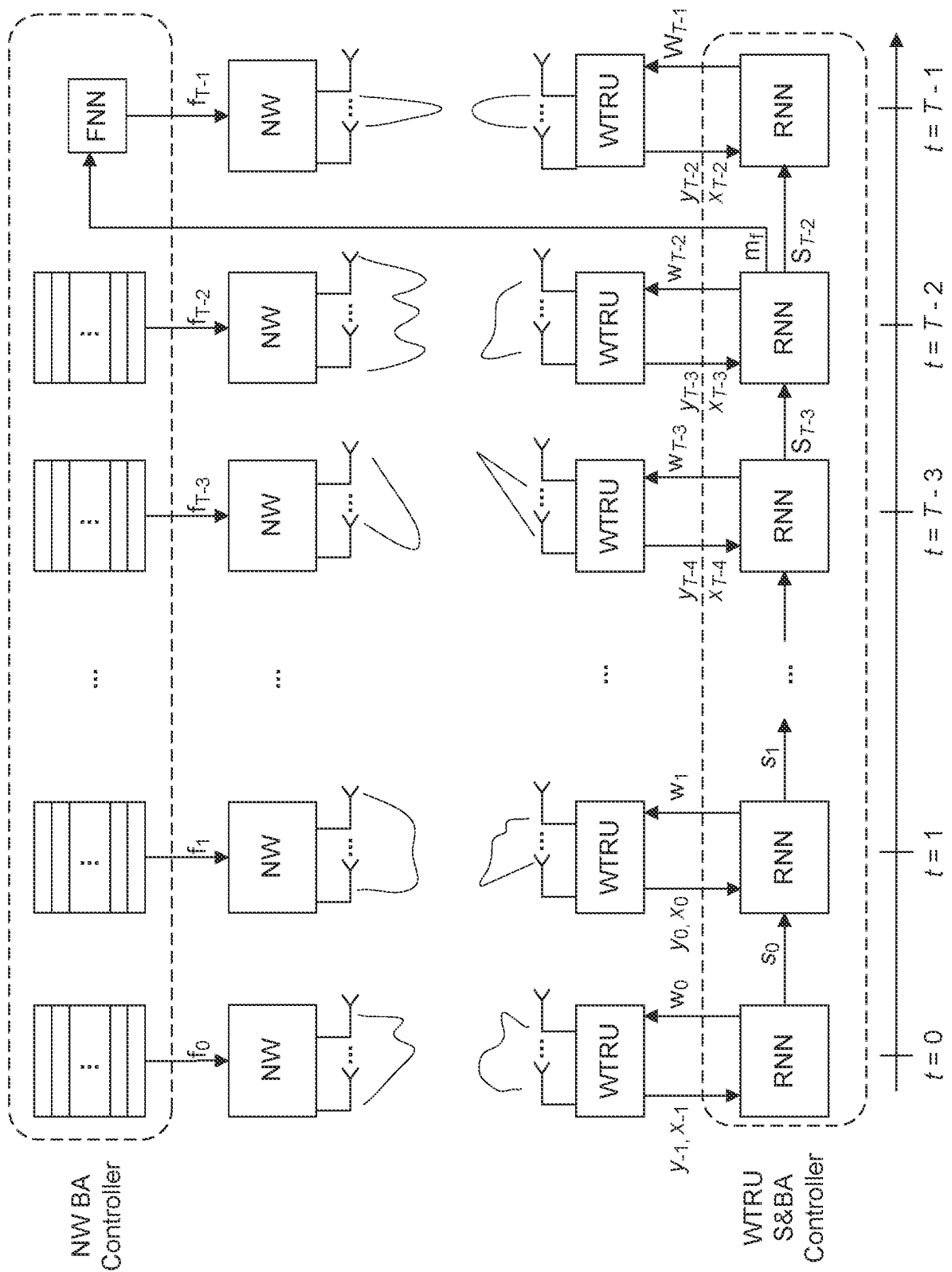


FIG. 4

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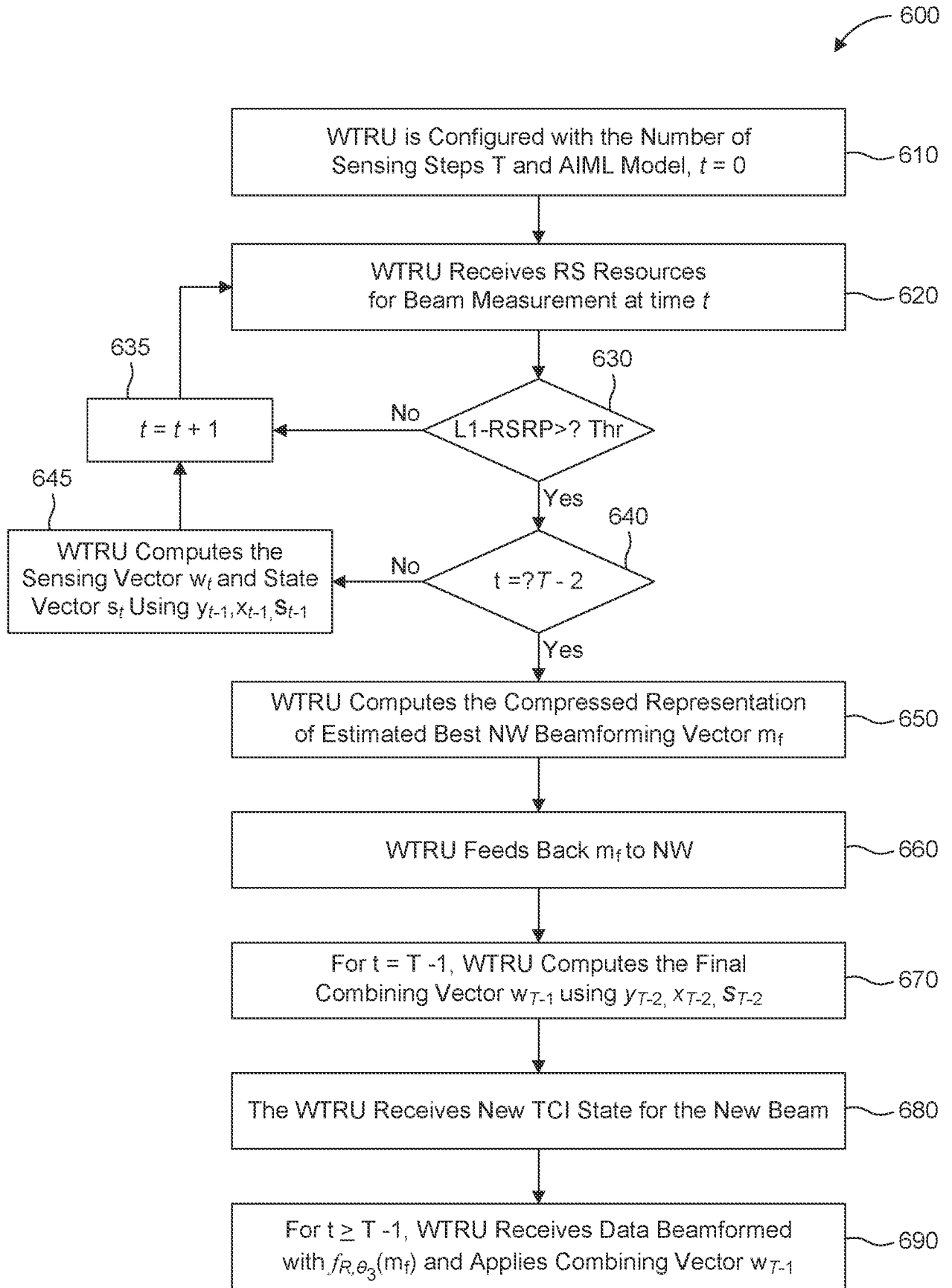


FIG. 6

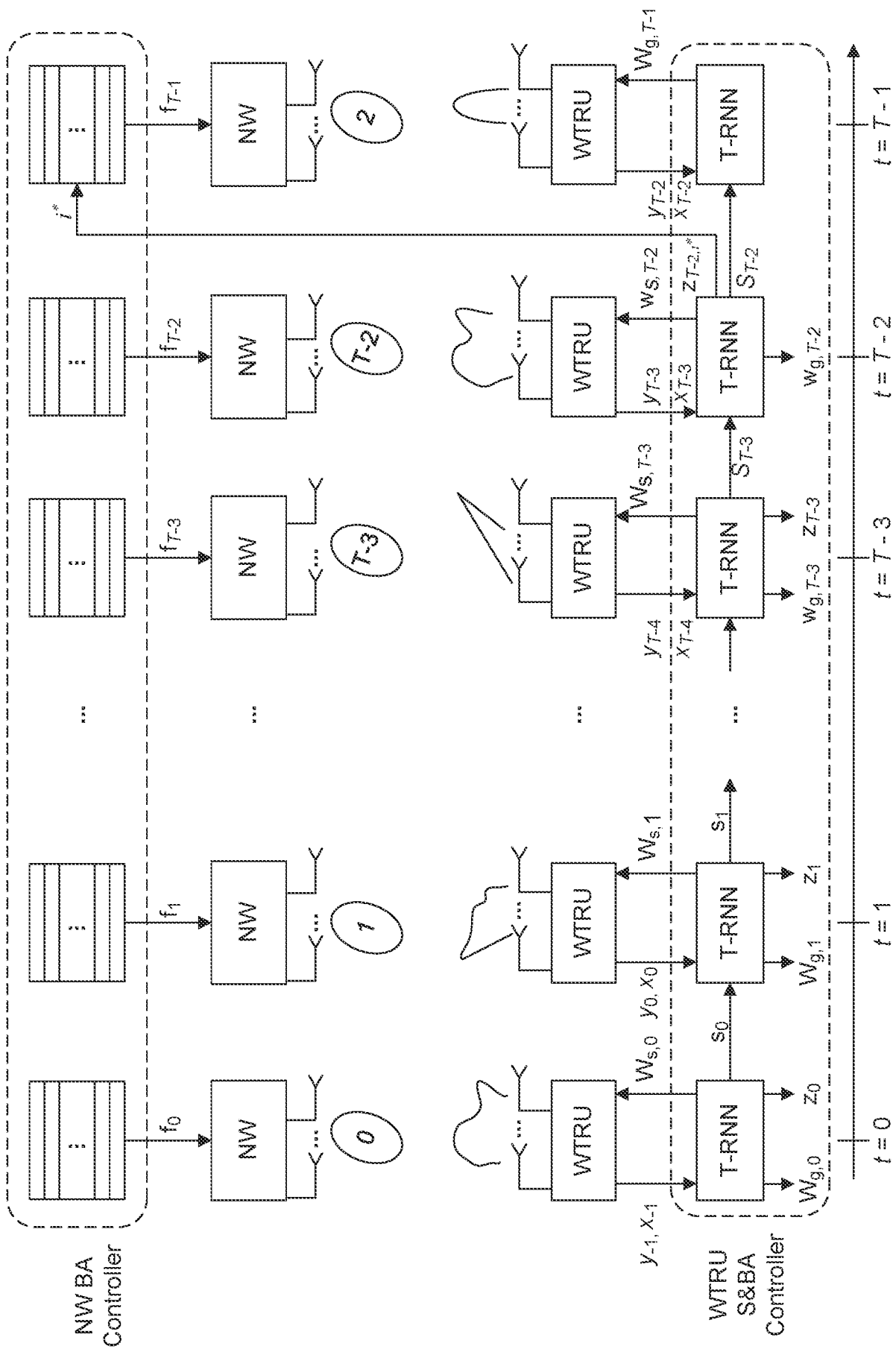


FIG. 7

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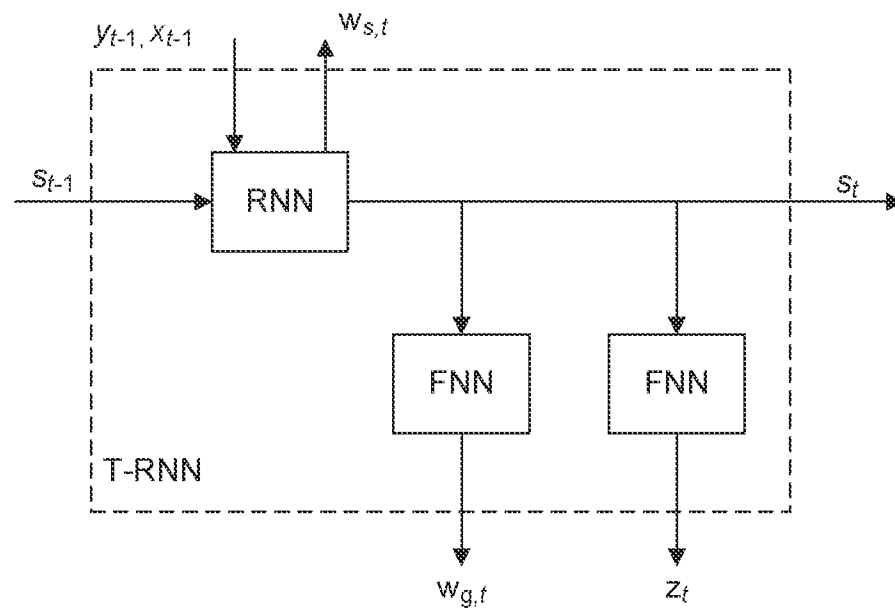


FIG. 8

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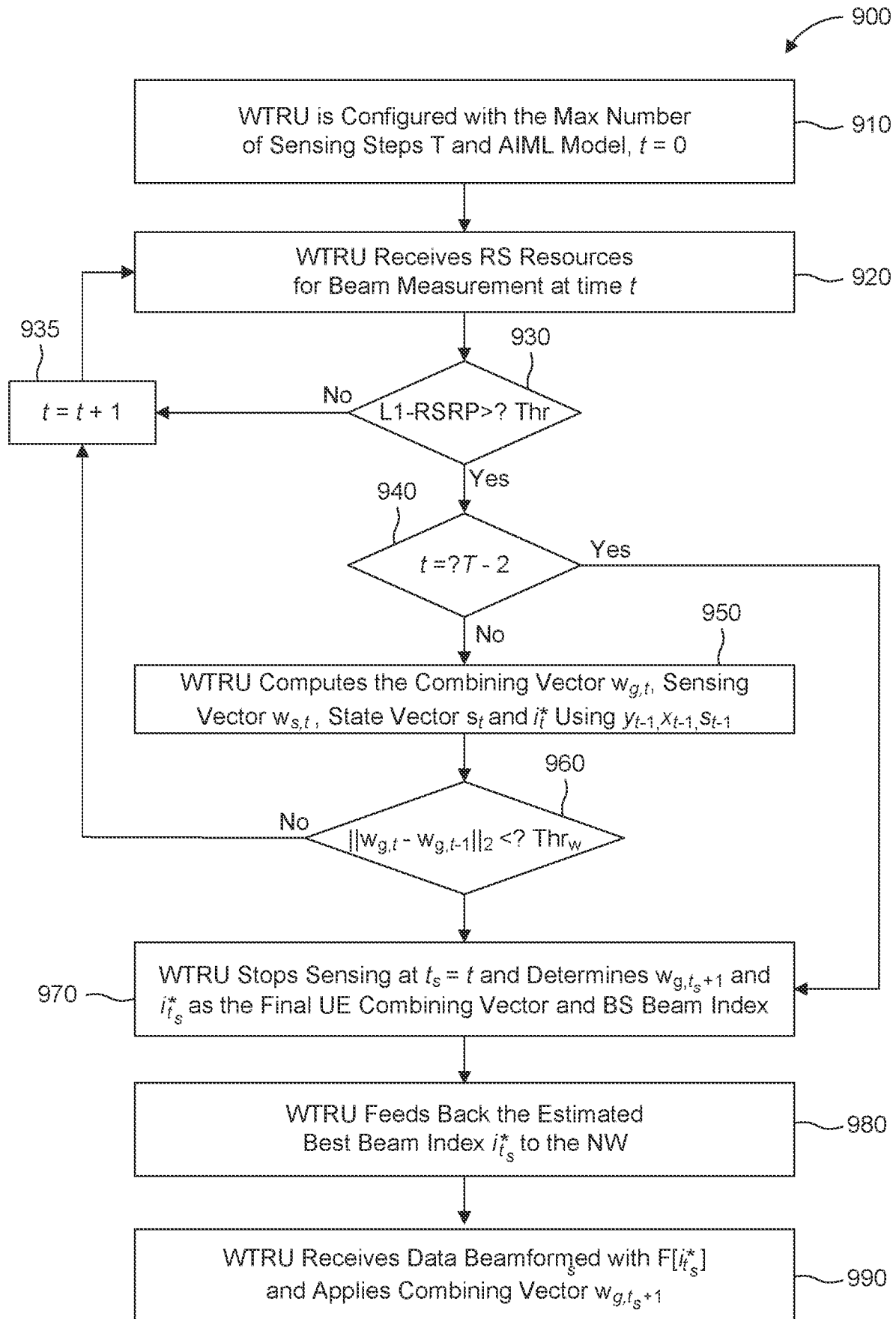


FIG. 9

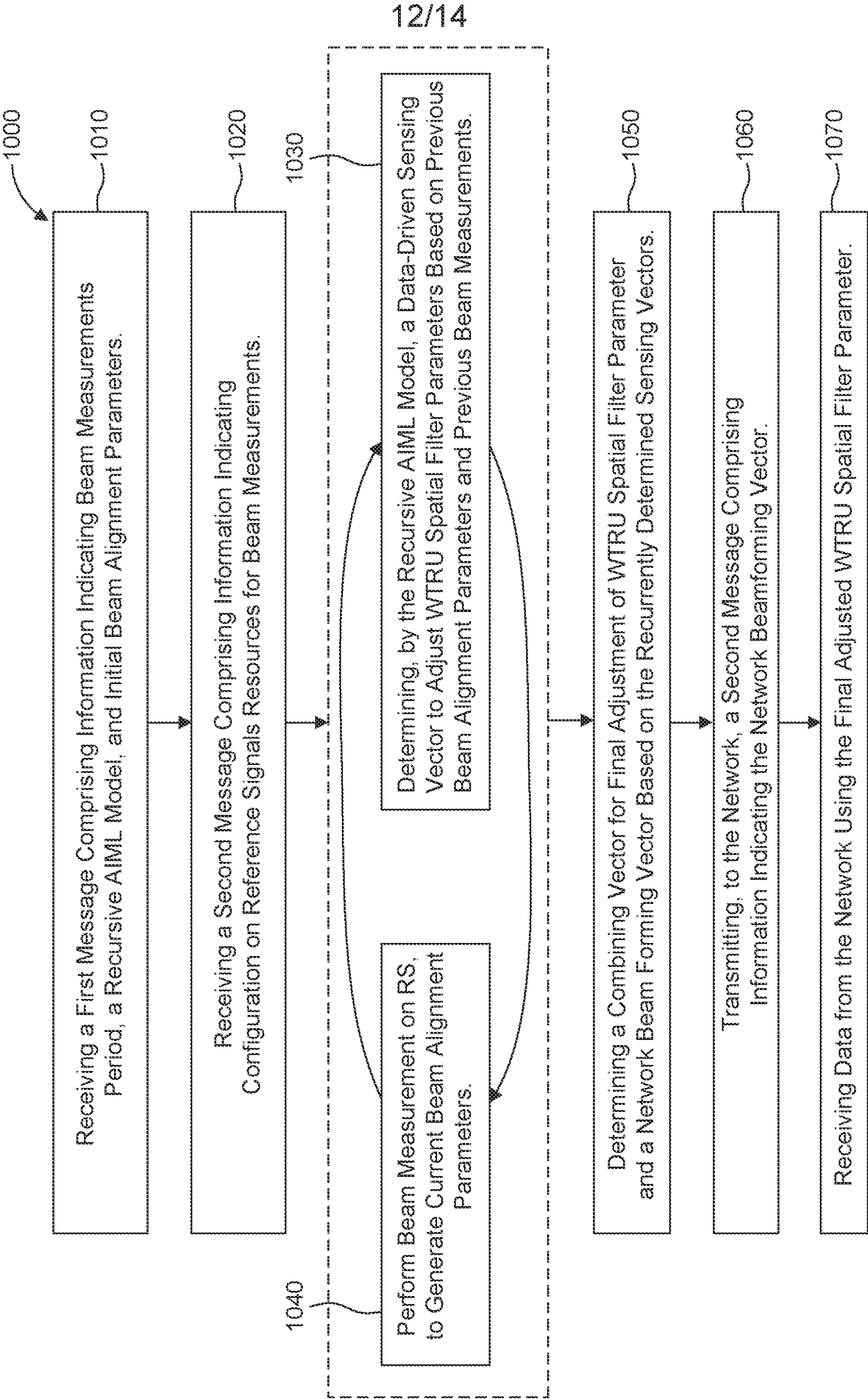


FIG. 10

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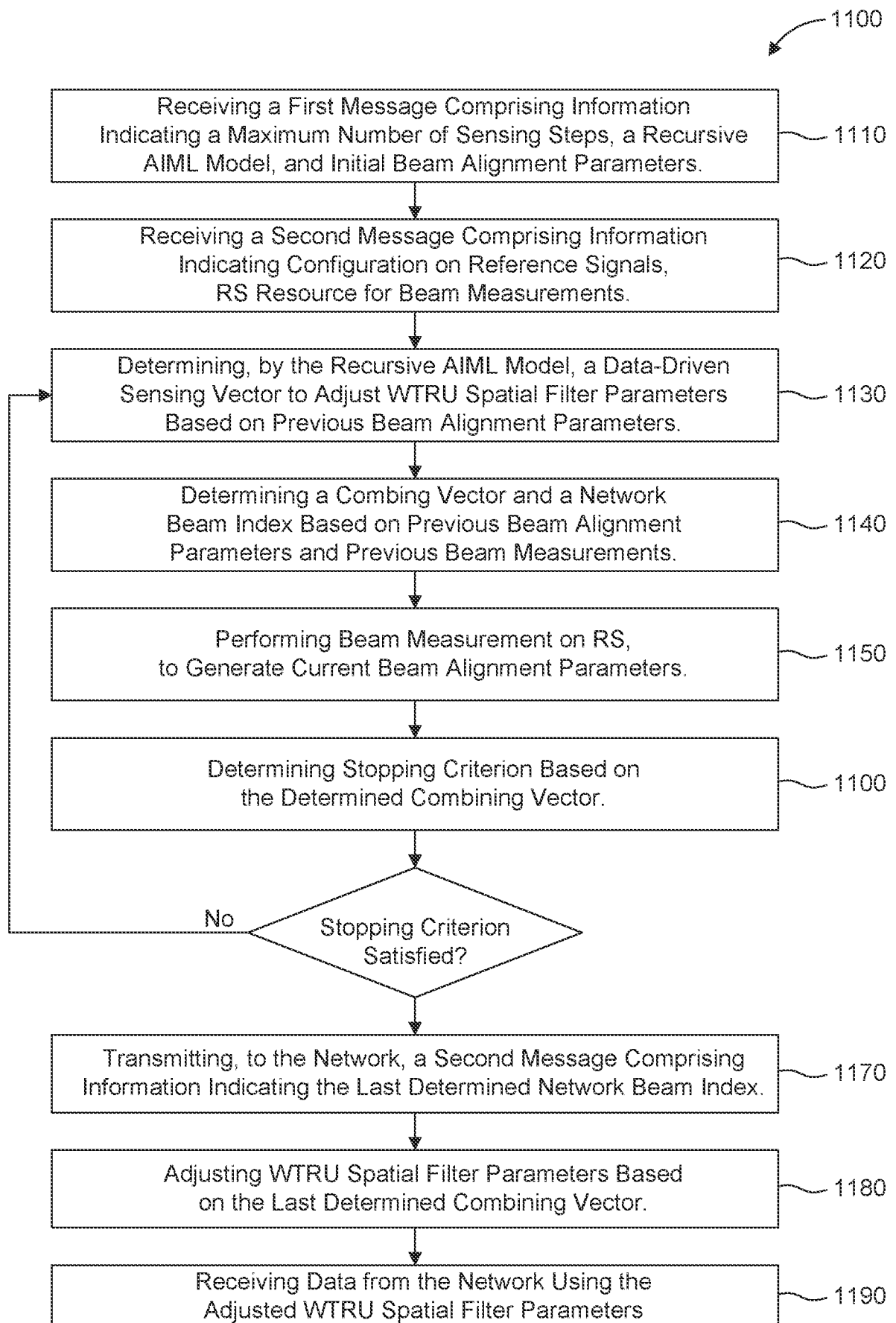


FIG. 11

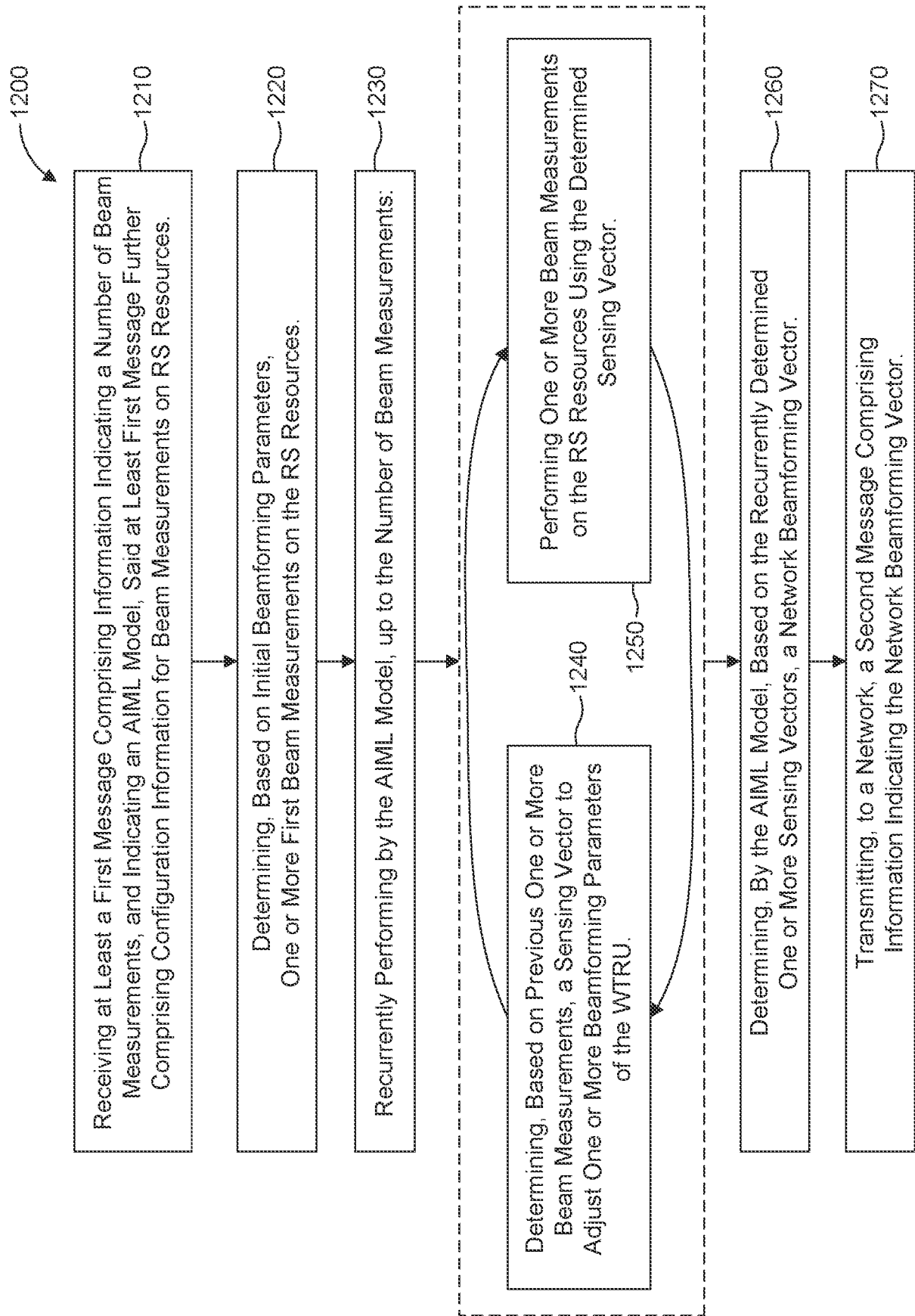


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/035598

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04B7/06 G06N3/08

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 G06N

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2023/287086 A1 (LG ELECTRONICS INC [KR]) 19 January 2023 (2023-01-19) - & EP 4 373 002 A1 (LG ELECTRONICS INC [KR]) 22 May 2024 (2024-05-22) paragraph [0001] - paragraph [0005] paragraph [0104] paragraph [0267] - paragraph [0270]; figure 21 paragraph [0324] - paragraph [0332]; figure 28 paragraph [0335] - paragraph [0346] paragraph [0369] - paragraph [0388]; figure 29 ----- - / - -	1 - 22



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

25 September 2024

Date of mailing of the international search report

10/10/2024

Name and mailing address of the ISA/

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Fax: (+31-70) 340-3016

Authorized officer

Sieben, Stefan

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/035598

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KHUNTETA SHUBHAM ET AL: "Recurrent Neural Network Based Beam Prediction for Millimeter-Wave 5G Systems", 2021 IEEE WIRELESS COMMUNICATIONS AND NETWORKING CONFERENCE (WCNC), IEEE, 29 March 2021 (2021-03-29), pages 1-6, XP033909085, DOI: 10.1109/WCNC49053.2021.9417509 [retrieved on 2021-04-27] the whole document -----	1 - 22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/035598

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023287086 A1	19-01-2023	EP 4373002 A1	22-05-2024
		KR 20240036036 A	19-03-2024
		WO 2023287086 A1	19-01-2023

EP 4373002 A1	22-05-2024	EP 4373002 A1	22-05-2024
		KR 20240036036 A	19-03-2024
		WO 2023287086 A1	19-01-2023
