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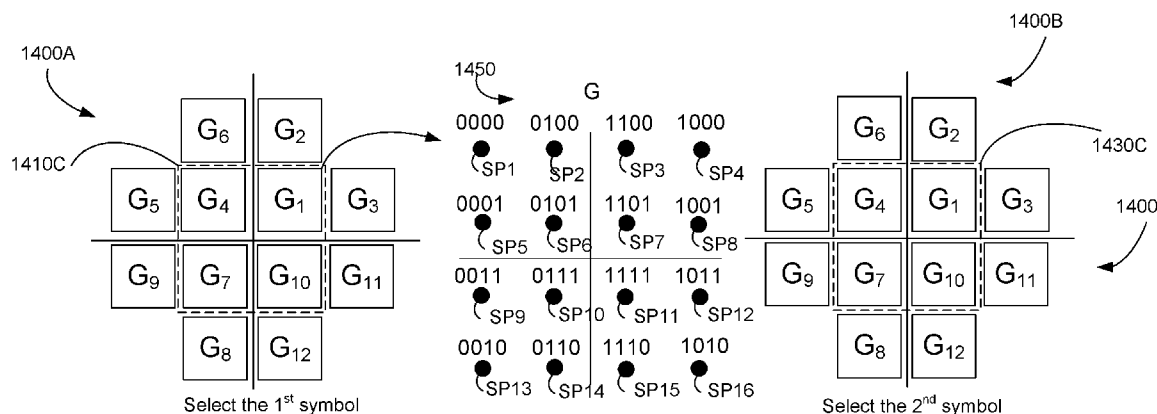
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(54) Title: METHODS, APPARATUS AND SYSTEMS USING A MULTIDIMENSIONAL GRAY CODING SCHEME FOR REAL NUMBER M -ARY QAM SIGNALINGFIG. 14: Hierarchical modulation: 12-ary QAM constellations superposed with 4^{m-1} -ary QAM constellations for $m = 3$.(57) Abstract: Methods, apparatus and systems using a multidimensional gray coding scheme for real number M -ary QAM signaling is disclosed. One representative method of data encoding includes segmenting a bit stream of binary data into sets; mapping the segmented sets of binary data to signal vectors of a multidimensional real number M -ary constellation; and generating M -ary signal elements corresponding to the mapped set of binary data based on the signal vectors of the multidimensional real number M -ary constellation.

**METHODS, APPARATUS AND SYSTEMS USING A MULTIDIMENSIONAL GRAY
CODING SCHEME FOR REAL NUMBER M -ARY QAM SIGNALING**

FIELD

[0001] The present invention relates to the field of communications and, more particularly, to methods, apparatus and systems using a coding scheme for real number M -ary QAM signaling.

RELATED ART

[0002] M -ary signal technology is being used in many digital communication areas including applications for digital data transmission via telephone lines in wired communication, in Digital Subscriber Line (DSL) technology, and in 4G mobile communications relating to Quadrature Amplitude Modulation (QAM).

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] 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 and the detailed description are not to be considered limiting, and other equally effective examples are possible and likely. Furthermore, like reference numerals in the Figures indicate like elements, and wherein:

FIG. 1 is a system diagram illustrating an example communications system in which one or more disclosed embodiments may be implemented;

FIG. 2 is a system diagram illustrating an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1;

FIG. 3 is a system diagram illustrating an example radio access network and another example core network that may be used within the communications system illustrated in FIG. 1;

FIG. 4 is a system diagram illustrating another example radio access network and another example core network that may be used within the communications system illustrated in FIG. 1;

FIG. 5 is a system diagram illustrating a further example radio access network and a further example core network that may be used within the communications system illustrated in FIG. 1;

FIG. 6 is a diagram illustrating a representative architecture for a real number M -ary QAM modulator;

FIGS. 7A and 7B are diagrams illustrating representative spatial, frequency, and/or time domains and signal vectors (SVs);

FIGS. 8A and 8B are diagrams illustrating different representative constellations;

FIG. 9 is a diagram illustrating a representative 3-ary QAM constellation with a time dimension of 2 (e.g., also referred to as 2 TD);

FIG. 10 is a diagram illustrating a representative gray code allocation operation of the 3-ary QAM constellation with 2 TD;

FIG. 11A is a diagram illustrating a representative 12-ary QAM constellation with 2 TD;

FIG. 11B is a diagram illustrating a representative 48-ary QAM constellation with 2 TD;

FIG. 11C is a diagram illustrating a representative 192-ary QAM constellation with 2 TD;

FIG. 12 is a diagram illustrating a representative 12-ary QAM superposed with 4-QAM that results in a 48-QAM constellation which is duplicated for selecting 2-symbol sequences;

FIG. 13 is a diagram illustrating an example constellation and corresponding bit-sequence matrix;

FIG. 14 is a diagram illustrating a representative hierarchical modulation for 12-ary constellations superposed with 4^{m-1} -ary constellations;

FIG. 15 is a diagram illustrating a representative cluster flipping operation;

FIG. 16A is a graph illustrating Bit Error Rate (BER) performance for various QAM schemes with binary mapping and with Gray mapping;

FIG. 16B is a graph illustrating BER performance for various QAM levels with Gray mapping;

FIG. 17 is a diagram illustrating a representative 6-ary QAM constellation with 2 TD;

FIG. 18 is a diagram illustrating representative gray code of the 6-ary QAM constellation with 2 TD of FIG. 17;

FIG. 19A is a diagram illustrating a representative 24-ary QAM constellation with 2 TD;

FIG. 19B is a diagram illustrating a representative 96-ary QAM constellation with 2 TD;

FIG. 19C is a diagram illustrating a representative 384-ary QAM constellation with 2 TD;

FIG. 20 is a diagram illustrating representative characteristics of a (3×2^m) -ary QAM constellation with an odd m (≥ 3);

FIG. 21 is a diagram illustrating a representative gray code allocation;

FIG. 22 is a diagram illustrating another representative gray code allocation;

FIG. 23 is a diagram illustrating a representative 28/3-ary QAM constellation with 3 TD;

FIG. 24 is a flowchart illustrating a representative method of data encoding;

FIG. 25 is a flowchart illustrating another representative method of data decoding;

FIG. 26 is a flowchart illustrating a representative method of data encoding;

FIG. 27 is a flowchart illustrating another representative method of data decoding; and

FIG. 28 is a flowchart illustrating a representative method of determining Gray code vectors for a real number 2 TD M -ary constellation.

DETAILED DESCRIPTION

[0004] A detailed description of illustrative embodiments may now be described with reference to the figures. However, while the present invention may be described in connection with representative embodiments, it is not limited thereto and it is to be understood that other embodiments may be used or modifications and additions may be made to the described embodiments for performing the same function of the present invention without deviating therefrom.

[0005] Although the representative embodiments are generally shown hereafter using wireless network architectures, any number of different network architectures may be used including networks with wired components and/or wireless components, for example.

[0006] FIG. 1 is a 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), and the like.

[0007] As shown in FIG. 1, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104, a core network 106/107/109, 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, 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 user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, and the like. The WTRU 102a, 102b, 102c and 102d is interchangeably referred to as a UE.

[0008] 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 to facilitate access to one or more communication networks, such as the core network 106/107/109, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, 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.

[0009] The base station 114a may be part of the RAN 103/104/105, 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 within a particular geographic region, which may be referred to as a cell (not shown). 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 one embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In another embodiment, the base station 114a may employ multiple-input multiple output (MIMO) technology and may utilize multiple transceivers for each sector of the cell.

[0010] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 115/116/117, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface 115/116/117 may be established using any suitable radio access technology (RAT).

[0011] 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 103/104/105 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 115/116/117 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 (DL) Packet Access (HSDPA) and/or High-Speed UL Packet Access (HSUPA).

[0012] In another 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 115/116/117 using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A).

[0013] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.11 (i.e., Wireless Fidelity (WiFi)), 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.

[0014] The base station 114b in FIG. 1 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, and the like. In one 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 another 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 yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, etc.) to establish a picocell or femtocell. As shown in FIG. 1, 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 core network 106/107/109.

[0015] The RAN 103/104/105 may be in communication with the core network 106/107/109, 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. For example, the core network 106/107/109 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. 1, it will be appreciated that the RAN 103/104/105 and/or the core network 106/107/109 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 103/104/105 or a different RAT. For example, in addition to being connected to the RAN 103/104/105, which may be utilizing an E-UTRA radio technology, the core network 106/107/109

may also be in communication with another RAN (not shown) employing a GSM, UMTS, CDMA 2000, WiMAX, or WiFi radio technology.

[0016] The core network 106/107/109 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or the 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 core network connected to one or more RANs, which may employ the same RAT as the RAN 103/104/105 or a different RAT.

[0017] 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. 1 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.

[0018] FIG. 2 is a system diagram illustrating an example WTRU 102. As shown in FIG. 2, 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 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.

[0019] 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 Array (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. 2 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 in an electronic package or chip.

[0020] 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 115/116/117. For example, in one embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In another 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 yet another 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.

[0021] Although the transmit/receive element 122 is depicted in FIG. 2 as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one 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 115/116/117.

[0022] 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 UTRA and IEEE 802.11, for example.

[0023] 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).

[0024] 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.

[0025] 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 115/116/117 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.

[0026] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or

wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (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, and the like.

[0027] 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 UL (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 139 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).

[0028] The processor 118 may execute the *M*-ary coding/decoding scheme. In certain representative embodiments, the WTRU 102 may include one or more auxiliary processors/hardware modules/chips to execute the *M*-ary coding/decoding scheme.

[0029] FIG. 3 is a system diagram illustrating the RAN 103 and the core network 106 according to another embodiment. As noted above, the RAN 103 may employ a UTRA radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 115. The RAN 103 may also be in communication with the core network 106. As shown in FIG. 3, the RAN 103 may include Node-Bs 140a, 140b, 140c, which may each include one or more transceivers for communicating with the WTRUs 102a, 102b, and 102c over the air interface 115. The Node-Bs 140a, 140b, 140c may each be associated with a particular cell (not shown) within the RAN 103. The RAN 103 may also include RNCs 142a, 142b. It will be appreciated that the RAN 103 may include any number of Node-Bs and RNCs while remaining consistent with an embodiment.

[0030] As shown in FIG. 3, the Node-Bs 140a, 140b may be in communication with the RNC 142a. Additionally, the Node-B 140c may be in communication with the RNC 142b. The Node-Bs 140a, 140b, 140c may communicate with the respective RNCs 142a, 142b via an Iub interface. The RNCs 142a, 142b may be in communication with one another via an Iur interface. Each of the RNCs 142a, 142b may be configured to control the respective Node-Bs 140a, 140b, 140c to which it is connected. In addition, each of the RNCs 142a, 142b may be configured to carry out or support other functionality, such as outer loop power control, load control, admission control, packet scheduling, handover control, macrodiversity, security functions, data encryption, and the like.

[0031] The core network 106 shown in FIG. 3 may include a media gateway (MGW) 144, a mobile switching center (MSC) 146, a serving GPRS support node (SGSN) 148, and/or a gateway GPRS support node (GGSN) 150. While each of the foregoing elements are depicted as part of the core network 106, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

[0032] The RNC 142a in the RAN 103 may be connected to the MSC 146 in the core network 106 via an IuCS interface. The MSC 146 may be connected to the MGW 144. The MSC 146 and the MGW 144 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.

[0033] The RNC 142a in the RAN 103 may also be connected to the SGSN 148 in the core network 106 via an IuPS interface. The SGSN 148 may be connected to the GGSN 150. The SGSN 148 and the GGSN 150 may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between and the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0034] As noted above, the core network 106 may also be connected to the other networks 112, which may include other wired and/or wireless networks that are owned and/or operated by other service providers.

[0035] FIG. 4 is a system diagram illustrating the RAN 104 and the core network 107 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 core network 107.

[0036] 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 one 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/or receive wireless signals from, the WTRU 102a.

[0037] 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 UL and/or DL, and the like. As shown in FIG. 4, the eNode-Bs 160a, 160b, 160c may communicate with one another over an X2 interface.

[0038] The core network 107 shown in FIG. 4 may include a mobility management entity (MME) 162, a serving gateway (SGW) 164, and a packet data network (PDN) gateway (or PGW) 166. While each of the foregoing elements are depicted as part of the core network 107, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the core network operator.

[0039] 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.

[0040] The serving gateway 164 may be connected to each of the eNode Bs 160a, 160b, 160c in the RAN 104 via the S1 interface. The serving gateway 164 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The serving gateway 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.

[0041] The serving gateway 164 may be connected to the PDN gateway 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.

[0042] The core network 107 may facilitate communications with other networks. For example, the core network 107 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 core network 107 may include, or may communicate with, an IP gateway (e.g., an IP multimedia subsystem (IMS) server) that serves as an interface between the core network 107 and the PSTN 108. In addition, the core network 107 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.

[0043] FIG. 5 is a system diagram illustrating the RAN 105 and the core network 109 according to an embodiment. The RAN 105 may be an access service network (ASN) that employs IEEE 802.16 radio technology to communicate with the WTRUs 102a, 102b, and 102c over the air interface 117. As will be further discussed below, the communication links between the different functional entities of the WTRUs 102a, 102b, 102c, the RAN 105, and the core network 109 may be defined as reference points.

[0044] As shown in FIG. 5, the RAN 105 may include base stations 180a, 180b, 180c, and an ASN gateway 182, though it will be appreciated that the RAN 105 may include any number of base stations and ASN gateways while remaining consistent with an embodiment. The base stations 180a, 180b, 180c may each be associated with a particular cell (not shown) in the RAN 105 and may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 117. In one embodiment, the base stations 180a, 180b, 180c may implement MIMO technology. The base station 180a, for example, may use multiple antennas to transmit wireless signals to, and/or receive wireless signals from, the WTRU 102a. The base stations 180a, 180b, 180c may also provide mobility management functions, such as handoff triggering, tunnel establishment, radio resource management, traffic classification, quality of service (QoS) policy enforcement, and the like. The ASN gateway 182 may serve as a traffic aggregation point and may be responsible for paging, caching of subscriber profiles, routing to the core network 109, and the like.

[0045] The air interface 117 between the WTRUs 102a, 102b, 102c and the RAN 105 may be defined as an R1 reference point that implements the IEEE 802.16 specification. In addition, each of the WTRUs 102a, 102b, and 102c may establish a logical interface (not shown) with the core network 109. The logical interface between the WTRUs 102a, 102b, 102c and the core network 109 may be defined as an R2 reference point, which may be used for authentication, authorization, IP host configuration management, and/or mobility management.

[0046] The communication link between each of the base stations 180a, 180b, and 180c may be defined as an R8 reference point that includes protocols for facilitating WTRU handovers and the transfer of data between base stations. The communication link between the base stations 180a, 180b, 180c and the ASN gateway 182 may be defined as an R6 reference point. The R6 reference point may include protocols for facilitating mobility management based on mobility events associated with each of the WTRUs 102a, 102b, 102c.

[0047] As shown in FIG. 5, the RAN 105 may be connected to the core network 109. The communication link between the RAN 105 and the core network 109 may be defined as an R3 reference point that includes protocols for facilitating data transfer and mobility management capabilities, for example. The core network 109 may include a mobile IP home agent (MIP-HA) 184, an authentication, authorization, accounting (AAA) server 186, and a gateway 188. While each of the foregoing elements are depicted as part of the core network 109, it will be appreciated that any of these elements may be owned and/or operated by an entity other than the core network operator.

[0048] The MIP-HA 184 may be responsible for IP address management, and may enable the WTRUs 102a, 102b, and 102c to roam between different ASNs and/or different core networks. The MIP-HA 184 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. The AAA server 186 may be responsible for user authentication and for supporting user services. The gateway 188 may facilitate interworking with other networks. For example, the gateway 188 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. The gateway 188 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.

[0049] Although not shown in FIG. 5, it will be appreciated that the RAN 105 may be connected to other ASNs, other RANS (e.g., RANs 103 and/or 104) and/or the core network 109 may be connected to other core networks (e.g., core network 106 and/or 107). The communication link between the RAN 105 and the other ASNs may be defined as an R4 reference point, which may include protocols for coordinating the mobility of the WTRUs 102a, 102b, 102c between the RAN 105 and the other ASNs. The communication link between the core network 109 and the other core networks may be defined as an R5 reference, which may include protocols for facilitating interworking between home core networks and visited core networks.

[0050] Although the WTRU is described in FIGS. 1-5 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.

[0051] In certain representative embodiments, apparatus and methods for generating real number Gray coded M -ary QAM signaling, for example with multiple dimensions: (1) in time; (2) in frequency; and/or (3) in the spatial domain, among others may be implemented. In certain representative embodiments, the apparatus and methods may include and/or use SVs.

[0052] For conventional M -ary signals, M needs to be a power of 2 (2^k , here k is integer) with may cause difficulty in its design. For example, if k is even in LTE, M may need to be increased by four time when M is increased. This may cause a burden on the design in the eNB implementation (e.g., gNB implementation and/or access point implementation, among others) and/or the WTRU (e.g., the UE) implementation. For example, this design may increase costs because of expensive amplifiers as M becomes larger.

[0053] In certain representative embodiments, by mapping binary symbol inputs to extended signals with 2 dimensions or more than 2 dimensions, for example, in a time domain, a real number M -ary QAM signal of which M can be increased incrementally and a procedure for generating a multi-dimensional Gray code may be implemented. In certain representative embodiments, a real number M -ary QAM may provide a low Peak-to-Average Power Ratio (PAPR) (e.g., below a threshold level) relative to the conventional M -ary QAM.

[0054] In certain representative embodiments, the real number M -ary QAM constellation may include angular points and in other representative embodiments, the real number M -ary QAM constellation does not include such angular points.

[0055] For a real number M -ary signal, if a value of M is not limited to a power of 2, M may be increased incrementally. For example, if a received signal power is changed depending on a distance between a mobile terminal (e.g., the WTRU 102) and a base station (e.g., the eNB 160, access point and/or gNB, among others), a value of M also may be changed (e.g., in a range from 4 to 256) and may cause degradation of communication efficiency due to its large granularity (e.g., coarse granularity). If M is changed with finer granularity, communication efficiency may be improved. Because it is contemplated that wireless positioning in 5G systems may be more sophisticated relative to 4G systems, communication efficiency may be maximized by selecting the most appropriate M depending on Signal-to-Noise Ratio (SNR) or other noise or interference related parameters between the WTRU 102 (and/or mobile terminal) and the base station (e.g., the eNB 160, access point and/or gNB, among others). Certain representative embodiments may use real number M -ary signals for indoor terminals with a fixed position or with a wireless backhaul system.

[0056] In certain representative embodiments, procedures for generating a real-valued QAM signal by extending TD to more than 2 dimension may be implemented.

[0057] In certain representative embodiments, procedures for achieving a Gray code for all SVs with an allocation to make PAPR low (e.g., below a threshold level) may be implemented.

[0058] In certain representative embodiments, procedures to generate one or more SVs, for example, by using a function from input binary symbols may be implemented.

Representative Real Number M -ary QAM

[0059] A QAM system may process a binary symbol with K bits input at every cycle. It is contemplated that M_1 -ary signals with N_1 times and M_2 -ary signals with N_2 times are transmitted for overall N

continuous QAM signals where $N = N_1 + N_2$. The number of signal vectors (SVs) which may be generated (e.g., generated totally), G can be expressed as shown in Equation 1 below.

$$G = M_1^{N_1} \times M_2^{N_2}. \quad (1)$$

[0060] The SV enables (e.g., is to make) binary symbols corresponding to more than two signal elements when TD is two or more than two and to differentiate it from ‘signal point’ which is used for terminology of M -ary signal scheme satisfying conventional $M=2^k$ with 1 TD. For example, signal points with more than two may be considered as an SV. K , the number of bits which can be transmitted per SV, may be derived as shown in Equation 2 below by applying a log operation on (1).

$$K = [N_1 \log_2 M_1 + N_2 \log_2 M_2] \quad (2)$$

where $[x]$ is the largest integer which does not exceed x . The actually used number of SVs in the communication system transmitting binary symbol is 2^K and thus, the number of unused SVs, G' is shown in Equation 3 below.

$$G' = G - 2^K = M_1^{N_1} \times M_2^{N_2} - 2^{[N_1 \log_2 M_1 + N_2 \log_2 M_2]}. \quad (3)$$

[0061] As the number of bits which may be transmitted per SV, for example, is K , the average number of bits k , which may be transmitted per one SP, is the value of dividing Equation 2 by N .

$$k = K / N = [N_1 \log_2 M_1 + N_2 \log_2 M_2] / N \quad (4)$$

where N is the total Time Dimension (TD). It is contemplated that k is not an integer number and instead may be a rational number. Although terms describing a time dimension are used herein, it is contemplated that these terms are interchangeable with terms describing a frequency, a spatial component in MIMO related schemes and/or other resources. For example, the constellation may be implemented to vary dynamically over any of: time, frequency and/or space. M , as the average of M_j ($j = 1, 2$), may be expressed as shown in Equation 5, as follows.

$$M = E[M_j] = \frac{N_1 M_1 + N_2 M_2}{N} \quad (5)$$

[0062] M may be a rational number. Generally, M may be defined as the number of SPs used for a constellation. Being different from a conventional M -ary QAM signal, unused SPs may exist in a rational M -ary QAM signal herein and, if the number of effective SPs is denoted by M_e , it may be determined based on Equation 4 as shown in Equation 6 below.

$$M_e = 2^k = 2^{[N_1 \log_2 M_1 + N_2 \log_2 M_2] / N} \quad (6)$$

where the number of effective SPs is a real number (e.g., because it has a rational power of two) (which is the reason why the signal is referred to as real number M -ary QAM signal herein). Because there are unused SVs as shown in Equation 3, $M_e \leq M (= E[M_j])$ holds.

Representative Real Number M -ary QAM Modulator

[0063] FIG. 6 is a diagram illustrating a representative architecture for a real number M -ary QAM modulator 600.

[0064] Referring to FIG. 6, the representative structure for the real number M -ary modulator 600 may include a serial-to-parallel converter 620, a symbol mapper 630, shaping filters 640 and 650, an oscillator 660, multiplexers 645 and 655, a phase shifter 670 and/or a summer 680, among others. A binary bit stream 610 may flow as input to the real number M -ary QAM modulator 600, and one symbol may be processed by the unit (e.g., of K bit). For example, K bits may be parallelized per cycle by the serial-to-parallel converter 620. The output of the serial-to-parallel converter 620 may be input to the symbol mapper 630, which may generate an I-component (In-phase) vector $\mathbf{x}_N = [x_1, \dots, x_N]$ and a Q-component (Quadrature-phase) vector $\mathbf{y}_N = [y_1, \dots, y_N]$ after receiving the K bits. One cycle time may be divided into N time periods. A conventional QAM modulator has only one time period per one cycle and scalar values for the in-phase and the quadrature component, respectively. The I component vector and the Q component vector may be expressed in a form that is a function of the binary symbol vector which may be input to the symbol mapper 630 as shown in Equation 7 and 8 follows.

$$\mathbf{x}_N = [x_1, \dots, x_N] = [x_1(\mathbf{b}_K), \dots, x_N(\mathbf{b}_K)] \quad (7)$$

$$\mathbf{y}_N = [y_1, \dots, y_N] = [y_1(\mathbf{b}_K), \dots, y_N(\mathbf{b}_K)], \quad (8)$$

where $\mathbf{b}_K = [b_{K-1}, \dots, b_0]$ is a binary symbol vector composed of K bits.

[0065] The n -th ($1 \leq n \leq N$) component (x_n, y_n) may be one of the SPs configuring a constellation in the n -th time period, as a single pair. The M_1 -ary may be transmitted N_1 times and the M_2 -ary may be transmitted N_2 times, if N_1 and N_2 are larger than 1 and $n_1 \neq n_2$, (x_{n_1}, y_{n_1}) and (x_{n_2}, y_{n_2}) have different components in the constellation from each other in a real number scheme. If one of N_1 and N_2 is 0, all (x_n, y_n) have the same components in the constellation.

[0066] The structure after the symbol mapper 630 may have, for example, two outputs (e.g., an in-phase component output and a quadrature phase component output) that may be added at a summer 680 and transmitted after moving through respective shaping filters 640 and 650 and multipliers 645 and 655,

respectively. The shaping filters 640 and 650 may generate shaped waveforms (e.g., of the baseband). The shaped waveform associated with the in-phase component output may be input to the first multiplier 645 (e.g., to be multiplied by a cosine waveform) and the shaped waveform associated with the quadrature phase component output may be input to the second multiplier 655 (e.g., to be multiplied by a sine waveform). It is contemplated that the finally modulated signal $s_N(t)$ may have an output of vector form $([s_1(t), \dots, s_N(t)])$.

[0067] The real M -ary QAM modulator 600 may have a symbol mapper 630 that may generate SVs and may use algorithms and/or structures (e.g., look up tables, among others) disclosed herein.

Representative Multidimensional Gray Code Generation Operation

[0068] In certain representative embodiments, the symbol mapper 630 may be implemented such that one bit difference (e.g., only one bit difference) between adjacent signals exists (for example to minimize and/or optimize a Bit Error Rate (BER), Packet Error Rate (PER), Probability Of Error (POE), and/or Energy per bit to Noise Power Spectral Density Ratio (E_b/N_0), among others), when or on condition that the binary symbol values are allocated. The one bit difference between adjacent signals may be referred to as a Gray code. In certain representative embodiments, there may be a one bit difference (e.g., only a one bit difference between adjacent SVs when binary symbols are allocated).

[0069] FIGS. 7A and 7B are diagrams illustrating representative spatial, frequency, and/or time domains and SVs.

[0070] Referring to FIG. 7A, a constellation 700 of 4-ary QAM (QPSK) may have a signal point (SP) 710 (e.g., SP(+1, +1) in quadrant 1) with two adjacent SPs 720 and 730 (e.g., SP(+1, -1) and SP(-1, +1)) (e.g. as the nearest SPs to (SP (+1, +1))). Referring to FIG. 7B, a constellation 750 of 2 TD (7/2)-ary QAM signal with $(M_1, N_1) = (4, 1)$ and $(M_2, N_2) = (3, 1)$ may have a SV $\{(+1, +1), (+1, +1)\}$ with four adjacent SVs $\{(+1, +1), (+1, -1)\}$, $\{(+1, -1), (+1, +1)\}$, $\{(+1, +1), (-1, +1)\}$ and $\{(-1, +1), (+1, +1)\}$. For example, these SVs (e.g., as a Gray code) may be used in the multidimensional M -ary signaling procedure. It is contemplated that the Gray code may be generated for multidimensional M -ary signaling and may depend on unused SV and positions of related SPs.

Representative (3×2^m) -ary QAM with 2 TD

[0071] In certain representative embodiments, a Gray code generation procedure for a multi-dimensional QAM signal with $M_j = (3 \times 2^m)$ ($j=1, 2$ and $m \geq 0$, where m is integer) may be implemented. Any of two different structures may be used in the constellations (e.g., all constellations).

[0072] FIGS. 8A and 8B are diagrams illustrating different representative constellations 800 and 850.

[0073] Referring to FIGS. 8A and 8B, a first representative type 1 constellation 800, as shown in FIG. 8A, may include a set of SPs 810, 820 and 830 denoted by $A = \{(-1, +1), (-1, -1), (+1, -1)\}$ and a second representative type 2 constellation 850, as shown in FIG. 8B, may include a set of SPs 860, 870 and 880 denoted by $B = \{(0, +2), (0, 0), (0, -2)\}$. Representative type 1 constellation 800 and representative type 2 constellation 850 may each have SPs (denoted by black SPs 810:830 and 860:880 and cross SPs 820 and 870) and may generate various vectors when combined with SPs in the other dimension (e.g., in time, in

frequency, in polarization and/or in space, among others). In certain representative embodiments, a black SP (hereafter sometimes referred to as a black point) may be combined with any points (e.g., SPs) of the other dimension or dimensions and/or a cross SP (hereafter sometimes referred to as a cross point) may be limited when it is combined with the other dimension or dimensions. For example, a vector composed of cross points (e.g., all cross points) may result in it being an unused SV, for example, for a Gray code.

[0074] A (3×2^m) -ary QAM with 2 TD for example may mean that $(M_1, N_1) = (3 \times 2^m, 2)$, and $(M_2, N_2) = (X, 0)$, where X is 'don't care' (e.g., does not matter as any value can be used for X , because N_2 is zero). $N_2 = 0$ and M_2 may have no meaning. According to Equations 1 to 5, the number of possible SVs (e.g., all SVs) is $G = (3 \times 2^m)^2$, transmission bit number per SV is $K = 2m + 3$, the number of unused SVs is $G' = 2^{2m}$, the number of transmission bits per SP is $k = m + 1.5$, the number of average SPs (arithmetic average) is $M = 3 \times 2^m$ and the number of effective SPs is $M_e = 2^{m+1.5}$.

Representative Procedures on Condition That m is Even

Representative 3-ary QAM for $(m=0)$

[0075] FIG. 9 is a diagram illustrating a representative 3-ary QAM constellation 900 with a time dimension of 2 (e.g., also referred to as 2 TD).

[0076] Referring to FIG. 9, a constellation 900 may include a first time period 910 and a second time period 920 and may be depicted in the case of $M = 3$ ($m = 0$). Vectors configured by cross points 930 and 960 (e.g., only cross points) may not be used. If the set in the first period 910 (e.g., 1st time period) is denoted by P_1 and the set in the second period 920 (e.g., 2nd time period) is denoted by P_2 , P_1 and P_2 may be expressed as $P_1 = A$ and/or $P_2 = \{(-x, -y) | x, y \in A\}$. P_1 may be the same as the set of the representative constellation type 1 SPs and P_2 may be one such that components of A (e.g., all components of A) may be, for example, rotated by 180 degrees.

[0077] In certain representative embodiments, finding signal synchronization without additional overhead may be beneficial. The shape of the constellation may be configured to be different between the first period 910 and the second period 920. It is contemplated to identify whether a SP at a certain moment may be in the first period 910 or may be in the second period 920, because the cross point 930 (e.g., SP(-1,-1)) in the first period 910 and the cross point 960 (e.g., SP(+1,+1)) in the second period 920 are SPs which are not found in the 2nd period 920 and in the 1st period 910, respectively.

[0078] If the total SV set U is established and can be generated from two SP sets, P_1 and P_2 by Cartesian product, $U = P_1 \times P_2$, the used set of vectors (e.g., actually used set of vectors) and unused set of vectors may be denoted as V and V^c , respectively, as shown in Equation 9.

$$V = U - V^c = P_1 \times P_2 - V^c \quad (9)$$

where $V^c = \{(-1, -1, +1, +1)\}$, and so $V = \{(-1, +1, +1, -1), (-1, +1, +1, +1), (-1, +1, -1, +1), (-1, -1, -1, +1), (+1, -1, -1, +1), (+1, -1, +1, +1), (+1, -1, +1, -1), (-1, -1, +1, -1)\}$. The elements of V each may be a SV.

[0079] FIG. 10 is a diagram illustrating a representative Gray code allocation 1000 for a 3-ary QAM with 2 TD.

[0080] Referring to FIG. 10, the unused vector $(-1, -1, +1, +1)$ has the most adjacent vectors. If this vector is used and one of the other vectors are used, a Gray code may not be generated. By not using the vector $(-1, -1, +1, +1)$, a Gray code may be possible (e.g., may be the only way) to generate a Gray code in the 3-ary QAM. For example, a SV1 $(-1, +1, +1, -1)$ may correspond to a bit sequence of '000'; SV2 $(-1, +1, +1, +1)$ may correspond to a bit sequence of '001'; SV3 $(-1, +1, -1, +1)$ may correspond to a bit sequence of '011'; SV4 $(-1, -1, +1, -1)$ may correspond to a bit sequence of '100'; SV5 $(-1, -1, -1, +1)$ may correspond to a bit sequence of '010'; SV6 $(+1, -1, +1, -1)$ may correspond to a bit sequence of '101'; SV7 $(+1, -1, +1, +1)$ may correspond to a bit sequence of '111'; and SV8 $(+1, -1, -1, +1)$ may correspond to a bit sequence of '110'.

Representative (3×2^m) -ary QAM with an Even $m (\geq 2)$

[0081] FIG. 11A is a diagram illustrating a representative 12-ary QAM constellation 1100 with 2 TD. FIG. 11B is a diagram illustrating a representative 48-ary QAM constellation 1140 with 2 TD. FIG. 11C is a diagram illustrating a representative 192-ary QAM constellation 1180 with 2 TD.

[0082] A generating equation may be used to implement a mapper by generalization from common properties which may be found for (3×2^m) -ary QAM in case of $m \geq 2$ and m is an even number. FIGS. 11A, 11B and 11C illustrate the constellations 1100, 1140 and 1180 for the first time period 1100A, 1140A and 1180A and the second time period 1100B, 1140B and 1180B in case of $m = 2, 4, 6$, respectively. If the modulation is represented as (3×4^m) -ary QAM, then m takes natural numbers. x_i^j denotes a sequence $x_i, \dots, x_j$ where a boldface lower case letter, such as x , to denote a row vector, and a boldface upper case letter G to denote a matrix.

[0083] For the case of (3×4^m) -ary QAM where $m=1$ (i.e., a 12-ary QAM), a mapping function may be shown in Table 1, which maps 3 bits to two symbols, each of which may be taken from the first quadrant of a 12-ary QAM. $f(\cdot)$ may be verified to be a Gray mapping between or among eight 2-symbol sequences and the valuations of the 3 bits.

$f(000)$	$f(001)$	$f(011)$	$f(010)$	$f(110)$	$f(111)$	$f(101)$	$f(100)$
1,3,1,3	1,3,1,1	1,3,3,1	1,1,3,1	3,1,3,1	3,1,1,1	3,1,1,3	1,1,1,3

Table 1 – Mapping Function

[0084] From the mapping function, for the 12-ary QAM in two complex dimensions, the following mapping is a Gray mapping:

$$v(b_0^6) = f(b_6, b_5, b_4) D(b_0^3) \quad (10)$$

where $D(b_0^3) = \text{diag}((-1)^{b_3}, (-1)^{b_2}, (-1)^{b_1}, (-1)^{b_0})$. The Gray mapping may be verified (e.g., by computer and/or shown analytically).

[0085] For N -ary QAM modulation, where $N = 3 \times 4^m$ with $m \geq 1$, the PAPR may be reduced for OFDM based waveforms modulated with 4^{m+1} -ary QAM, for example, by removing a number of constellation points (e.g., a quarter or about a quarter of the constellation points) from a 4^{m+1} -ary QAM constellation. The resulting constellation may be a 12-ary QAM superposed with 4^{m-1} -ary QAM constellations. A subset of the 2-symbol sequences drawn from two N -ary QAM constellations may be selected.

[0086] A Gray mapping may be constructed that may map k bits to 2-symbol sequences, where

$$k = \lfloor \log_2 N^2 \rfloor = 3 + 4m. \quad (11)$$

[0087] FIG. 12 is a diagram illustrating a 12-ary QAM superposed with 4-QAM that may result in a 48-QAM constellation 1200 and may be duplicated for selecting 2-symbol sequences. For example, each SP in the 12-ary QAM may be superposed with (e.g., may incorporate) four SP of a 4-QAM constellation to enable a 48-QAM constellation.

[0088] Referring to FIG. 12, an example of the constellations 1200A and 1200B for $m = 2$ is shown and the modulation order may be $k/2 = 1.5 + 2m$, which may be a half integer.

[0089] A Gray mapping generally refers to a condition in which for any pair of symbol sequences (e.g., 2-symbol sequences) that are nearest to each other, the bit sequences that the pair represent differ by 1 bit (e.g., by only 1 bit). The Gray mapping may be constructed in a number of operations/steps (e.g., two operations/steps) by (1) mapping part of a bit sequence to the 2-symbol sequence drawn from two scaled 12-ary QAM constellations, and/or (2) mapping the remaining bits to a symbol sequence (e.g., 2-symbol sequence) drawn from two flipped superposing constellations.

[0090] For example, when a k -bit sequence is b , and the 2-symbol sequence is $v(b) = (x_1(b), y_1(b), x_2(b), y_2(b))$, where $x_i(b)$ and $y_i(b)$ may be coordinates of symbol i for $i = 1, 2$, Equations 12 and 13 may be defined as follows:

$$t(b_{k-7}^{k-1}) = f(b_{k-1}, b_{k-2}, b_{k-3})D(b_{k-7}^{k-4}) \quad (12)$$

$$= (\tilde{x}_1, \tilde{y}_1, \tilde{x}_2, \tilde{y}_2) \quad (13)$$

where $D(b_{k-7}^{k-4}) = \text{diag}((-1)^{b_{k-4}}, (-1)^{b_{k-5}}, (-1)^{b_{k-6}}, (-1)^{b_{k-7}})$. The Gray mapping may be as shown by Equations 14 and 15, as follows:

$$v(b) = 2^{m-1}t(b_{k-7}^{k-1}) + (s(\tilde{x}_1, \tilde{y}_1, b_{(k-7)/2}^{k-8}), s(\tilde{x}_2, \tilde{y}_2, b_0^{(k-9)/2})) \quad (14)$$

where $\tilde{x}_1, \tilde{y}_1, \tilde{x}_2, \tilde{y}_2$ are coordinates defined in Equation 12, and

$$s(\tilde{x}_1, \tilde{y}_1, b_{\frac{k-7}{2}}^{k-8}) = p \left(U^{\text{mod}_2(\frac{|\tilde{y}_1-1|}{2})} G U^{\text{mod}_2(\frac{|\tilde{x}_1-1|}{2})}, b_{\frac{k-7}{2}}^{k-8} \right) \quad (15)$$

where $\text{mod}_2(\cdot)$ stands for the modulo 2 operation, G may represent a Gray mapping for an implicit uniform 4^{m-1} -ary QAM constellation, U may be an antidiagonal matrix that may perform matrix flipping, and p may return a point from the constellation denoted by bits $b_{\frac{k-8}{2}}^{k-8}$, $\tilde{x}_1$ and $\tilde{y}_1$.

[0091] The antidiagonal matrix U may have the same dimension as G , and it may flip a matrix vertically if it left multiplies the matrix and may flip the matrix horizontally if it right multiplies the matrix. For example, the antidiagonal matrix U corresponding to a 4×4 matrix G is shown as follows:

$$U = \begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \quad (16)$$

[0092] FIG. 13 is a diagram illustrating a representative constellation 1300A and bit-sequence matrix 1300B for $n = 4$. The function $p(G, b_1^n)$ may provide Gray mapping and may map the bit sequence b_1^n to a constellation point from an implicit uniform 2^n -QAM constellation C (e.g., constellation 1300A). Entries (e.g., each entry) of G may be a sequence of n bits and may be an unsigned binary representation of an integer in the range from 0 to $2^n - 1$, as shown for the example $n = 4$ in FIG. 13. The center of the constellation C may be at the origin and a minimum distance may be 2.

[0093] Referring to FIG. 13, if the constellation SPs are labeled at the i th row and the j th column by C_{ij} , where $i, j = 0, 1, \dots, n-1$, $C_{ij} = (2j - n + 1, -2i + n - 1)$, the mapping may be one-to-one between G_{ij} and C_{ij} , as illustrated for $n = 4$. For example, each SP (e.g., (SP 1310 (+1,+1)) in the constellation 1300A may be 2 away from its four closest neighboring SPs (e.g., SP 1320 (+1,+3), SP 1330 (+3,+1), SP 1340 (+1,-1) and SP 1350 (-1,+1)). The corresponding bits of bit-sequence matrix bit (e.g., mapping matrix) 1300B: for (SP 1310 (+1,+1)) is '1101'; for one of the closest neighbors SP 1320 (+1,+3) is '1100'; for another one of the closest neighbors SP 1330 (+3,+1) is '1001'; for a third one of the closest neighbors SP 1340 (+1,-1) is '1111'; and for a fourth one of the closest neighbors SP 1350 (-1,+1) is '0101'. The corresponding bit sequences of the closest neighbors relative to '1101' have exactly 1 bit difference from '1101' (e.g., may be considered a portion of a gray mapping).

[0094] FIG. 14 is a diagram illustrating a representative hierarchical modulation for 12-ary constellations superposed with 4^{m-1} -ary constellations (e.g., for $m = 3$) using a bit mapping matrix 1450 (sometime referred to as mapping matrix G).

[0095] Referring to FIG. 14, the 12-ary constellations 1400 may include a first constellation 1400A superposed with a 16-ary QAM constellation (e.g., the first constellation 1400A may include clusters C1 ... C12 (shown as squares)), which may each have a plurality of SPs (e.g., 16 SPs, SP1 ... SP16) and may have an associated bit mapping matrix G1 ... G12, for example, for selection of a first symbol and a second

constellation 1400B superposed with a 16-ary QAM constellation (e.g., the second constellation 1400B may include clusters C1 ... C12 (shown as squares)), which may have a plurality of SPs (e.g., 16 SPs SP1...SP16) and may have an associated bit mapping matrix G1...G12, for example, for selection of a second symbol. For example, a representative 16-ary QAM constellation (e.g., cluster C1 associated with bit mapping matrix G1) may include 16 constellation SPs (e.g., SP1, SP2, SP3, ... SP16) representing 4 bits in accordance with bit mapping matrix G1.

[0096] The mapping associated with Equation 14 is a Gray mapping. For example, the constellation for (3×4^m) -ary QAM may be used for a hierarchical modulation. The first term in Equation 14 may map the 7 bits b_{k-1}^{k-7} to two cluster centers (e.g., a first cluster center 1400C associated with the first clusters C1, C4, C7 and C10 of the first constellation 1400A and a second cluster center 1430C associated with the second clusters C1, C4, C7 and C10 of the second constellation 1400B), which may be a scaled version of a 2-symbol sequence drawn from two 12-ary QAM constellations 1400. The second term in Equation 14 may map the remaining $k-7$ bits to two constellation SPs within two selected clusters (e.g., two remaining constellation points, for example not in the cluster centers 1400C and 1430C, of the first constellation 1400A and/or the second constellation 1400B). A Gray mapping may be constructed that may be described by Equation 14.

[0097] The mapping within a cluster C_i where $i=1, \dots, 12$ may be as shown (e.g., G_i) and may be a Gray mapping. For any pair of 2-symbol sequences at the minimum distance (e.g., 2), the pair may differ in one symbol (e.g., only one symbol) and/or in one coordinate (e.g., only one coordinate). The differing symbols may be in any of: the first constellation 1400A and/or the second constellation 1400B. For the case where the symbols are in the first constellation 1400A (or the case where the symbols are in the second constellation 1400B similarly), the two differing symbols (e.g., the first symbols of the two 2-symbol sequences) may be either in the same cluster (e.g., cluster C1) or in two clusters (e.g., cluster C1:C2, C1:C3, C1:C4 or C1:C10) that are next to and/or face each other. If the differing symbols are in the same cluster (e.g., the cluster C1), the b_{k-7}^{k-1} sequences for the two 2-symbol sequences are to be the same (e.g., since $t(\cdot)$ is a one-to-one mapping). The $b_{(k-7)/2}^{k-8}$ sequences for the two 2-symbol sequences may differ in 1 bit (e.g., only 1 bit and the bit mapping G_i may be a Gray mapping). The $b_0^{(k-9)/2}$ sequences for the two 2-symbol sequences may be identical. For example, the two whole bit sequences for the two 2-symbol sequences may differ by 1 bit (e.g., only in or by 1 bit). If the two differing symbols are in two clusters (e.g., the clusters C1 and C2) that are next to and/or face each other (e.g., having mappings G_1 and G_2) but not the in the clusters C1 and C7 (e.g., having mappings G_1 and G_7), the b_{k-7}^{k-1} sequences for the two 2-symbol sequences may differ by 1 bit (e.g., in or by only 1 bit), for example, because $t(\cdot)$ may be a Gray mapping (e.g., see Equations (10) and (12)). In certain representative embodiments, the $b_{(k-7)/2}^{k-8}$ sequences for the two 2-symbol sequences may be identical. For example, the condition and/or requirement (e.g., for

the $b_{(k-7)/2}^{k-8}$ sequences for the two 2-symbol sequences to be identical) is not satisfied if G_i 's are the same, (e.g., $G_i = G$, where $i = 1, \dots, 12$ and G is a Gray mapping).

[0098] FIG. 15 is a diagram illustrating flipping of clusters C1 ... C12 illustrated in FIG. 14 to make the symbols facing each other on either side of the boundary have the same bit sequence.

[0099] By flipping bit mapping matrix G (as shown in FIG. 14) horizontally, vertically or both, the condition and/or requirement (e.g., for the $b_{(k-7)/2}^{k-8}$ sequences for the two 2-symbol sequences to be identical) may be satisfied. The matrix flipping may be denoted (e.g., succinctly denoted) by matrix multiplication with an antidiagonal matrix. The resulting matrix is in the form $U^{i_1} G U^{i_2}$, where $i_1 = 0, 1$ and $i_2 = 0, 1$. For example, UG flips matrix G vertically such that UG may be as follows.

$$\begin{vmatrix} 0010 & 0110 & 1110 & 1010 \\ 0011 & 0111 & 1111 & 1011 \\ 0001 & 0101 & 1101 & 1001 \\ 0000 & 0100 & 1100 & 1000 \end{vmatrix}$$

[0100] GU flips matrix G horizontally such that GU may be as follows.

$$\begin{vmatrix} 1000 & 1100 & 0100 & 0000 \\ 1001 & 1101 & 0101 & 0001 \\ 1011 & 1111 & 0111 & 0011 \\ 1010 & 1110 & 0110 & 0010 \end{vmatrix}$$

[0101] UGU flips matrix G both vertically and horizontally such that UGU may be as follows.

$$\begin{vmatrix} 1010 & 1110 & 0110 & 0010 \\ 1011 & 1111 & 0111 & 0011 \\ 1001 & 1101 & 0101 & 0001 \\ 1000 & 1100 & 0100 & 0000 \end{vmatrix}$$

[0102] In certain representative embodiments, $b_0^{(k-9)/2}$ for the two 2-symbol sequences may be identical. The two whole bit sequences for the two 2-symbol sequences may differ by 1 bit (e.g., only by and/or in 1 bit). The flipping operation does not change the Gray mapping within a cluster C1...C12 and may be able to satisfy the Gray mapping (e.g., mapping requirement) for the case where the two differing symbols are in the same cluster C1 ... C12. The above described construction provides and/or establishes a Gray mapping.

[0103] Referring to FIG. 15, the first constellation 1400A and the second constellation 1400B may include clusters C1 ... C12, for example with mappings such that: (1) the clusters C1, C5 and C12 may have a first

mapping (e.g., G associated with bit mapping matrix 1450), (2) the clusters C2, C9 and C10 may have a second mapping (e.g., UG associated with mapping matrix G 1450 flipped vertically), (3) the clusters C3, C4 and C8 may have a third mapping (e.g., GU associated with bit mapping matrix G 1450 flipped horizontally), and/or (4) the clusters C6, C7 and C11 may have a fourth mapping (e.g., UGU associated with bit mapping matrix G 1450 flipped both vertically and horizontally).

[0104] Inspecting the matrix exponents in FIG. 15 together with Equation 13 may yield Equation 15 and Equation 14 may give, may provide and/or may establish a Gray mapping.

[0105] Although a 48-ary 2TD constellation 1400A:1400B is shown that provides a Gray mapping, it is contemplated that other Gray mappings are possible. For example, other gray mappings may be established by a rotation of the constellations 1400A:1400B, a translation of the constellations 1400A:1400B, a mirroring of the constellations 1400A:1400B, flipping vertically and/or horizontally of the constellations 1400A:1400B, among others.

[0106] Although a M -ary 2TD constellation 1400A:1400B is shown that provides a Gray mapping, it is contemplated that other Gray mappings are possible. For example, other gray mappings may be established by a bit mapping matrix G 1450 of a different size (e.g., 2×2 , 8×8 , for example $N \times N$ among others).

Representative Error Performance

[0107] FIG. 16A is a graph illustrating Bit Error Rate (BER) performance for various QAM schemes with binary mapping and with Gray mapping (e.g., 48-QAM binary, 48-QAM Gray code, 12-QAM binary and 12-QAM Gray code).

[0108] Referring to FIG. 16A, the BER is reduced for Gray code mapping with respect to binary mapping for the same QAM level. The BER performance are shown without channel coding: (1) for the 48-QAM with binary mapping (labeled 48-QAM binary); (2) for 48-QAM with Gray mapping (labeled 48-QAM Gray); (3) for 12-QAM with binary mapping (labeled 12-QAM binary); and (4) for 12-QAM Gray mapping (labeled 12-QAM Gary).

[0109] FIG. 16B is a graph illustrating BER performance for various QAM levels with Gray mapping (e.g., 64-QAM, 48-QAM, 16-QAM and 12-QAM).

[0110] Referring to FIG. 16B, the BER is reduced for lower QAM levels (e.g., 4-QAM may have a lower BER with respect to 64-QAM).

[0111] The Gray mapping described above may improve (e.g., may significantly improve the BER performance (e.g., reduce the BER below a threshold)). In FIGS 16A, the BER vs. E_b/N_0 for 12-QAM and 48-QAM with Gray mapping or with binary mapping (e.g., which is not a Gray mapping) may be obtained as follows. The 2-symbol sequences may be sorted according to the 4 coordinates sequentially in ascending order. The 'least' 2-symbol sequence may be assigned label 0, and the next 'least' 2-symbol sequence may be assigned label 1, and so on. The assigned labels may be converted into binary sequences. The use of Gray mapping may result in performance gains (e.g., significant performance gain), for example, about 3 dB for 48-QAM at a BER=0.1.

Representative Procedures when m is Odd

Representative 6-ary QAM ($m=1$)

[0112] FIG. 17 is a diagram illustrating a representative 6-ary QAM constellation with 2 TD.

[0113] Referring to FIG. 17, the representative 6-ary QAM constellation 1700 may have two time dimensions (e.g., a first constellation 1710 with a first time period, a second constellation 1720 and a second time period) and may generate a gray coded 6-ary QAM. If the signal point (SP) set of the first time period 1710 and the second time period 1720 are denoted by P_1 and P_2 , respectively, $P_1 = P_1^0 \cup P_1^1$ and $P_2 = P_2^0 \cup P_2^1$ may be obtained. These sets (e.g., all of the sets) may be expressed and/or set by a type 2 constellation (e.g., the constellation type in FIG. 8B). For example, $P_1^0 = \{(x+1, y) \mid x, y \in B\}$ and $P_1^1 = \{(x-1, y) \mid x, y \in B\}$ may be a parallel translation of B parallel to the x axis as +1 and -1, respectively, and $P_2^0 = \{(y, x+1) \mid x, y \in B\}$ and $P_2^1 = \{(y, x-1) \mid x, y \in B\}$ may be a rotatory translation of B by 90 degrees clockwise thereafter and then a parallel translation of it to y axis as +1 and -1.

Representative (3×2^m) -ary QAM with the odd $m (\geq 3)$

[0114] FIG. 18 is a diagram illustrating a representative Gray code of the 6-ary QAM constellation with 2 TD.

[0115] Referring to FIG. 18, signal vector (SV) $\mathbf{V}^{00}$, $\mathbf{V}^{01}$, $\mathbf{V}^{10}$, $\mathbf{V}^{11}$ may be generated by combinations of sets (e.g., each set) for implementing a Gray code allocation. The 6-ary QAM may be a basis form in case of the (3×2^m) -ary QAM with the odd $m (\geq 3)$.

[0116] The SV generating equation may be set and/or established by finding common properties associated with m being odd (e.g., as in the description for the case of an even m).

[0117] FIG. 19A is a diagram illustrating a representative 24-ary QAM constellation with 2 TD.

[0118] Referring to FIG. 19A, the 24-ary QAM constellation with 2 TD 1900 may include a first constellation 1910 in a first time period and a second constellation 1920 in a second time period. The first constellation 1910 may be a rectangular 24 point (e.g., 4×6) constellation that may be vertically aligned or horizontally aligned. The second constellation 1920 may be another rectangular 24 point (e.g., 6×4) constellation that may be vertically aligned or horizontally aligned. The first constellation 1910 and the second constellation 1920 may include (e.g., may each include) black points and cross points such that the cross points of one constellation (e.g., the first constellation 1910) may be limited in combination with other cross points of the other constellation (e.g., the second constellation 1920), for example, for establishing a Gray mapping.

[0119] FIG. 19B is a diagram illustrating a representative 96-ary QAM constellation with 2 TD.

[0120] Referring to FIG. 19B, the 96-ary QAM constellation with 2 TD 1950 may include a first constellation 1960 in a first time period and a second constellation 1970 in a second time period. The first constellation 1960 may be a rectangular 96 point (e.g., 8×12) constellation that may be vertically aligned or horizontally aligned. The second constellation 1960 may be another rectangular 96 point (e.g., 12×8) constellation that may be vertically aligned or horizontally aligned. The first constellation 1960 and the

second constellation 1970 may include (e.g., may each include) black points and cross points such that the cross points of one constellation (e.g., the first constellation 1960) may be limited in combination with other cross points of the other constellation (e.g., the second constellation 1970), for example, for establishing a Gray mapping.

[0121] FIG. 19C is a diagram illustrating a representative 384-ary QAM constellation with 2 TD.

[0122] Referring to FIG. 19C, the 384-ary QAM constellation with 2 TD 1980 may include a first constellation 1990 in a first time period and a second constellation 1995 in a second time period. The first constellation 1990 may be a rectangular 384 point (e.g., 16 x 24) constellation that may be vertically aligned or horizontally aligned. The second constellation 1995 may be another rectangular 384 point (e.g., 24 x 16) constellation that may be vertically aligned or horizontally aligned. The first constellation 1990 and the second constellation 1995 may include (e.g., may each include) black points and cross points such that the cross points of one constellation (e.g., the first constellation 1990) may be limited in combination with other cross points of the other constellation (e.g., the second constellation 1995), for example, for establishing a Gray mapping.

[0123] Referring now to FIGS. 19A, 19B, 19C, constellation 1900 for the first time period and the second time period in the case of $m = 3$, constellation 1950 for the first time period and the second time period in the case of $m = 5$ and constellation 1980 for the first time period and second time period in the case of $m = 7$ are illustrated. When configurations of SPs are considered and/or set, the common shape, as illustrated in FIGS. 19A, 19B and 19C, may be signaled, known, predefined and/or determined. The constellations have common property irrespective of the value m .

[0124] Although rectangular shaped constellations that are either vertically or horizontally aligned are shown, it is contemplated that other orientations and/or angular orientations are possible such as a 45° or 135° angular orientation.

[0125] In certain representative embodiments, other common shapes may include, for example: (1) cross-shaped constellations (e.g., as shown in FIGS. 11A, 11B and 11C); (2) circular-shaped constellations (not shown); and/or (3) square-shaped (not shown), among others.

[0126] In certain representative embodiments, cross shaped, square shaped and other shaped constellations may be rotated and/or angularly oriented (e.g., set at a particular angular orientation).

[0127] FIG. 20 is a diagram illustrating representative characteristics of a (3×2^m) -ary QAM constellation with an odd $m (\geq 2)$.

[0128] Referring to FIG. 20, P_n may be denoted as an SP set in n -th ($n = 1, 2$) time period and P_n^i ($0 \leq i \leq 3$) as the set of SPs positioned at each quadrant. P_n^i may include and/or may be composed of three subsets P_n^{ij} ($0 \leq j \leq 5$). The total set in the n -th period may be expressed as Equation 16 as follows:

$$P_n = P_n^0 \cup P_n^1 \cup P_n^2 \cup P_n^3 = \bigcup_{i=0}^3 P_n^i = \bigcup_{i=0}^3 \bigcup_{j=0}^5 P_n^{ij}. \quad (16)$$

[0129] When $\mathbf{U}$ is defined as the overall SV set made or generated by combination of SPs in the first and second time period, and $\mathbf{V}$ and $\mathbf{V}^c$ are defined as a used vector set and an unused vector set, Equations 17 through 20 may be expressed as follows:

$$\mathbf{U} = \prod_{n=1}^N P_n = P_1 \times P_2 = \left(\bigcup_{i_1=0}^3 P_1^{i_1} \right) \times \left(\bigcup_{i_2=0}^3 P_2^{i_2} \right) = \bigcup_{i_1=0}^3 \bigcup_{i_2=0}^3 (P_1^{i_1} \times P_2^{i_2}) \quad (17)$$

$$\mathbf{V}^c = \bigcup_{i_1=0}^3 \bigcup_{i_2=0}^3 ((P_1^{i_1} \cup P_1^{i_4}) \times (P_2^{i_2} \cup P_2^{i_4})), \quad (18)$$

$$\mathbf{V} = \mathbf{U} - \mathbf{V}^c = \bigcup_{i_1=0}^3 \bigcup_{i_2=0}^3 \mathbf{V}^{i_1 i_2}, \quad (19)$$

where

$$\mathbf{V}^{i_1 i_2} = \bigcup_{j_1=0}^5 \bigcup_{j_2=0}^5 (P_1^{i_1 j_1} \times P_1^{i_1 j_1}) - \{(P_1^{i_1} \times P_2^{i_2}) \cup (P_1^{i_1} \times P_2^{i_4}) \cup (P_1^{i_4} \times P_2^{i_2}) \cup (P_1^{i_4} \times P_2^{i_4})\} \quad (20)$$

[0130] The number of elements of P_n^{ij} may be shown in the Equation 21, as follows:

$$n(P_n^{ij}) = 2^{m-3} \quad (21)$$

[0131] FIGS. 21 and 22 are diagrams illustrating an allocation of Gray codes among SV subsets. Referring to FIGS. 21 and 22, the value of binary data may be the transform of superscripts i_1 and i_2 of $\mathbf{V}^{i_1 i_2}$ into a binary number. This has the same signs of the SV's components (x_1, y_1, x_2, y_2) . In the case of the $\mathbf{V}^{00}$, it is a combination of P_1^0 and P_2^0 , and has all positive signs (++++), (e.g., because components of P_1^0 (x_1, y_1) and components of P_2^0 (x_2, y_2) have all positive signs). The most significant four bits may be assigned as the sign of the respective SP.

[0132] It is contemplated how to allocate the next significant five bits of K binary symbol bits for the case of the odd m . For example, $\mathbf{V}^{00}$ and its adjacent subset vectors (e.g., four subset vectors $\mathbf{V}^{02}$, $\mathbf{V}^{10}$, $\mathbf{V}^{01}$, $\mathbf{V}^{20}$) are shown in FIG. 22, based on Equation 14 and FIG. 14. The next significant five bits of the binary symbol vector may have connection with the values of j_1 and j_2 denoting a certain subset in a quadrant of the first time period and the second time period.

[0133] The middle point $\text{MP}(P_n^{ij})$ of elements of the SP subset (e.g., all elements of SP subset) P_n^{ij} may be obtained and/or determined to make the next significant five bits map to actual values of the elements. Because the shape of constellation in the first time period may be different from the constellation in the second time period in the case of the odd m , $P_1^{i_1 j}$ and $P_2^{i_2 j}$ may be derived respectively. The middle point of $P_1^{i_1 j}$ may be derived from FIGS. 19A, 19B, 19C and 20, as shown in Equations 22, as follows.

$$\begin{aligned}
MP(P_1^{i_1^0}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 3, (-1)^{b_0(i_1)} \cdot 5) \\
MP(P_1^{i_1^1}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 3, (-1)^{b_0(i_1)} \cdot 3) \\
MP(P_1^{i_1^2}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 3, (-1)^{b_0(i_1)} \cdot 1) \\
MP(P_1^{i_1^3}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 1, (-1)^{b_0(i_1)} \cdot 5) \\
MP(P_1^{i_1^4}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 1, (-1)^{b_0(i_1)} \cdot 3) \\
MP(P_1^{i_1^5}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_1)} \cdot 1, (-1)^{b_0(i_1)} \cdot 1)
\end{aligned} \tag{22}$$

[0134] The middle point of $P_2^{i_2^j}$ may be derived, as shown in Equations 23, as follows.

$$\begin{aligned}
MP(P_2^{i_2^0}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 5, (-1)^{b_0(i_2)} \cdot 3) \\
MP(P_2^{i_2^1}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 3, (-1)^{b_0(i_2)} \cdot 3) \\
MP(P_2^{i_2^2}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 1, (-1)^{b_0(i_2)} \cdot 3) \\
MP(P_2^{i_2^3}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 5, (-1)^{b_0(i_2)} \cdot 1) \\
MP(P_2^{i_2^4}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 3, (-1)^{b_0(i_2)} \cdot 1) \\
MP(P_2^{i_2^5}) &= 2^{(m-1)/2-1}((-1)^{b_1(i_2)} \cdot 1, (-1)^{b_0(i_2)} \cdot 1)
\end{aligned} \tag{23}$$

[0135] For $m=3$ (for example, $M=24$), a basis vector $\mathbf{f}(b_{K-5}, \dots, b_{K-9})$ may be defined as a SV generated by combinations of $P_1^0 = \{(3, 5), (3, 3), (3, 1), (1, 5), (1, 3), (1, 1)\}$ and $P_2^0 = \{(5, 3), (3, 3), (1, 3), (5, 1), (3, 1), (1, 1)\}$ which may exist in the first quadrant (e.g., $i_1=0, i_2=0$) of the first time period and/or the second time period. This basis vector is described in Table 2 as follows.

f(0,0,0,0,0)	f(0,0,0,0,1)	f(0,0,0,1,1)	f(0,0,0,1,0)	f(0,0,1,1,0)	f(0,0,1,1,1)	f(0,0,1,0,1)	f(0,0,1,0,0)
+3,+5,+5,+3	+3,+5,+3,+3	+3,+5,+1,+3	+3,+3,+1,+3	+3,+1,+1,+3	+3,+1,+3,+3	+3,+1,+5,+3	+3,+3,+5,+3
f(0,1,0,0,0)	f(0,1,0,0,1)	f(0,1,0,1,1)	f(0,1,0,1,0)	f(0,1,1,1,0)	f(0,1,1,1,1)	f(0,1,1,0,1)	f(0,1,1,0,0)
+3,+5,+5,+1	+3,+5,+3,+1	+3,+5,+1,+1	+3,+3,+1,+1	+3,+1,+1,+1	+3,+1,+3,+1	+3,+1,+5,+1	+3,+3,+5,+1
f(1,1,0,0,0)	f(1,1,0,0,1)	f(1,1,0,1,1)	f(1,1,0,1,0)	f(1,1,1,1,0)	f(1,1,1,1,1)	f(1,1,1,0,1)	f(1,1,1,0,0)
+1,+5,+5,+1	+1,+5,+3,+1	+1,+5,+1,+1	+1,+3,+1,+1	+1,+1,+1,+1	+1,+1,+3,+1	+1,+1,+5,+1	+1,+3,+5,+1
f(1,0,0,0,0)	f(1,0,0,0,1)	f(1,0,0,1,1)	f(1,0,0,1,0)	f(1,0,1,1,0)	f(1,0,1,1,1)	f(1,0,1,0,1)	f(1,0,1,0,0)
+1,+5,+5,+3	+1,+5,+3,+3	+1,+5,+1,+3	+1,+3,+1,+3	+1,+1,+1,+3	+1,+1,+3,+3	+1,+1,+5,+3	+1,+3,+5,+3

Table 2 - Basis vector for a Gray code of (3×2^m) -ary QAM with the odd m .

[0136] For example, summarizing results, $\mathbf{v}(\mathbf{b}_K)$ for the case of the odd m may be, as shown in Equation 24, as follows:

$$\mathbf{v}(\mathbf{b}_K) = (2^{(m-1)/2-1})\mathbf{f}(b_{K-5}, \dots, b_{K-9})\mathbf{D}(b_{K-1}, \dots, b_{K-4}) + \mathbf{g}(b_{K-10}, \dots, b_0), \tag{24}$$

where $\mathbf{D}$ is a sign matrix, $\text{diag}((-1)^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}})$. The relative position vector $\mathbf{g}(b_{K-10}, \dots, b_0)$ may be a function of the least significant bits equal to or less than $(K-10)$ -th and may be set forth as shown in Equation 25, as follows:

$$\mathbf{g}(b_{K-10}, \dots, b_0) = \begin{cases} \left(\sum_{l=0}^L 2^l (-1)^{b_{4l+3}}, \sum_{l=0}^L 2^l (-1)^{b_{4l+2}}, \sum_{l=0}^L 2^l (-1)^{b_{4l+1}}, \sum_{l=0}^L 2^l (-1)^{b_{4l}} \right) & m \geq 5 \\ (0, 0, 0, 0) & m = 3 \end{cases} \quad (25)$$

where $L = (m-5)/2$.

Other Representative Embodiments

Representative Procedures when m is Even

[0137] The Gray code of the SVs, as a function of $\mathbf{b}$, for the (3×2^m) -ary QAM with an even m may be obtained by understanding the 12-ary QAM (e.g., because FIGS. 11A, 11B and 11C have very similar characteristics). The differences are the positions and the number of elements in P_n^j . The SPs of the first quadrant in the 12-ary QAM may be referred to as the basis points for even m . By multiplying $2^{m/2-1}$ by the component of each SP in FIG. 11A, the midpoint of elements in P_n^j in FIG. 11B may be obtained. The SPs (e.g., all of the SPs) in FIG. 11B may be described (e.g., completely described) by adding the relative displacement from the midpoint. The SVs of the 12-ary QAM generated by the 1st quadrant SPs of the 1st time period and 2nd time period may be denoted as the ‘basis vector’ $\mathbf{f}(b_{K-5}, b_{K-6}, b_{K-7}) = [f_3, f_2, f_1, f_0]$, where $\mathbf{g}(b_{K-8}, \dots, b_0) = [g_3, g_2, g_1, g_0]$ and $\mathbf{S}(b_{K-5}, b_{K-6}, b_{K-7}) = \text{diag}[-1]^{s_3}, (-1)^{s_2}, (-1)^{s_1}, (-1)^{s_0}$ that may denote the relative displacement vector and the sign matrix of $\mathbf{g}$, respectively. The elements f_i and s_i ($0 \leq i \leq 2N$) may be functions of the next most significant 3 bits in Table 3 as follows.

$[b_{K-5}, b_{K-6}, b_{K-7}]$	0,0,0	0,0,1	0,1,1	0,1,0	1,1,0	1,1,1	1,0,1	1,0,0
$[f_3, f_2, f_1, f_0]$	1,3,1,3	1,3,1,1	1,3,3,1	1,1,3,1	3,1,3,1	3,1,1,1	3,1,1,3	1,1,1,3
$[s_3, s_2, s_1, s_0]$	0,1,0,1	0,1,0,0	0,1,1,0	0,0,1,0	1,0,1,0	1,0,0,0	1,0,0,1	0,0,0,1

TABLE 3 - Basis and sign vectors of (3×2^M) -ary QAM with even M

[0138] The SPs around the midpoint of the subset may be determined by the remaining bits excluding the most significant seven bits in the binary symbol vector $\mathbf{b}$. The generating equation for a SV $\mathbf{v}(\mathbf{b}) = [x_1(\mathbf{b}), y_1(\mathbf{b}), x_2(\mathbf{b}), y_2(\mathbf{b})]$ may be represented as Equation 26 as follows:

$$\mathbf{v}(\mathbf{b}) = (2^{m/2-1} \cdot \mathbf{f}(b_{K-5}, b_{K-6}, b_{K-7}) + \mathbf{g}(b_{K-8}, \dots, b_0) \mathbf{S}) \mathbf{D} \quad (26)$$

where $\mathbf{D} = \text{diag}[-1]^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}}$ may be referred to as a sign matrix of $\mathbf{v}(\mathbf{b})$, which may be a function of the most significant four bits, and $\mathbf{g}(b_{K-8}, \dots, b_0) = [g_3, g_2, g_1, g_0]$ may be a function of the least significant bits excluding the most significant seven bits and g_i may be expressed in Equation 27 as follows:

$$g_i = \begin{cases} \sum_{l=0}^L 2^l (-1)^{b'_{4l+i}} & m \geq 4 \\ 0 & m = 2 \end{cases} \quad (27)$$

where $L=(m-4)/2$ and $(b'_{4L+i}, \dots, b'_{4l+i}, \dots, b'_i)$ may be the binary code derived from Gray code $(b_{4L+i}, \dots, b_{4l+i}, \dots, b_i)$ for $0 \leq i \leq 3$.

[0139] For m equal to an odd number (e.g., for odd m), the SPs of the first quadrant in the 24-ary QAM constellation are referred to as basis points. By multiplying the component of a SP on its constellation by $2^{(m-1)/2-1}$, the midpoint of elements in P_n^{ij} in FIG. 20 may be obtained. The SPs (e.g., all of the SPs) in FIG. 20 may be completely described by adding the relative displacement from the midpoint. The SVs of the 24-ary QAM generated by the 1st quadrant SPs in the 1st time period and the 2nd time period may be referred to as the ‘basis vector’ denoted by $\mathbf{f}(b_{K-5}, b_{K-6}, b_{K-7}, b_{K-8}, b_{K-9})$ which may be a function of the next most significant 5 bits. For example, the basis vector $\mathbf{f}$ may be generated by the combination of $P_1^0 = \{(3, 5), (3, 3), (3, 1), (1, 5), (1, 3), (1, 1)\}$ and $P_2^0 = \{(5, 3), (3, 3), (1, 3), (5, 1), (3, 1), (1, 1)\}$. In Table 4, f_i and s_i ($0 \leq i \leq 2N$) are shown, which are the element of basis vector and sign matrix of $\mathbf{g}$, respectively.

$[b_{K-5}, \dots, b_{K-9}]$	0,0,0,0,0	0,0,0,0,1	0,0,0,1,1	0,0,0,1,0	0,0,1,1,0	0,0,1,1,1	0,0,1,0,1	0,0,1,0,0
$[f_3, f_2, f_1, f_0]$	3,5,5,3	3,5,3,3	3,5,1,3	3,1,1,3	3,1,1,3	3,1,3,3	3,1,5,3	3,3,5,3
$[s_3, s_2, s_1, s_0]$	1,0,0,1	1,0,1,1	1,0,0,1	1,1,0,1	1,0,0,1	1,0,1,1	1,0,0,1	1,1,0,1
$[b_{K-5}, \dots, b_{K-9}]$	0,1,0,0,0	0,1,0,0,1	0,1,0,1,1	0,1,0,1,0	0,1,1,1,0	0,1,1,1,1	0,1,1,0,1	0,1,1,0,0
$[f_3, f_2, f_1, f_0]$	3,5,5,1	3,5,3,1	3,5,1,1	3,1,1,1	3,1,1,1	3,1,3,1	3,1,5,1	3,3,5,1
$[s_3, s_2, s_1, s_0]$	1,0,0,0	1,0,1,0	1,0,0,0	1,1,0,0	1,0,0,0	1,0,1,0	1,0,0,0	1,1,0,0
$[b_{K-5}, \dots, b_{K-9}]$	1,1,0,0,0	1,1,0,0,1	1,1,0,1,1	1,1,0,1,0	1,1,1,1,0	1,1,1,1,1	1,1,1,0,1	1,1,1,0,0
$[f_3, f_2, f_1, f_0]$	1,5,5,1	1,5,3,1	1,5,1,1	1,1,1,1	1,1,1,1	1,1,3,1	1,1,5,1	1,3,5,1
$[s_3, s_2, s_1, s_0]$	0,0,0,0	0,0,1,0	0,0,0,0	0,1,0,0	0,0,0,0	0,0,1,0	0,0,0,0	0,1,0,0
$[b_{K-5}, \dots, b_{K-9}]$	1,0,0,0,0	1,0,0,0,1	1,0,0,1,1	1,0,0,1,0	1,0,1,1,0	1,0,1,1,1	1,0,1,0,1	1,0,1,0,0
$[f_3, f_2, f_1, f_0]$	1,5,5,3	1,5,3,3	1,5,1,3	1,1,1,3	1,1,1,3	1,1,3,3	1,1,5,3	1,3,5,3
$[s_3, s_2, s_1, s_0]$	0,0,0,1	0,0,1,1	0,0,0,1	0,1,0,1	0,0,0,1	0,0,1,1	0,0,0,1	0,1,0,1

Table 4 - Basis and sign vectors of (3×2^M) -ary QAM with odd M

[0140] For example, summarizing results, $\mathbf{v}(\mathbf{b})$ for odd m may be, as shown in Equation 28, as follows:

$$\mathbf{v}(\mathbf{b}) = (2^{(m-1)/2-1} \cdot \mathbf{f}(b_{K-5}, \dots, b_{K-9}) + \mathbf{g}(b_{K-10}, \dots, b_0) \mathbf{S}) \mathbf{D} \quad (28)$$

where $\mathbf{S}$ and $\mathbf{D}$ may be the same as in Equation 14, and $\mathbf{g}(b_{K-10}, \dots, b_0) = [g_3, g_2, g_1, g_0]$ may be a function of the least significant bits excluding the most significant nine bits, where g_i may be expressed in Equation 29 as follows:

$$g_i = \begin{cases} \sum_{l=0}^L 2^l (-1)^{b'_{4l+i}} & m \geq 5 \\ 0 & m = 3 \end{cases} \quad (29)$$

where $L = (m-5)/2$. After a Gray mapping is obtained as described above, a permutation of the bits or rearrangement of the bits may be implemented. The result will be another Gray mapping.

Representative (3×2^m) -ary QAM with 3 or more TD

[0141] Although it has been disclosed that Gray codes may be allocated for TD of 1 or 2, it is contemplated that Gray codes may be allocated for TD of greater than 2. For example, a TD of 2 for a (3×2^m) -ary QAM with a resolution of 0.5 bit may not be possible because one SP can transfer $k = m+1.5$ bit in average spectral efficiency. To provide the appropriate resolution of under 0.5 bit, the time order may need to be

increased to more than 2 TD, or a combination of constellations which have different numbers of SP may be used. Table 5 illustrates a scheme of 3 time dimensional or combining constellations that are different from each other to provide the resolution of a 0.5 bit.

Bits/SP	1 TD	2 TD	3 TD	4 TD
2.0	4-ary			
2.5		6-ary (6×6)		
3.0		9-ary (6×12)	(28/3)-ary (4×12×12)	9-ary (6×6×12×12)
3.5		12-ary (12×12)		
4.0	16-ary			
4.5		24-ary (24×24)		
5.0		36-ary (24×48)	(112/3)-ary (16×48×48)	36-ary (24×24×48×48)
5.5		48-ary (48×48)		
6.0	64-ary			
6.5		96-ary (96×96)		
7.0		144-ary (96×192)	(448/3)-ary (64×192×192)	144-ary (96×96×192×192)
7.5		192-ary (192×192)		
8.0	256-ary			
8.5		384-ary (384×768)		
9.0		576-ary (384×384)	(1,792/3)-ary (256×768×768)	576-ary (384×384×768×768)
9.6		768-ary (768×768)		
10.0	1,024-ary			

Table 5 - 0.5 bit resolution table by using (3×2^m) -ary QAM.

[0142] From Table 5, any middle bit value may be known or determined by combining constellations which have different numbers of transmission bits per SP. For example, to transmit 3 bit per SP, 2 TD 9-ary QAM may be established by combining 6-ary and 12-ary. $(28/3)$ -ary QAM may be established by combining 4-ary, 12-ary and 12-ary. Another 9-ary QAM may be established by combining 6-ary, 6-ary, 12-ary and 12-ary. The 2TD 9-ary may have low complexity because it may have a low time order, 4TD 9-ary QAM may have a high complexity because it may have a high time order. 4TD 9-ary QAM may have benefits (for example, of including the possibility of applying a conventional or standard Gray code allocation).

[0143] FIG. 23 is a diagram illustrating a $28/3$ -ary QAM constellation with 3 TD.

[0144] Referring to FIG. 23, the $28/3$ -ary QAM constellation with 3 TD 2300 may include a first constellation 2310 in a first time period, a second constellation 2320 in a second time period, and a third constellation 2330 in a third time period. For example, the first constellation 2310 may include 4 SPs and may have a minimum distance between SPs of $d_{\min 1}$, the second constellation 2320 may include 12 SPs and may have a minimum distance between SPs of $d_{\min 2}$ and the third constellation 2330 may include 12 SPs and may have a minimum distance between SPs of $d_{\min 2}$.

[0145] The second constellation 2320 and the third constellation 2330 may include (e.g., may each include) black points and cross points such that the cross points of one constellation (e.g., the second constellation 2320) may be limited in combination with other cross points of the other constellation (e.g., the third constellation 2330), for example, for establishing a Gray mapping.

[0146] Although various 2 TD and 3 TD constellations are shown having particular constellations in the first, second and further time periods (e.g., shown in a particular order), any order of those constellations is possible. For example, in FIG. 23 the first, second and third constellations 2310, 2320 and 2320 may be implemented in any order.

[0147] A constellation (e.g., a multi-dimensional constellation) may provide a target number of bits/SP (e.g., 3bits/SP). For example, the target number of bits/SP may be determined and/or established by using the 3 TD (28/3)-ary QAM where $(M_1, N_1) = (4, 1)$, $(M_2, N_2) = (12, 2)$ in the constellations and $N = N_1 + N_2 = 3, M = E[M_j] = 28/3$.

[0148] To optimize and/or improve a symbol error probability for combining different constellations, different Euclidean distances may be set from each other. For example, $d_{\min 1}$ used in M_1 -ary and $d_{\min 2}$ used in M_2 -ary may have different values and the ratio may be as shown in Equation 26, as follows.

$$\frac{d_{\min 2}}{d_{\min 1}} = \sqrt{\frac{k_1}{k_2}} = \sqrt{\frac{N_1 \log_2 M_1}{N_2 \log_2 M_2}} \quad (26)$$

[0149] Although the determination of a Gray mapping has been shown algorithmically, it is contemplated that for predetermined multi-dimensional constellations the Gray mapping (e.g., Gray code mapping may be predetermined (e.g., established in a table, established algorithmically, and/or established as a hybrid operation (e.g., partially in a table with the remaining bits of the mapping determined dynamically via algorithm). For example, in a 3TD constellation a portion of the SV associated with 2 dimensions may be tabulated and another portion associated with the last dimension may be dynamically established based on the constellation of the third dimension chosen. As another example, the table associated with large M-ary constellation may be large (e.g., very large) such that, for example, the hybrid operation or the algorithmic operation may be advantageous.

[0150] FIG. 24 is a flowchart illustrating a representative method of data encoding.

[0151] Referring to FIG. 24, the representative method 2400 may include, at block 2410, a WTRU 102 or network entity 160 (e.g., eNB and/or gNB, among others) (also sometime referred to as a transmission entity) that may segment a bit stream of binary data into sets. At block 2420, the transmission entity 102 and/or 160 may map the segmented sets of binary data to signal vectors (SVs) of a multidimensional real number M -ary constellation 750, 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300. At block 2430, the transmission entity 102 and/or 160 may generate M -ary signal elements corresponding to the mapped set of binary data based on the SVs of the multidimensional real number M -ary constellation

750, 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300. In certain representative embodiments, the SVs (each of the SVs) may be a Gray code vector.

[0152] In certain representative embodiments, the multidimensional real number M -ary constellation 750, 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300 may include multiple dimensions in any of: (1) time; (2) frequency; (3) polarization; and/or (4) a spatial domain.

[0153] In certain representative embodiments, the transmission entity 102 and/or 160 may set N constellations for N respective time periods, where N is an integer number greater than 1, as the multidimensional real number M -ary constellation 900, 1700, 1900, 1950, 1980, and 2300, and at least one constellation 910, 1710, 1910, 1960, 1990 2310 of the N constellations may be different from a second one 920, 1720, 1920, 1970, 1995, 2320 of the N constellations, respectively.

[0154] In certain representative embodiments, the transmission entity 102 and/or 160 may bit invert the bit stream of binary data or a portion of the bit stream of binary data prior to the segmentation.

[0155] In certain representative embodiments, the transmission entity 102 and/or 160 may bit reverse the bit stream of binary data or a portion of the bit stream of binary data prior to the segmentation.

[0156] In certain representative embodiments, the transmission entity 102 and/or 160 may determine the SVs based on a signal vector generation operation using $\mathbf{v}^T(\mathbf{b}_K) = (2^{m/2-1})\mathbf{D}(b_{K-1}, \dots, b_{K-4})\mathbf{f}^T(b_{K-5}, b_{K-6}, b_{K-7}) + \mathbf{g}^T(b_{K-8}, \dots, b_0)$ where $\mathbf{D}$ is a sign matrix, $\text{diag}((-1)^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}})$ and $\mathbf{g}(b_{K-10}, \dots, b_0)$ is a relative position vector which is a function of least significant bits and $\mathbf{f}$ is a basis vector.

[0157] In certain representative embodiments, the transmission entity 102 and/or 160 may change the multidimensional real number M -ary constellation (e.g., constellation 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, 2300) to a changed multidimensional real number M -ary constellation such that any of: a first or a second constellation (e.g., first or second constellation 910:920, 1100A:1100B, 1140A:1140B, 1180A:1180B, 1400A:1400B, 1710:1720, 1910:1920, 1960:1970, 1990:1995, 2310:2320) is any of: (1) a rotation of SPs of the first or second constellation (e.g., the first or second constellation 910:920, 1100A:1100B, 1140A:1140B, 1180A:1180B, 1400A:1400B, 1710:1720, 1910:1920, 1960:1970, 1990:1995 and 2310:2320) of the multidimensional real number M -ary constellation 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980 and 2300 prior to the change; (2) a translation of the SPs of the first or second constellation (e.g., the first or second constellation 910:920, 1100A:1100B, 1140A:1140B, 1180A:1180B, 1400A:1400B, 1710:1720, 1910:1920, 1960:1970, 1990:1995 and 2310:2320) of the multidimensional real number M -ary constellation 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300 prior to the change; and/or (3) a mirror image of the SPs of the first or second constellation (e.g., the first or second constellation 910:920, 1100A:1100B, 1140A:1140B, 1180A:1180B, 1400A:1400B, 1710:1720, 1910:1920, 1960:1970, 1990:1995 and 2310:2320) of the multidimensional real number M -ary constellation 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, 2300 prior to the change.

[0158] In certain representative embodiments, the multidimensional real number M -ary constellation 750, 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300 may have at least two dimensions. For

example, the multidimensional real number M -ary constellation 750, 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300 may have at least two dimensions of any of: time, frequency, polarization and/or spatial domain.

[0159] In certain representative embodiments, the multidimensional real number M -ary constellation 900, 1100, 1140, 1180, 1400, 1700, 1900, 1950, 1980, and 2300 may include a first constellation 910, 1100A, 1140A, 1180A, 1400A, 1710, 1910, 1960, 1990, and 2310 associated with a first time period and a second constellation 920, 1100B, 1140B, 1180B, 1400B, 1720, 1920, 1970, 1995, and 2320 associated with a second time period that is different from the first time period, as a first M -ary constellation type (e.g., time-based constellation type). Other M -ary constellation types are possible including: (1) frequency-based constellation types; (2) polarization-based constellation types; and (3) spatial-based constellation types, among others. For example, the frequency-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first frequency or frequency range and a second constellation associated with a second frequency or frequency range that is different from the first frequency or frequency range. As another example, the polarization-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first polarization or polarization range and a second constellation associated with a second polarization or polarization range that is different from the first polarization or polarization range. As a further example, the spatial-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first spatial domain and a second constellation associated with a second spatial domain that is different from the first spatial domain.

[0160] In certain representative embodiments, the first constellation may include a first number of SPs and the second constellation may include a second number of SPs, which are the same number of SPs or a different number of SPs from the first number of SPs. For example, a respective SV may include a SP from the first constellation and a SP from the second constellation.

[0161] In certain representative embodiments, the second constellation may be any of: (1) a rotation of SPs of the first constellation; (2) a translation of the SPs of the first constellation; and/or (3) a mirror image of the SPs of the first constellation. In certain examples, the first constellation and/or the second constellation may have SPs that are in a square formation, a rectangular formation (e.g., constellations 1910, 1920, 1960, 1960, 1990 and/or 1995) or a cross shaped formation (e.g., constellations 1100A, 1110B, 1140A, 1140B, 1180A and/or 1180B). The crossed shaped formation 1100A, 1110B, 1140A, 1140B, 1180A and/or 1180B may provide a low Peak to Average Power Ratio (PAPR) (e.g., which is lower than the PAPR associated with a square constellation having the same dimensions. For example, the first cross shaped constellation 1100A and/or 1110B in FIG. 11A (e.g., a 12 M -ary constellation) may provide a lower PAPR than a corresponding 16 M -ary square shaped 4x4 SP constellation, for example by eliminating the high power associated with corner SPs in the 16 M -ary square shaped 4x4 SP constellation.

[0162] In certain representative embodiments, the transmission entity 102 and/or 160 may determine the SVs of the multidimensional real number M -ary constellation that are Gray code vectors. For example, the mapping of the segmented sets to SVs of the multidimensional real number M -ary constellation may

include the transmission entity 102 and/or 160 or another entity mapping the segmented sets to the determined SVs. In certain representative embodiments, the mapping of the segmented sets to SVs of the multidimensional real number M -ary constellation may be determined, predetermined, signaled and/or dynamically established. As one example, the transmission entity 102 and/or 160 may determine whether a respective SV of the SVs of the real number M -ary constellation cannot be part of the Gray code based on a number of nearest SPs associated with SPs included in the respective SV. As another example, the transmission entity 102 and/or 160 may determine whether a SP of one of the first constellation or the second constellation is one of: (1) a first type of SP (e.g., an unconstrained SP and/or a black SP) or (2) a second type of SP (e.g., a constrained SP and/or a crossed SP) such that SVs associated with the Gray code include one second type of SP.

[0163] In certain representative embodiments, the transmission entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation used for mapping the segmented sets to the SVs. For example, the transmission entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation by determining SVs forming Gray code vectors of a Gray code for the changed multidimensional real number M -ary constellation and may map the segmented sets of binary data to the determined SVs. In certain examples, the transmission entity 102 and/or 160 may change a constellation size of at least one constellation of the multidimensional real number M -ary constellation by a factor which is or is not 2^N , where N is a positive integer value. In other examples, the transmission entity 102 and/or 160 may set N constellations for N respective time periods, where N is an integer number greater than 1 such that at least one constellation (e.g., and possible other constellations) of the N constellations is or are different from a second one of the N constellations. In certain representative embodiments, after a last one of the N respective time periods, the transmission entity 102 and/or 160 may: (1) set a further set of constellations for a further set of time periods or (2) set the same N constellations for N respective further time periods. For example, the further set of time periods may be: (1) the same N time periods; or (2) a number of time periods that is more or less than the N time periods. In certain representative embodiments, the further set of constellations may include: (1) the same N constellations; (2) a subset of the same N constellations; or (3) constellations that are different from the N constellations.

[0164] In certain examples, the transmission entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation based on an error measurement. For example, the error measurement may be a bit error rate or a Signal to Noise Ratio (SNR) between a transmitter (e.g., the transmission entity 102 and/or 160) and a receiver (e.g., a reception entity 160 and/or 102).

[0165] In certain examples, the transmission entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation by: determining a portion of a lookup table or the lookup table that is associated with the changed multidimensional real number M -ary constellation; and mapping the segmented sets of binary data to SVs of the changed multidimensional real number M -ary constellation using the lookup table. For example, the mapping of the segmented sets of binary data to SVs of the changed multidimensional real number M -ary constellation using the lookup table may include: (1) obtaining a sign matrix based on the N most significant bits of a respective set of the binary data, where N

is a positive integer value; (2) looking up, in the lookup table, a portion of a respective SV, as a basis vector; (3) algorithmically determining a second portion of the SV, as a relative position vector; and generating, using the sign matrix, the basis vector and the relative position vector, the SV for mapping of a respective segmented set of binary data to a generated SV.

[0166] In certain examples, the transmission entity 102 and/or 160 may receive and/or send a control signal indicating the multidimensional real number M -ary constellation used for mapping.

[0167] In certain examples, the multidimensional M -ary constellation may include any of: (1) one or more (3×2^m) -ary constellations; (2) one or more (4^{m-1}) -ary constellations, where m is a positive integer; one or more cross shaped constellations and/or (4) one or more rectangular constellations, among others. For example, a multidimensional (3×2^m) -ary constellation may include a plurality of low PAPR constellations, each cross shaped.

[0168] FIG. 25 is a flowchart illustrating another representative method of data decoding.

[0169] Referring to FIG. 25, the representative method 2500 may include, at block 2510, a WTRU 102 or network entity 160 (e.g., eNB and/or gNB, among others) (also sometime referred to as a reception entity) that may obtain M -ary signal elements from a received signal. At block 2520, the reception entity 102 and/or 160, for respective M -ary signal elements, may determine a SV associated with a multidimensional real number M -ary constellation. At block 2530, the reception entity 102 and/or 160 may generate binary data corresponding to the determined SV. For example, the generating of the binary data may include error checking of the binary data based on the determined SV being a Gray code vector.

[0170] In certain representative embodiments, the multidimensional real number M -ary constellation may include multiple dimensions in any of: (1) time; (2) frequency; (3) polarization; and/or (3) a spatial domain.

[0171] In certain representative embodiments, the reception entity 102 and/or 160 may set N constellations for N respective time periods, where N is an integer number greater than 1, as the multidimensional real number M -ary constellation, and at least one constellation of the N constellations may be different from a second one of the N constellations.

[0172] In certain representative embodiments, the reception entity 102 and/or 160 may output a bit stream of binary data corresponding to a plurality of determined SVs. For example, the reception entity 102 and/or 160 may bit invert the bit stream of binary data or a portion of the bit stream of binary data prior to the output of the bit stream.

[0173] In certain representative embodiments, the reception entity 102 and/or 160 may bit reverse the bit stream of binary data or a portion of the bit stream of binary data prior to the output of the bit stream.

[0174] In certain representative embodiments, the reception entity 102 and/or 160 may determine the SVs based on a SV generation operation using

$\mathbf{v}^T(\mathbf{b}_K) = (2^{m/2-1})\mathbf{D}(b_{K-1}, \dots, b_{K-4})\mathbf{f}^T(b_{K-5}, b_{K-6}, b_{K-7}) + \mathbf{g}^T(b_{K-8}, \dots, b_0)$ where $\mathbf{D}$ may be a sign matrix, $\text{diag}((-1)^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}})$ and $\mathbf{g}(b_{K-10}, \dots, b_0)$ may be a relative position vector which may be a function of least significant bits and $\mathbf{f}$ may be a basis vector.

[0175] In certain representative embodiments, the reception entity 102 and/or 160 may change the multidimensional real number M -ary constellation to a changed multidimensional real number M -ary constellation such that any of: a first constellation for a first time period or a second constellation for a second time period are any of: (1) a rotation of SPs of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change; (2) a translation of the SPs of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change; and/or (3) a mirror image of the SPs of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change, among others.

[0176] In certain representative embodiments, the multidimensional real number M -ary constellation may have at least two dimensions. For example, the multidimensional real number M -ary constellation may have at least two dimensions of any of: time, frequency, polarization and/or a spatial domain.

[0177] In certain representative embodiments, the multidimensional real number M -ary constellation may include a first constellation associated with a first time period and a second constellation associated with a second time period that is different from the first time period, as a first M -ary constellation type (e.g., time-based constellation type). Other M -ary constellation types are possible including: (1) frequency-based constellation types; (2) polarization-based constellation types; and/or (3) spatial-based constellation types, among others. For example, the frequency-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first frequency or frequency range and a second constellation associated with a second frequency or frequency range that is different from the first frequency or frequency range. As another example, the polarization-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first polarization or polarization range and a second constellation associated with a second polarization or polarization range that is different from the first polarization or polarization range. As a further example, the spatial-based constellation type may provide a multidimensional M -ary constellation that may include a first constellation associated with a first spatial domain and a second constellation associated with a second spatial domain that is different from the first spatial domain.

[0178] In certain representative embodiments, the first constellation may include a first number of SPs and the second constellation may include a second number of SPs different from the first number of SPs, wherein a respective SV may include a SP from the first constellation and a SP from the second constellation.

[0179] In certain representative embodiments, the second constellation may be any of: (1) a rotation of SPs of the first constellation; (2) a translation of the SPs of the first constellation; and/or (3) a mirror image of the SPs of the first constellation.

[0180] In certain representative embodiments, the first constellation and the second constellation may have SPs that are in a rectangular formation or a cross shaped formation.

[0181] In certain representative embodiments, the reception entity 102 and/or 160 may determine the SVs of the multidimensional real number M -ary constellation used as a Gray code. For example, the mapping

of the segmented sets to SVs of a multidimensional real number M -ary constellation may include mapping of the segmented sets to the SVs used as the Gray code.

[0182] In certain representative embodiments, the reception entity 102 and/or 160 may determine whether a respective SV of the SVs of the real number M -ary constellation cannot be part of the Gray code based on a number of nearest SPs associated with SPs included in the respective SV.

[0183] In certain representative embodiments, the reception entity 102 and/or 160 may determine whether a SP of one of the first constellation or the second constellation is one of: (1) a first type of SP or (2) a second type of SP such that SVs associated with the Gray code may include one second type of SP.

[0184] In certain representative embodiments, the reception entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation used for mapping the segmented sets to the SVs.

[0185] In certain representative embodiments, the reception entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation by: determining SVs forming a Gray code for the changed multidimensional real number M -ary constellation; and mapping the segmented sets of binary data to the determined SVs.

[0186] In certain representative embodiments, the reception entity 102 and/or 160 may change a constellation size of one or more constellations of the multidimensional real number M -ary constellation by a factor which is or is not 2^N , where N is a positive integer value.

[0187] In certain representative embodiments, the reception entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation by: setting N constellations for N respective time periods, where N is an integer number greater than 1 and after a last one of the N respective time periods, setting a further set of constellations for a further set of time periods. For example, at least one constellation of the N constellations may be different from a second one of the N constellations. For example, the further set of time periods may be: (1) the same N time periods; or (2) a number of time periods that is more or less than the N time periods. In certain examples, the further set of constellations may include: (1) the same N constellations; (2) a subset of the same N constellations; or (3) constellations that are different from the N constellations.

[0188] In certain representative embodiments, the reception entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation based on an error measurement. For example, the error measurement may be a bit error rate or a Signal to Noise Ratio (SNR) between a transmitter and a receiver.

[0189] In certain representative embodiments, the reception entity 102 and/or 160 may dynamically change the multidimensional real number M -ary constellation by: determining a portion of a lookup table or the lookup table that is associated with the changed multidimensional real number M -ary constellation; and may map the segmented sets of binary data to SVs of the changed multidimensional real number M -ary constellation using the lookup table. For example, the mapping of the segmented sets of binary data to SVs of the changed multidimensional real number M -ary constellation using the lookup table may include any of: obtaining a sign matrix based on the N most significant bits of a respective set of the binary data,

where N is a positive integer value; looking up, in the lookup table, a portion of a respective signal vector, as a basis vector; algorithmically determining a second portion of the signal vector, as a relative position vector; and/or generating, using the sign matrix, the basis vector and the relative position vector, the signal vector for mapping of a respective segmented set of binary data to a generated signal vector.

[0190] In certain representative embodiments, the reception entity 102 and/or 160 may receive or send a control signal indicating the multidimensional real number M -ary constellation (e.g., the type of constellation to be used for communication).

[0191] FIG. 26 is a flowchart illustrating a representative method of data encoding.

[0192] Referring to FIG. 26, the representative method 2600 may include, at block 2610, a transmission entity 102 and/or 160 that may any of: bit invert or bit reverse a bit stream of binary data or a portion of the bit stream of binary data. At block 2620, the transmission entity 102 and/or 160, may segment the bit stream of binary data into sets. At block 2630, the transmission entity 102 and/or 160 may map the segmented sets of binary data to SVs of a multidimensional M -ary constellation. At block 2640, the transmission entity 102 and/or 160 may generate signal elements corresponding to the mapped set of binary data based on the SVs of the multidimensional M -ary constellation.

[0193] In certain representative embodiments, the multidimensional M -ary constellation may include any of: one or more (3×2^m) -ary constellations or one or more 4^{m-1} -ary constellations, where m is a positive integer. For example, the one or more (3×2^m) -ary constellations may include a plurality of low PAPR constellations, each cross shaped (and/or in a shape to reduce the distance to the most distant one or more SPs from the origin of the respective constellation).

[0194] FIG. 27 is a flowchart illustrating another representative method of data decoding.

[0195] Referring to FIG. 27, the representative method 2700 may include, at block 2710, a reception entity 102 and/or 160 that may obtain M -ary signal elements from a received signal. At block 2720, the reception entity 102 and/or 160, for respective M -ary signal elements, may determine a SV associated with a multidimensional M -ary constellation. At block 2730, the reception entity 102 and/or 160, may generate a bit stream corresponding to the determined SV. At block 2740, the reception entity 102 and/or 160, may generate binary data that includes any of: bit inverting or bit reversing the bit stream or a portion of the bit stream, as the binary data. At block 2750, the reception entity 102 and/or 160, may error check of the binary data based on the determined SV being a Gray code vector.

[0196] FIG. 28 is a flowchart illustrating a representative method of determining Gray code vectors for a real number 2 Time Dimensional (2TD) M -ary constellation.

[0197] Referring to FIG. 28, the representative method 2800 may include, at block 2810, a processor that may determine a base mapping matrix that is Gray mapped. At block 2820, the processor may associate the base mapping matrix to SPs of first portions of a first constellation corresponding to a first time period and to the same SPs of first portions of a second constellation. At block 2830, the processor may associate a horizontally flipped version of the base mapping matrix to SPs of second portions of the first constellation corresponding to the first time period and to the same SPs of second portions of the second constellation. At block 2840, the processor may associate a vertically flipped version of the base mapping matrix to SPs

of third portions of the first constellation corresponding to the first time period and to the same SPs of third portions of the second constellation.

At block 2850, the processor may associate a horizontally and vertically flipped version of the base mapping matrix to SPs of fourth portions of the first constellation corresponding to the first time period and to the same SPs of fourth portions of the second constellation. At block 2860, the processor, for each respective Gray code vector, may select two SPs by: (1) selecting one of the SPs from an edge portion of the first constellation and one of the SPs from a center portion of the second constellation, as the respective Gray code vector; (2) selecting one of the SPs from an edge portion of the second constellation and one of the SPs from a center portion of the first constellation, as the respective Gray code vector; or (3) selecting one of the SPs from the edge portion of the first constellation and one of the SPs from the edge portion of the second constellation, as the respective Gray code vector.

[0198] Although features and elements are described 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. In addition, the methods described 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 non-transitory computer-readable storage media include, but are not limited to, a read only memory (ROM), 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 102, UE, terminal, base station, RNC, or any host computer.

[0199] Moreover, in the embodiments described above, processing platforms, computing systems, controllers, and other devices containing processors are noted. These devices may contain 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."

[0200] 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 exemplary embodiments are not limited to the above-mentioned platforms or CPUs and that other platforms and CPUs may support the provided methods.

[0201] 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 is understood that the representative embodiments are not limited to the above-mentioned memories and that other platforms and memories may support the described methods.

[0202] 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.

[0203] 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 vs. 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.

[0204] 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 contain 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. Suitable processors include, by way of example, 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), Application Specific Standard Products (ASSPs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), and/or a state machine.

[0205] 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.

[0206] 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, when referred to herein, the terms "station" and its abbreviation "STA", "user equipment" and its abbreviation "UE" may mean (i) a wireless transmit and/or receive unit (WTRU), such as described infra; (ii) any of a number of embodiments of a WTRU, such as described infra; (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, such as described infra; (iii) a wireless-capable and/or wired-capable device configured with less than all structures and functionality of a WTRU, such as described infra; or (iv) the like. Details of an example WTRU, which may be representative of any UE recited herein, are provided below with respect to FIGS. 1-5.

[0207] In certain representative embodiments, 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.).

[0208] The herein described subject matter sometimes illustrates different components contained 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 intermediate 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.

[0209] 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.

[0210] 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 contain 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 containing such introduced claim recitation to embodiments containing 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" or "group" 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.

[0211] 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.

[0212] 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 and/or set having 1-3 cells refers to groups/sets having 1, 2, or 3 cells. Similarly, a group/set having 1-5 cells refers to groups/sets having 1, 2, 3, 4, or 5 cells, and so forth.

[0213] 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.

[0214] A processor in association with software may be used to implement a radio frequency transceiver for use in a wireless transmit receive unit (WTRU), user equipment (UE), terminal, base station, Mobility Management Entity (MME) or Evolved Packet Core (EPC), or any host computer. The WTRU may be used in conjunction with modules, implemented in hardware and/or software including a Software Defined Radio (SDR), and other components such as a camera, a video camera module, a videophone, a speakerphone, a vibration device, a speaker, a microphone, a television transceiver, a hands free headset, a keyboard, a Bluetooth® module, a frequency modulated (FM) radio unit, a Near Field Communication (NFC) Module, a liquid crystal display (LCD) display unit, an organic light-emitting diode (OLED) display unit, a digital music player, a media player, a video game player module, an Internet browser, and/or any Wireless Local Area Network (WLAN) or Ultra Wide Band (UWB) module.

[0215] Although the invention has been described in terms of communication systems, it is contemplated that the systems may be implemented in software on microprocessors/general purpose computers (not

shown). In certain embodiments, one or more of the functions of the various components may be implemented in software that controls a general-purpose computer.

[0216] In addition, although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is claimed is:

1. A method of data encoding, comprising:
segmenting a bit stream of binary data into sets;
mapping the segmented sets of binary data to the signal vectors of a multidimensional real number M -ary constellation; and
generating M -ary signal elements corresponding to the mapped set of binary data based on the signal vectors of the multidimensional real number M -ary constellation,
wherein each of the signal vectors is a Gray code vector.
2. The method of claim 1, wherein the multidimensional real number M -ary constellation includes multiple dimensions in any of: (1) time; (2) frequency; (3) polarization; or (4) a spatial domain.
3. The method of claim 1, further comprising setting N constellations for N respective time periods, where N is an integer number greater than 1, as the multidimensional real number M -ary constellation, wherein at least one constellation of the N constellations is different from a second one of the N constellations.
4. The method of claim 1, further comprising bit inverting the bit stream of binary data or a portion of the bit stream of binary data prior to segmentation.
5. The method of claim 1, further comprising bit reversing the bit stream of binary data or a portion of the bit stream of binary data prior to segmentation.
6. The method of claim 1, further comprising determining the signal vectors based on a signal vector generation operation using

$$\mathbf{v}^T(\mathbf{b}_K) = (2^{m/2-1})\mathbf{D}(b_{K-1}, \dots, b_{K-4})\mathbf{f}^T(b_{K-5}, b_{K-6}, b_{K-7}) + \mathbf{g}^T(b_{K-8}, \dots, b_0)$$
 where $\mathbf{D}$ is a sign matrix, $\text{diag}((-1)^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}})$ and $\mathbf{g}(b_{K-10}, \dots, b_0)$ is a relative position vector which is a function of least significant bits and $\mathbf{f}$ is a basis vector.
7. The method of claim 1, further comprising changing the multidimensional real number M -ary constellation to a changed multidimensional real number M -ary constellation such that any of: a first constellation for a first time period or a second constellation for a second time period are any one of or any combination of: (1) a rotation of signal points of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change; (2) a translation of the signal points of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change; (3) a mirror image of the signal points of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change.
8. The method of claim 1, wherein the multidimensional real number M -ary constellation has at least two time dimensions.
9. The method of claim 8, wherein the multidimensional real number M -ary constellation includes a first constellation associated with a first time period and second constellation associated with a second time period that is different from the first time period.

10. The method of claim 9, wherein the first constellation includes a first number of signal points and the second constellation include a second number of signal points different from the first number of signal points, wherein a respective signal vector includes a signal point from the first constellation and a signal point from the second constellation.

11. The method of claim 9, wherein the second constellation is any one of or any combination of: (1) a rotation of signal points of the first constellation; (2) a translation of the signal points of the first constellation; or (3) a mirror image of the signal points of the first constellation.

12. The method of claim 9, wherein the first constellation and the second constellation have signal points that are in a rectangular formation or a cross shaped formation.

13. The method of claim 1, further comprising determining the signal vectors of the multidimensional real number M -ary constellation that are Gray code vectors,

wherein the mapping of the segmented sets to signal vectors of a multidimensional real number M -ary constellation includes mapping of the segmented sets to the determined signal vectors that are Gray code vectors.

14. The method of claim 13, wherein the determining of the signal vectors that are the Gray code vectors includes determining whether a respective signal vector of the signal vectors of the real number M -ary constellation cannot be part of the Gray code based on a number of nearest signal points associated with signal points included in the respective signal vector.

15. The method of claim 13, wherein the determining of the signal vectors that are the Gray code vectors includes determining whether a signal point of one of the first constellation or the second constellation is one of: (1) a first type of signal point or (2) a second type of signal point such that signal vectors associated with the Gray code include one second type of signal point.

16. A method of determining Gray code vectors for a real number 2 Time Dimensional (2TD) M -ary constellation, the method comprising:

determining a base mapping matrix that is Gray mapped;

associating the base mapping matrix to signal points (SPs) of first portions of a first constellation corresponding to a first time period and to the same SPs of first portions of a second constellation;

associating a horizontally flipped version of the base mapping matrix to SPs of second portions of the first constellation corresponding to the first time period and to the same SPs of second portions of the second constellation;

associating a vertically flipped version of the base mapping matrix to SPs of third portions of the first constellation corresponding to the first time period and to the same SPs of third portions of the second constellation; and

associating a horizontally and vertically flipped version of the base mapping matrix to SPs of fourth portions of the first constellation corresponding to the first time period and to the same SPs of fourth portions of the second constellation; and

for each respective Gray code vector selecting two SPs by:

(1) selecting one of the SPs from an edge portion of the first constellation and one of the SPs from a center portion of the second constellation, as the respective Gray code vector;

(2) selecting one of the SPs from an edge portion of the second constellation and one of the SPs from a center portion of the first constellation, as the respective Gray code vector; or

(3) selecting one of the SPs from the edge portion of the first constellation and one of the SPs from the edge portion of the second constellation, as the respective Gray code vector.

17. A Transmit/Receive Unit (TRU) configured to communicate encoded data, comprising:
a processor configured to:

segment a bit stream of binary data into sets,

map the segmented sets of binary data to the signal vectors of a multidimensional real number M -ary constellation, and

generate M -ary signal elements corresponding to the mapped set of binary data based on the signal vectors of the multidimensional real number M -ary constellation,

wherein each of the signal vectors is a Gray code vector; and

a transmitter configured to transmit a signal in accordance with the generated M -ary signal elements.

18. The TRU of claim 17, wherein the multidimensional real number M -ary constellation includes multiple dimensions in any of: (1) time; (2) frequency; (3) polarization; or (4) a spatial domain.

19. The TRU of claim 17, further comprising setting N constellations for N respective time periods, where N is an integer number greater than 1, as the multidimensional real number M -ary constellation, wherein at least one constellation of the N constellations is different from a second one of the N constellations.

20. The TRU of claim 17, wherein the processor is configured to bit invert the bit stream of binary data or a portion of the bit stream of binary data prior to segmentation.

21. The TRU of claim 17, wherein the processor is configured to bit reverse the bit stream of binary data or a portion of the bit stream of binary data prior to segmentation.

22. The TRU of claim 17, wherein the processor is configured to determine the signal vectors based on a signal vector generation operation using

$$\mathbf{v}^T(\mathbf{b}_K) = (2^{m/2-1})\mathbf{D}(b_{K-1}, \dots, b_{K-4})\mathbf{f}^T(b_{K-5}, b_{K-6}, b_{K-7}) + \mathbf{g}^T(b_{K-8}, \dots, b_0)$$

where $\mathbf{D}$ is a sign matrix, $\text{diag}((-1)^{b_{K-1}}, (-1)^{b_{K-2}}, (-1)^{b_{K-3}}, (-1)^{b_{K-4}})$ and $\mathbf{g}(b_{K-10}, \dots, b_0)$ is a relative position vector which is a function of least significant bits and $\mathbf{f}$ is a basis vector.

23. The TRU of claim 17, wherein the processor is configured to: change the multidimensional real number M -ary constellation to a changed multidimensional real number M -ary constellation such that any of: a first constellation for a first time period or a second constellation for a second time period are any one of or any combination of: (1) a rotation of signal points of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change; (2) a translation of the signal points of the first constellation or the second constellation of the

multidimensional real number M -ary constellation prior to the change; (3) a mirror image of the signal points of the first constellation or the second constellation of the multidimensional real number M -ary constellation prior to the change.

24. The TRU of claim 17, wherein the multidimensional real number M -ary constellation has at least two time dimensions.

25. The TRU of claim 24, wherein the multidimensional real number M -ary constellation includes a first constellation associated with a first time period and second constellation associated with a second time period that is different from the first time period.

26. The TRU of claim 25, wherein the first constellation includes a first number of signal points and the second constellation include a second number of signal points different from the first number of signal points, wherein a respective signal vector includes a signal point from the first constellation and a signal point from the second constellation.

27. The TRU of claim 25, wherein the second constellation is any one of or any combination of: (1) a rotation of signal points of the first constellation; (2) a translation of the signal points of the first constellation; or (3) a mirror image of the signal points of the first constellation.

28. The TRU of claim 25, wherein the first constellation and the second constellation have signal points that are in a rectangular formation or a cross shaped formation.

29. The TRU of claim 17, wherein the processor is configured to:
determine the signal vectors of the multidimensional real number M -ary constellation that are Gray code vectors; and

map the segmented sets to the determined signal vectors that are Gray code vectors.

30. The TRU of claim 29, wherein the processor is configured to determine whether a respective signal vector of the signal vectors of the real number M -ary constellation cannot be part of the Gray code based on a number of nearest signal points associated with signal points included in the respective signal vector.

31. The TRU of claim 29, wherein the processor is configured to determine whether a signal point of one of the first constellation or the second constellation is one of: (1) a first type of signal point or (2) a second type of signal point such that signal vectors associated with the Gray code include one second type of signal point.

32. The TRU of claim 29, wherein the processor is configured to determine whether a signal point of one of the first constellation or the second constellation is one of: (1) a first type of signal point or (2) a second type of signal point such that signal vectors associated with the Gray code include one second type of signal point.

33. The TRU of claim 17, wherein the transmitter is configured to transmit any of: (1) via a wire, (2) optically or (3) wirelessly.

34. An apparatus configured to determine Gray code vectors for a real number 2 Time Dimensional (2TD) M -ary constellation, comprising:
a processor configured to:

determine a base mapping matrix that is Gray mapped;

associate the base mapping matrix to signal points (SPs) of first portions of a first constellation corresponding to a first time period and to the same SPs of first portions of a second constellation;

associate a horizontally flipped version of the base mapping matrix to SPs of second portions of the first constellation corresponding to the first time period and to the same SPs of second portions of the second constellation;

associate a vertically flipped version of the base mapping matrix to SPs of third portions of the first constellation corresponding to the first time period and to the same SPs of third portions of the second constellation; and

associate a horizontally and vertically flipped version of the base mapping matrix to SPs of fourth portions of the first constellation corresponding to the first time period and to the same SPs of fourth portions of the second constellation; and

for each respective Gray code vector select two SPs by:

- (1) selecting one of the SPs from an edge portion of the first constellation and one of the SPs from a center portion of the second constellation, as the respective Gray code vector;
- (2) selecting one of the SPs from an edge portion of the second constellation and one of the SPs from a center portion of the first constellation, as the respective Gray code vector; or
- (3) selecting one of the SPs from the edge portion of the first constellation and one of the SPs from the edge portion of the second constellation, as the respective Gray code vector.

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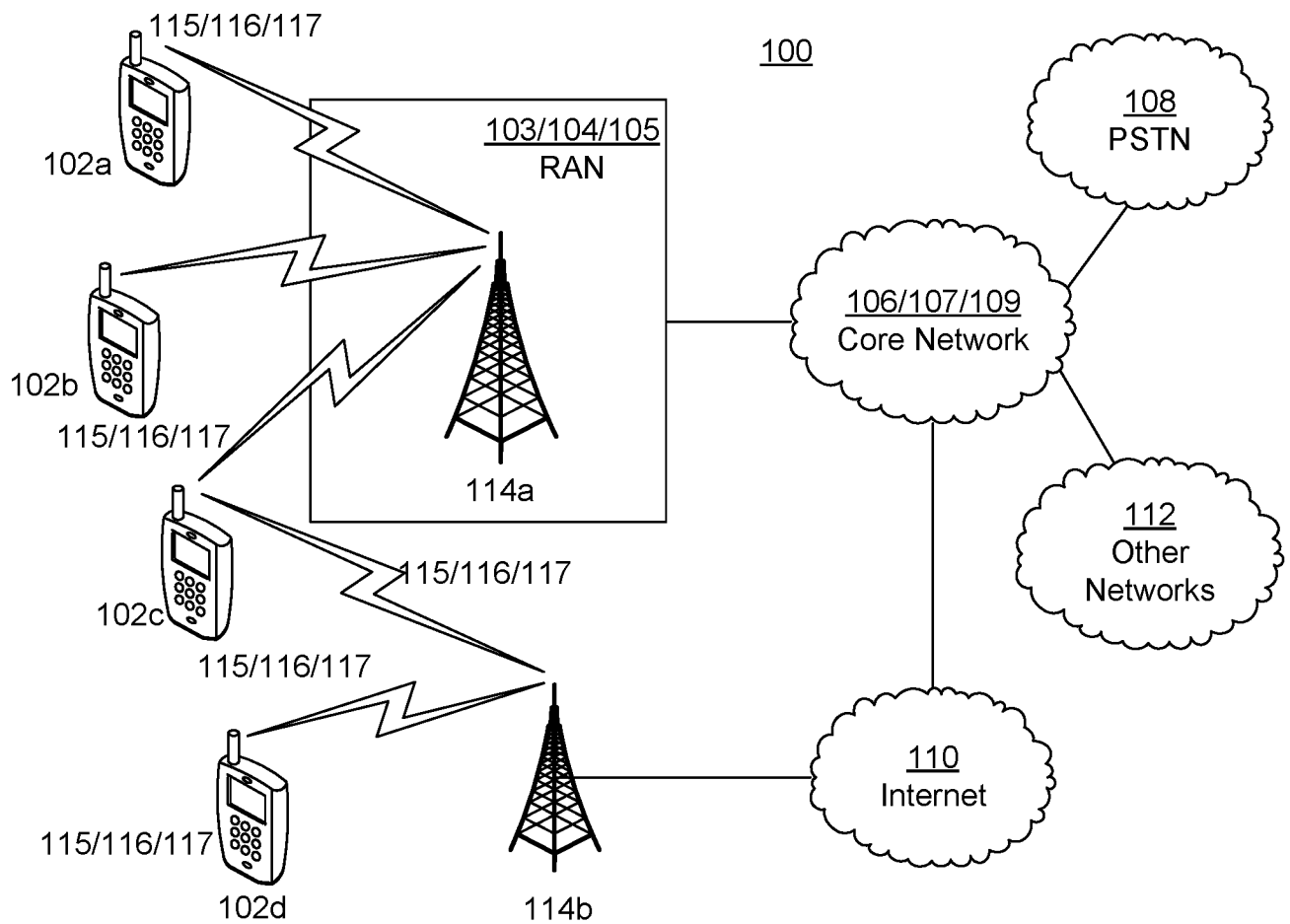


FIG. 1

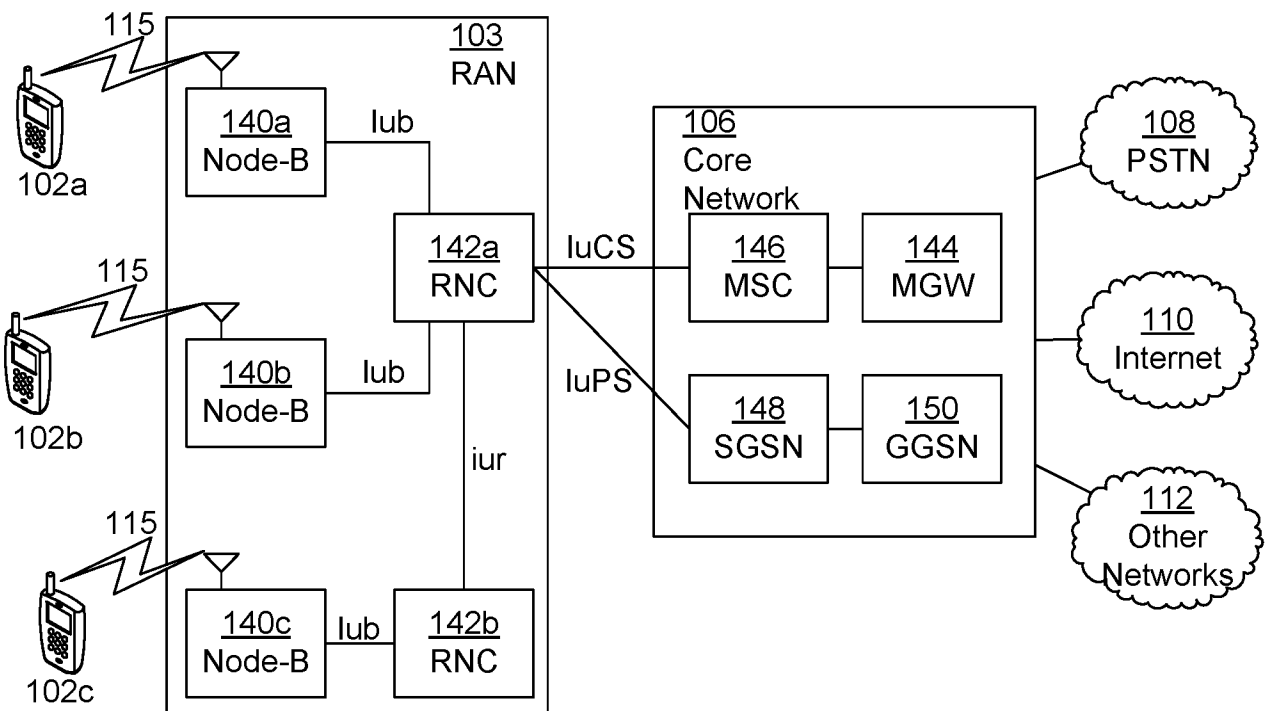


FIG. 3

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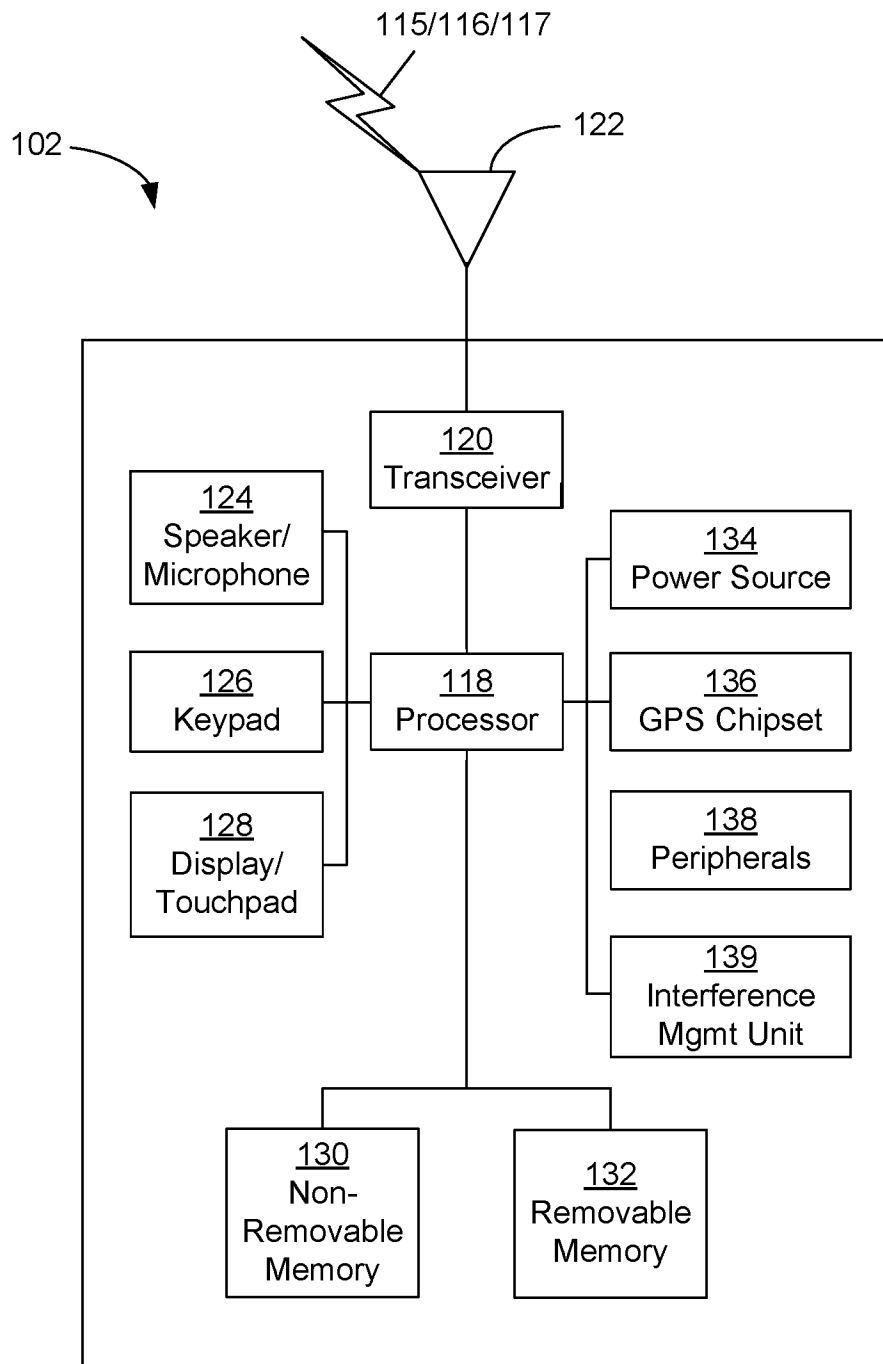


FIG. 2

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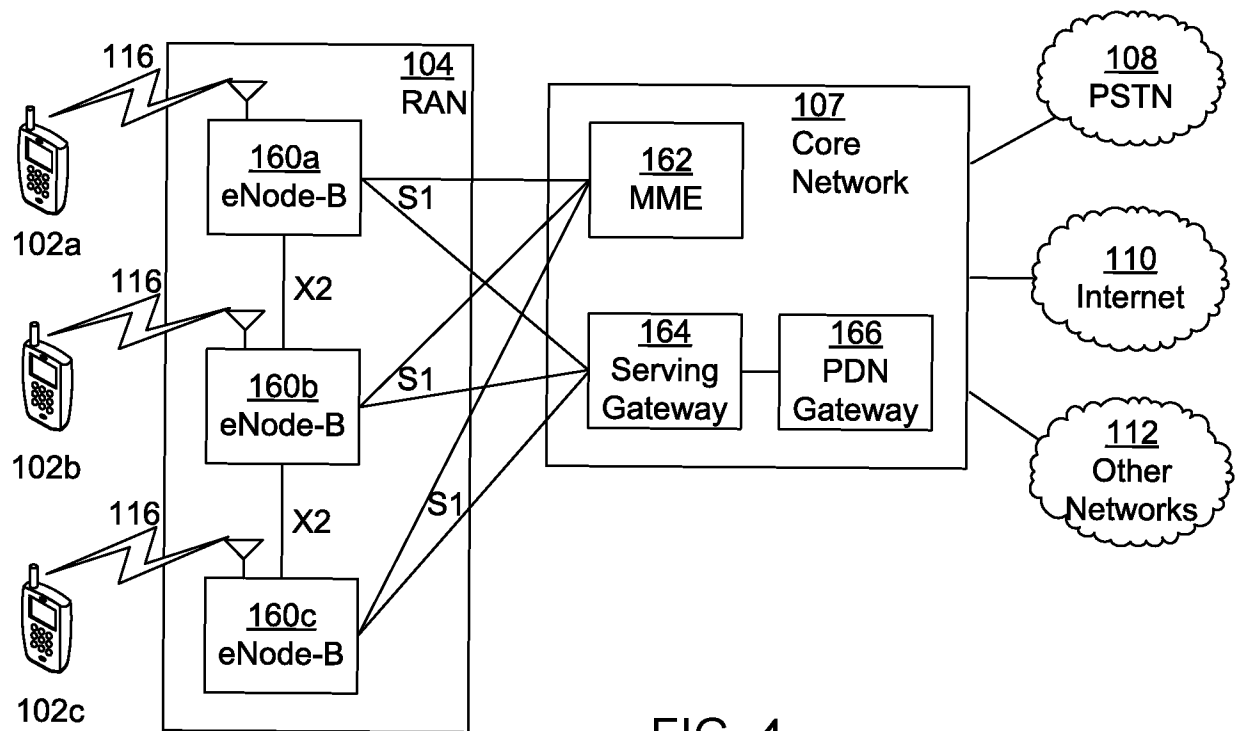


FIG. 4

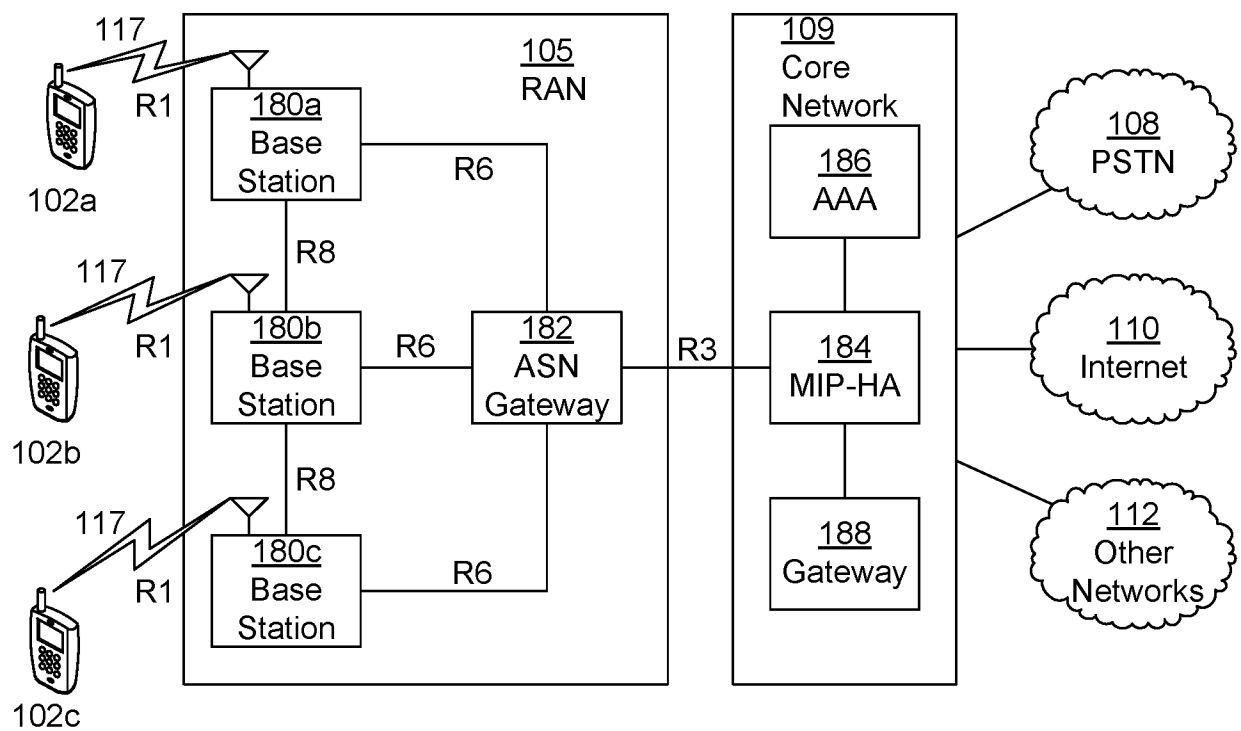


FIG. 5

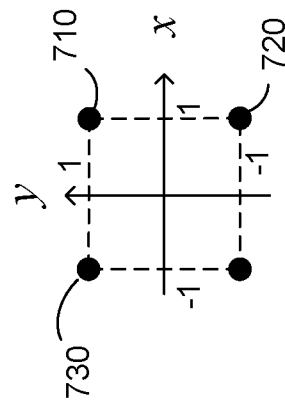
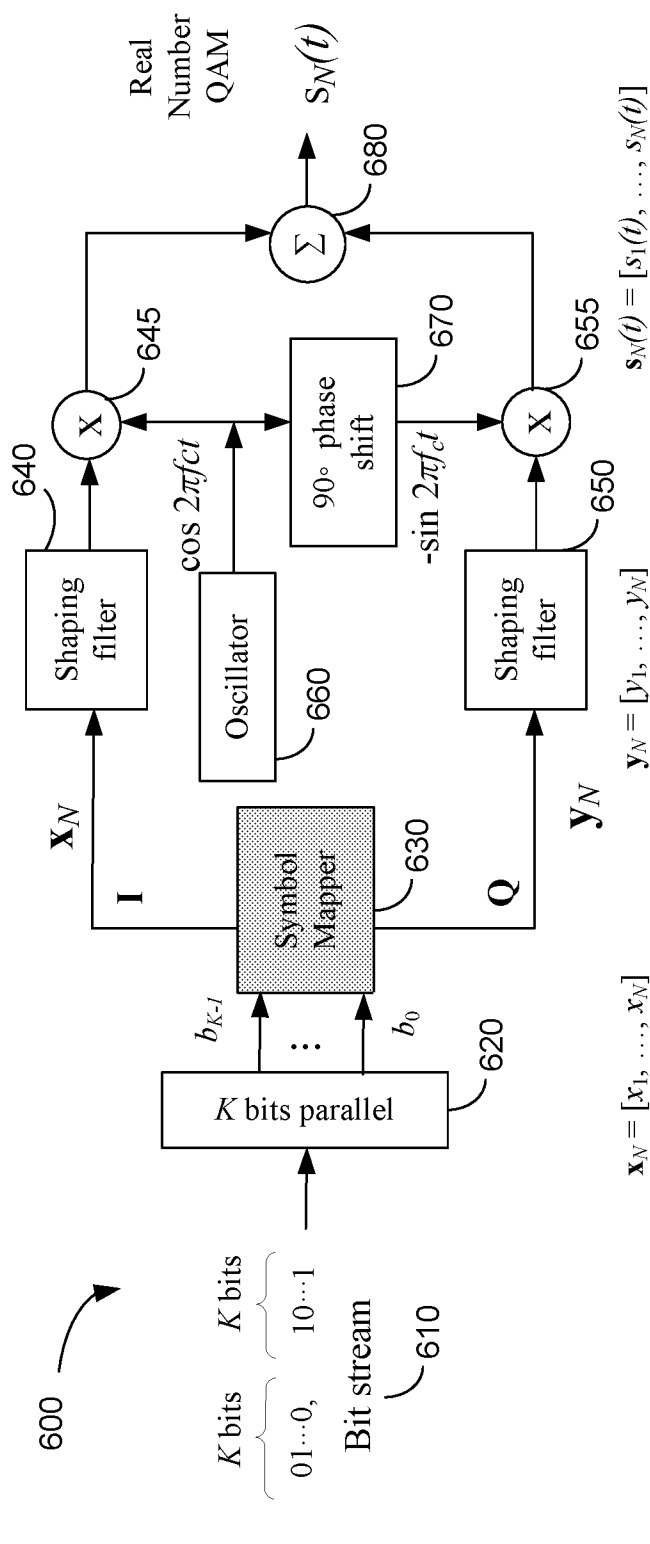


FIG. 7A: 4-ary QAM (QPSK)

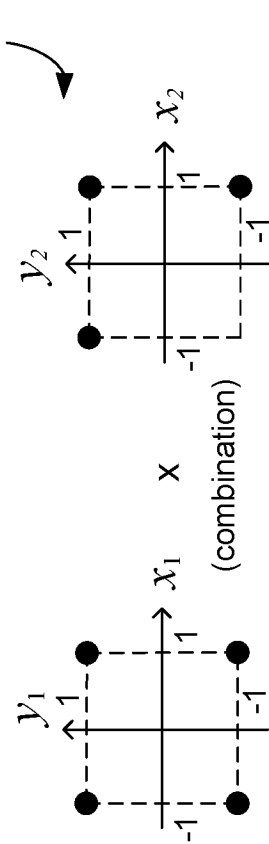


FIG. 7B: 2TD QAM with $M_1=4$ and $M_2=3$

Adjacent SPs and SVs

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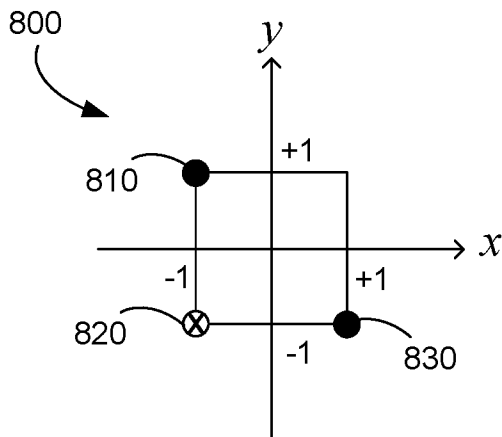


FIG. 8A: Type 1 Constellation

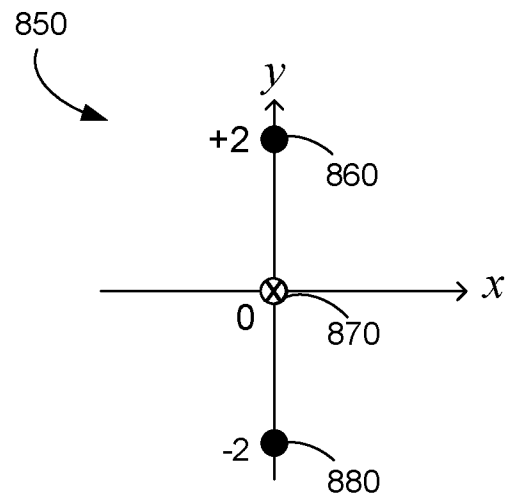


FIG. 8B: Type 2 Constellation

Two constellations

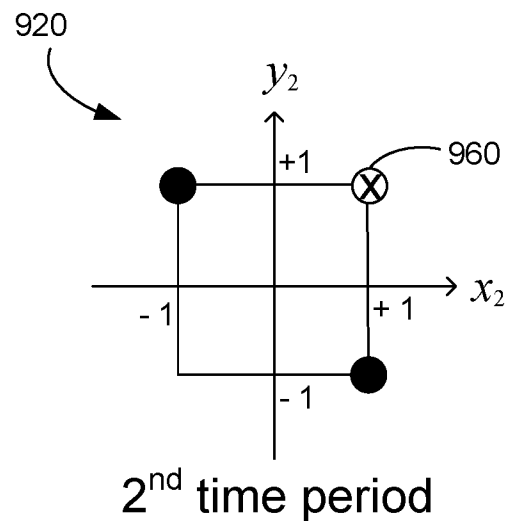
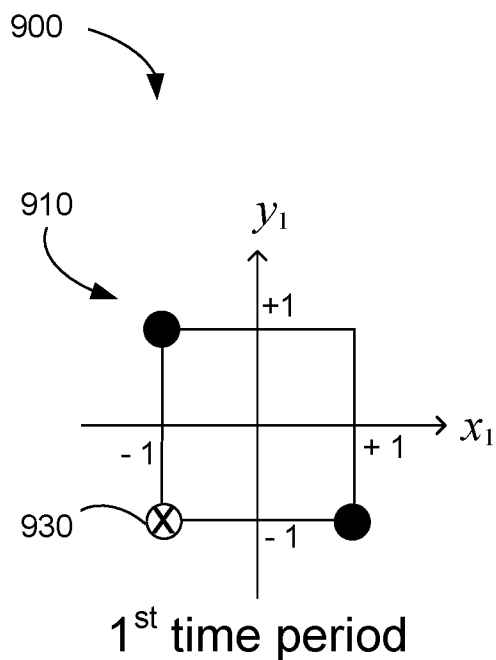


FIG. 9: 3-ary QAM Constellation with 2 TD

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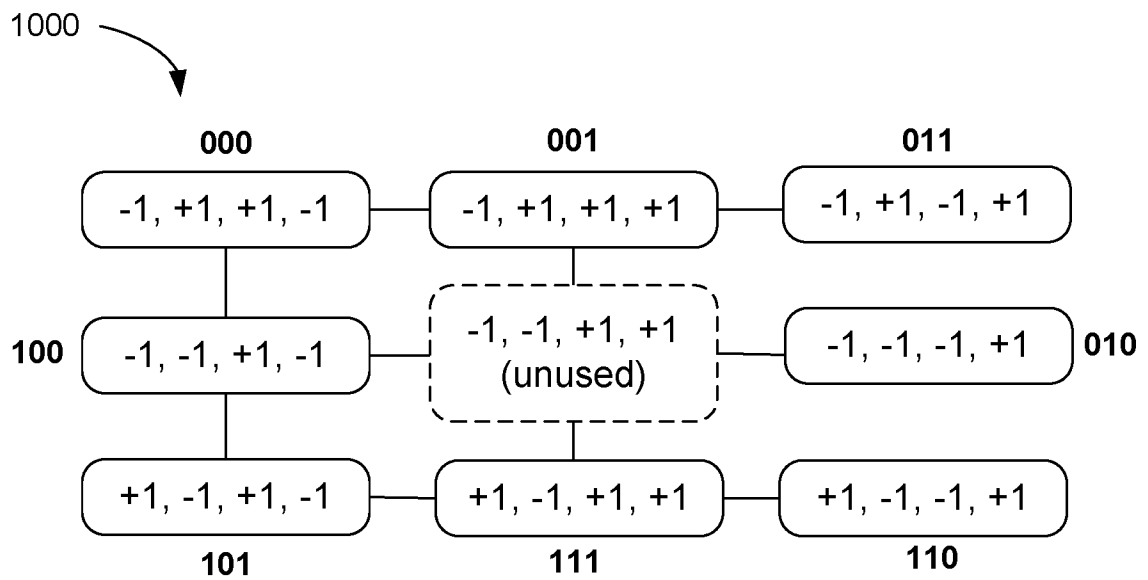


FIG. 10: Gray code of 3-ary QAM with 2 TD

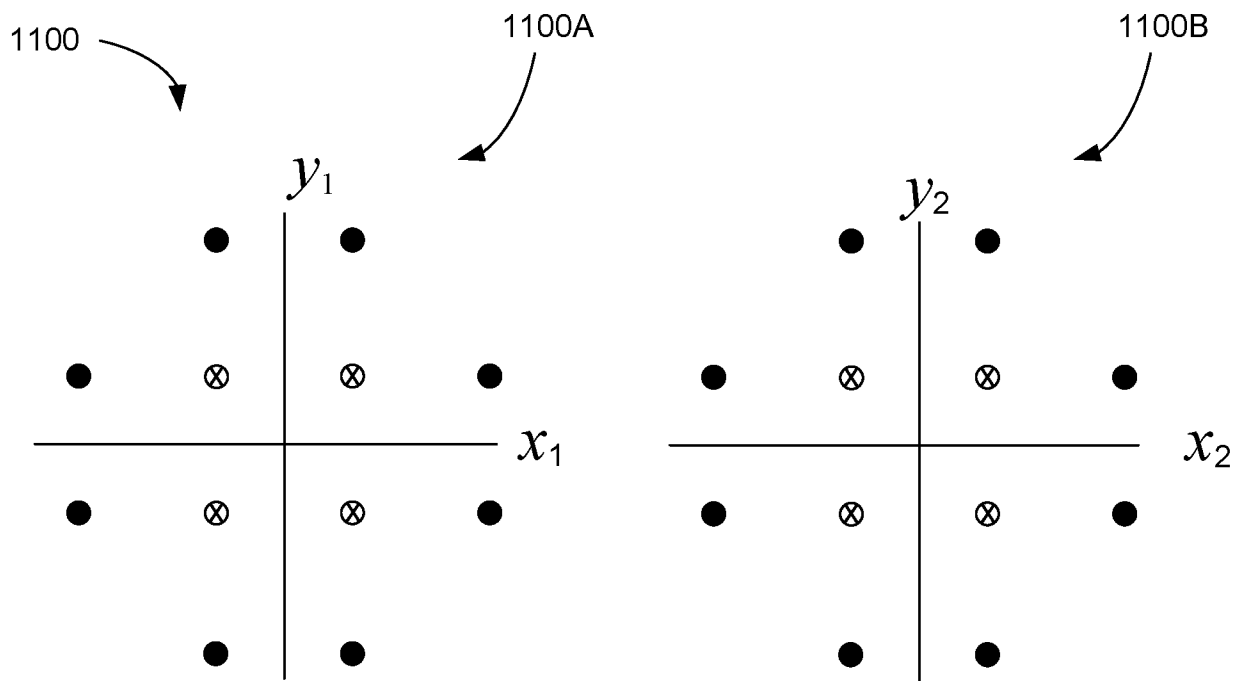


FIG. 11A: 12-ary QAM Constellation with 2 TD

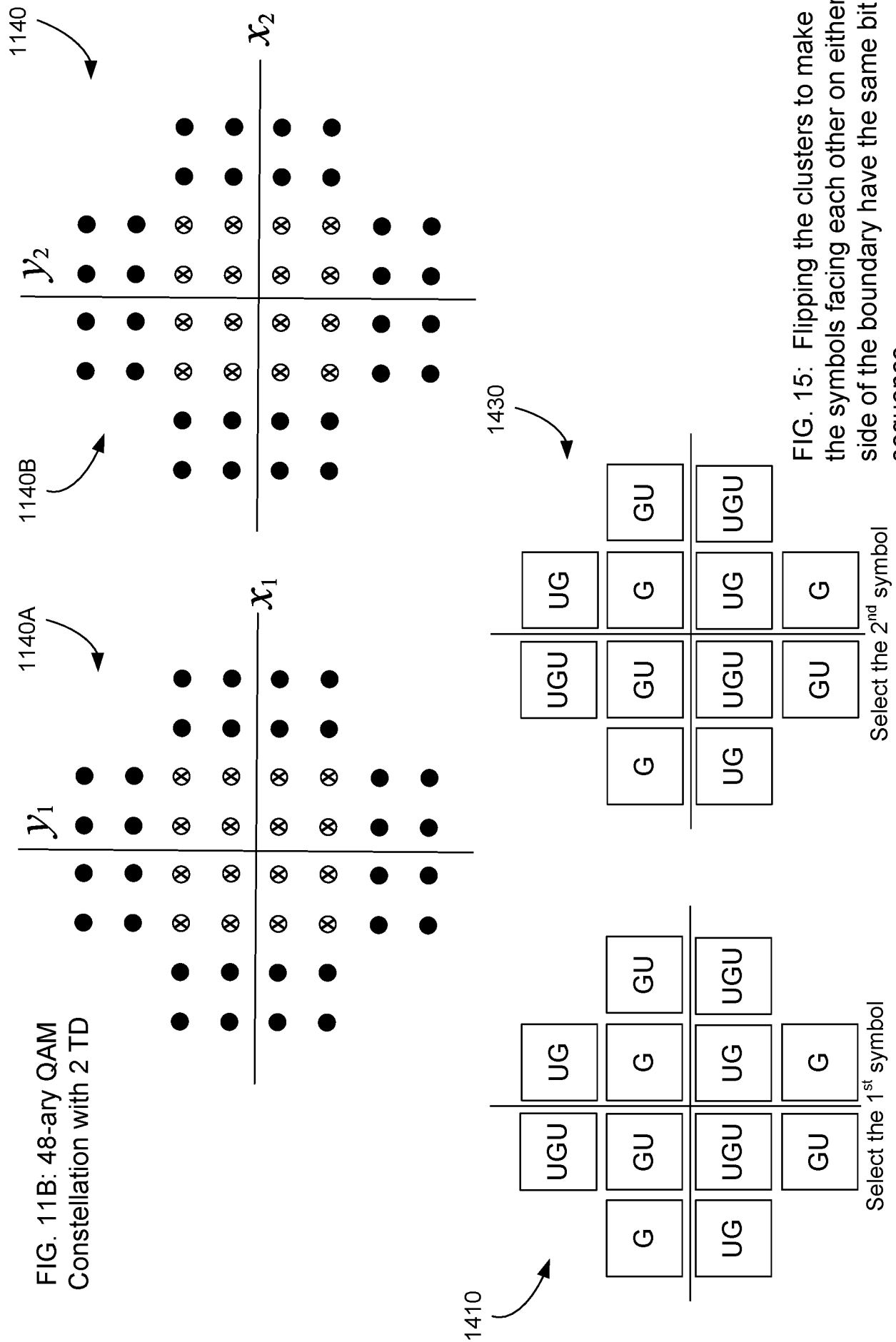


FIG. 15: Flipping the clusters to make the symbols facing each other on either side of the boundary have the same bit sequence.

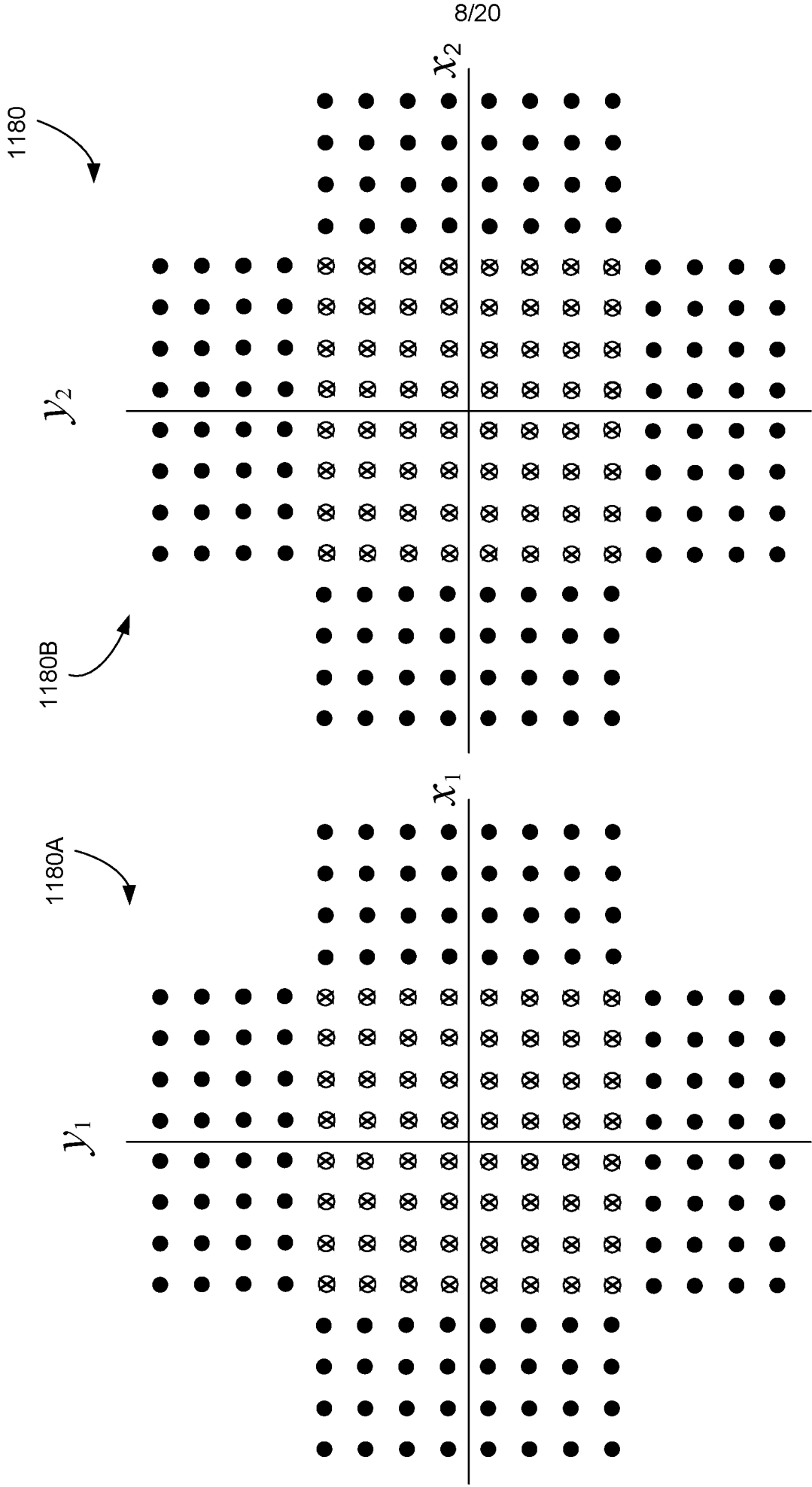


FIG. 11C: 192-ary QAM Constellation with 2TD

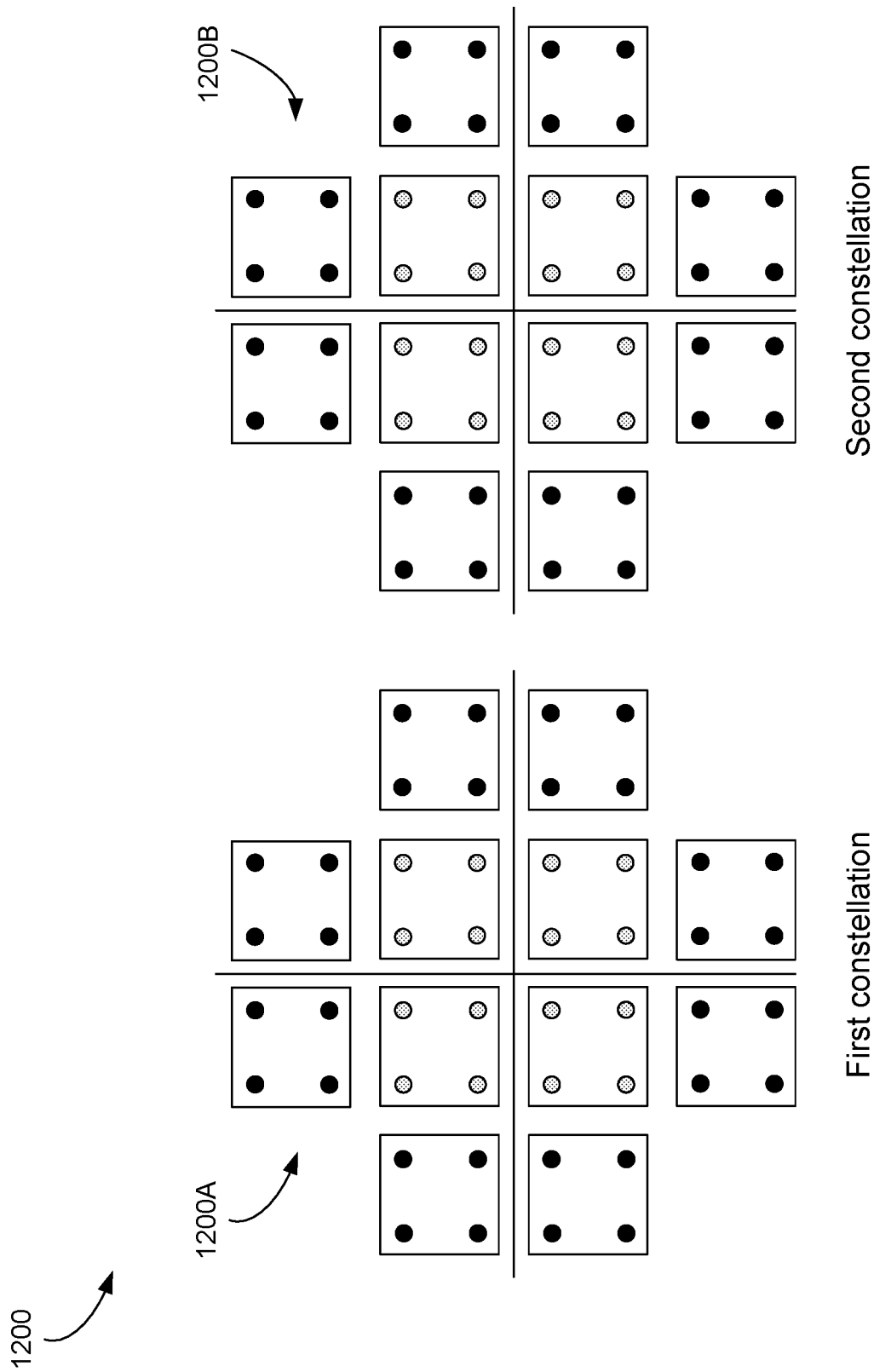


FIG. 12: A 12-ary QAM superposed with 4-QAM results in a 48-QAM constellation, which is then duplicated for selecting 2-symbol sequences.

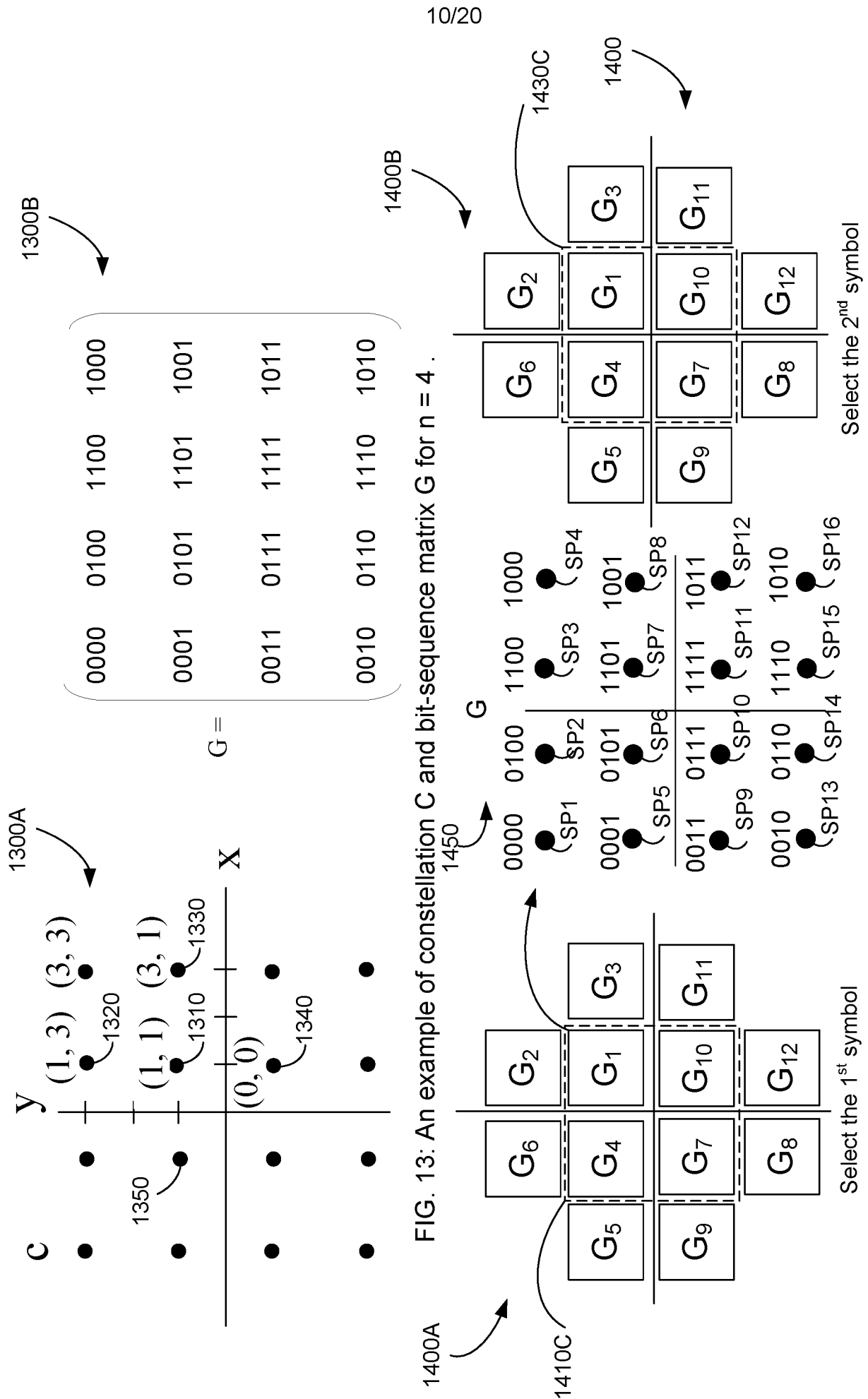


FIG. 14: Hierarchical modulation: 12-ary QAM constellations superposed with 4^{m-1} -ary QAM constellations for $m = 3$.

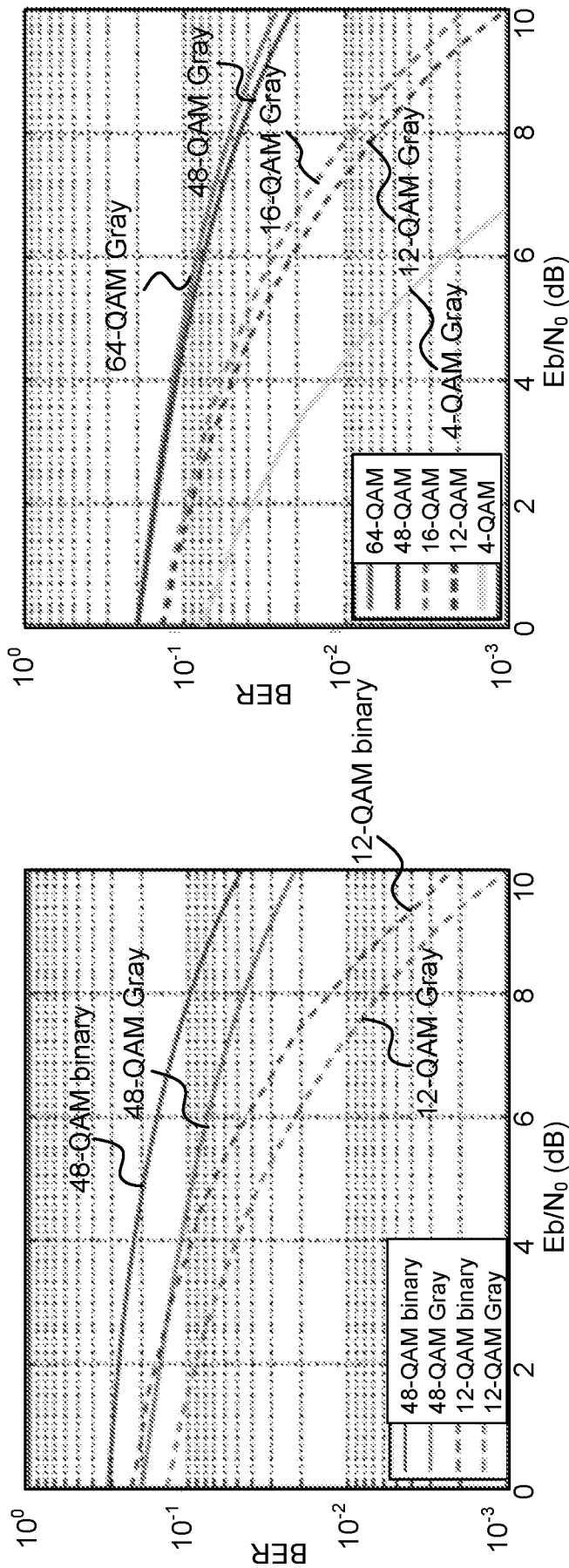


FIG. 16A

FIG. 16B

FIG. 16A BER performance without channel coding (a) for 48-QAM with binary mapping (blue solid line) and Gray mapping (red solid line), and for 12-QAM with binary mapping (blue dashed line) and Gray mapping (red dashed line);

FIG. 16B: BER performance for various QAM schemes with Gray mapping.

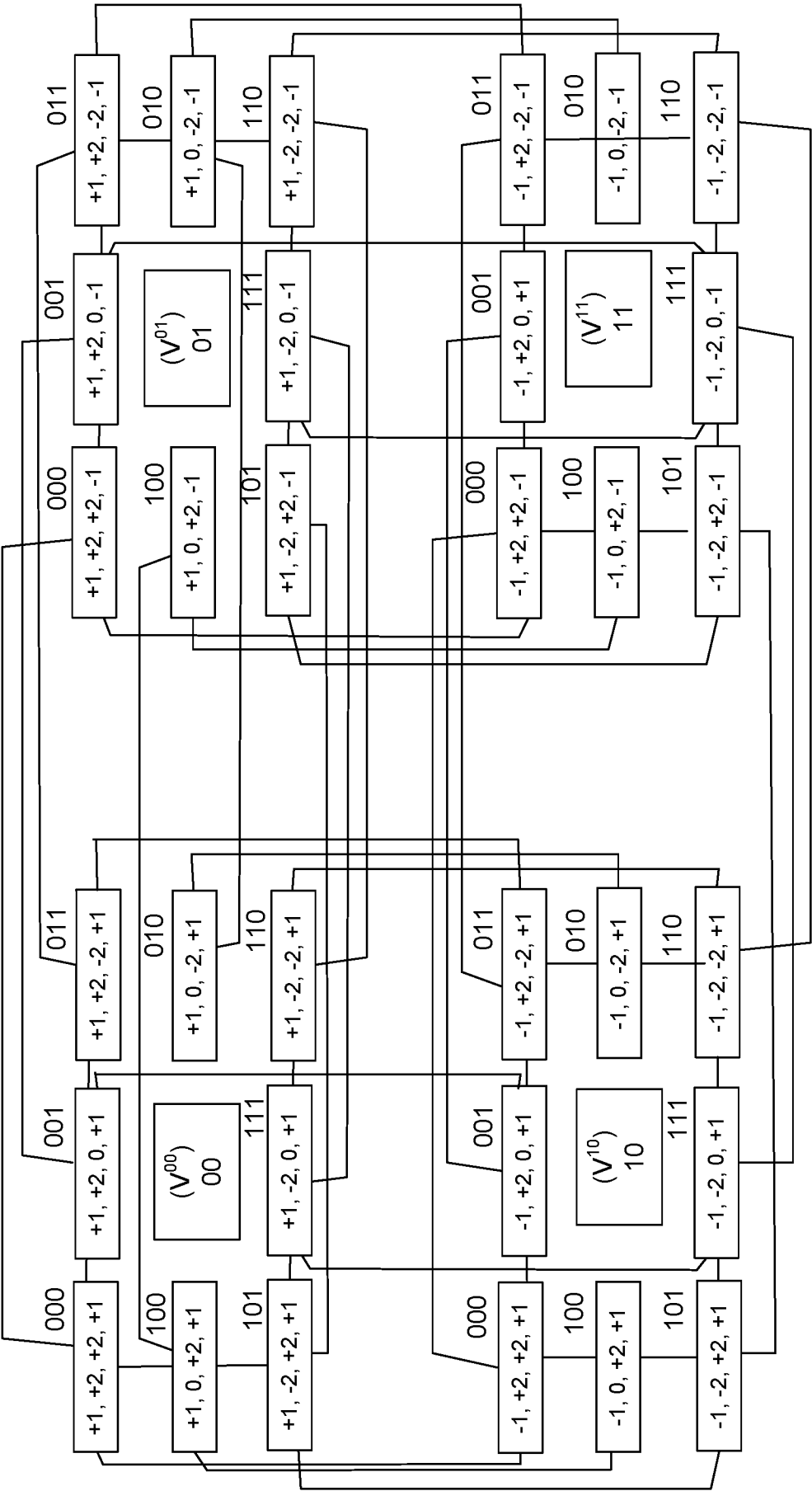


FIG. 18: Gray code of 6-ary QAM with 2 TD

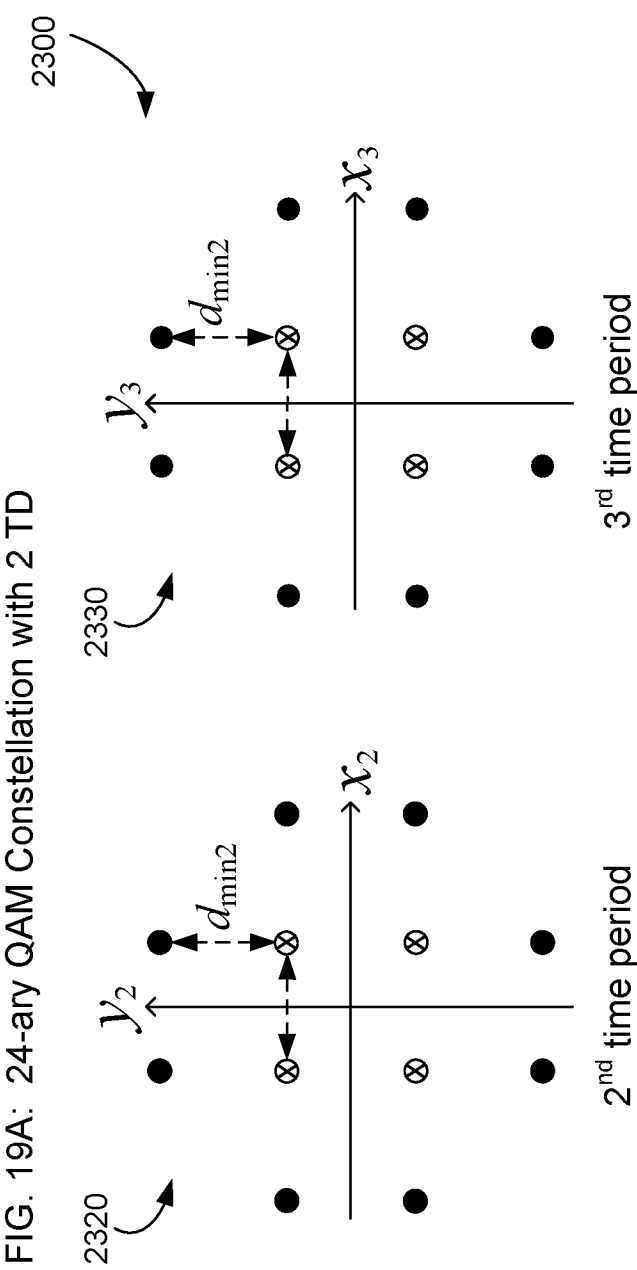
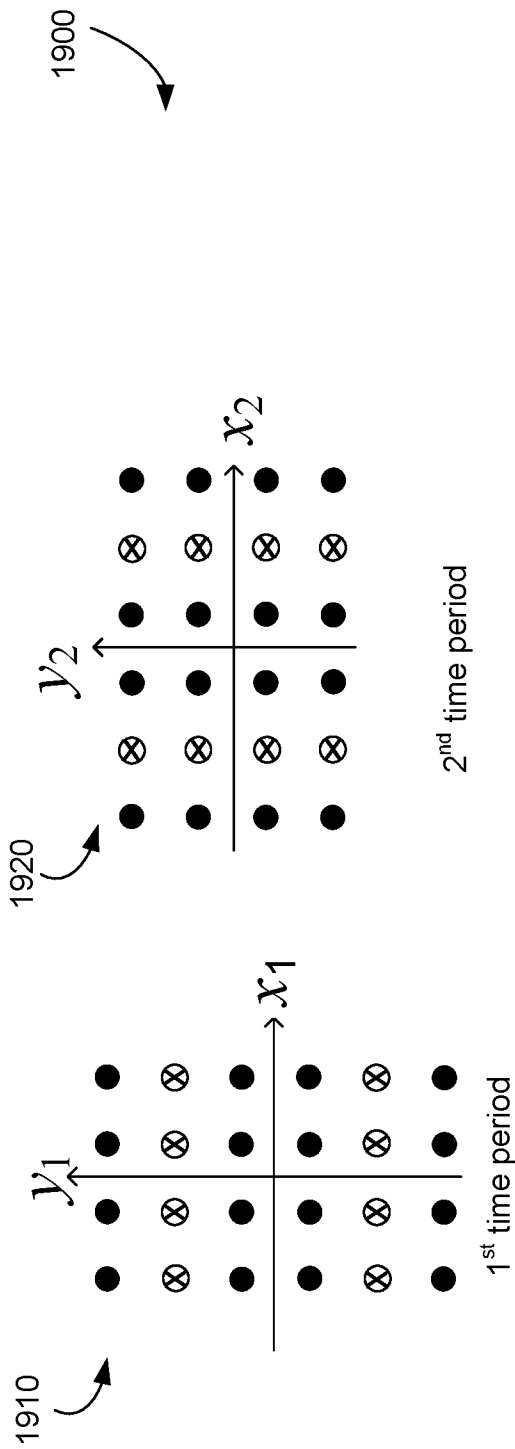


FIG. 19A: 24-ary QAM Constellation with 2 TD

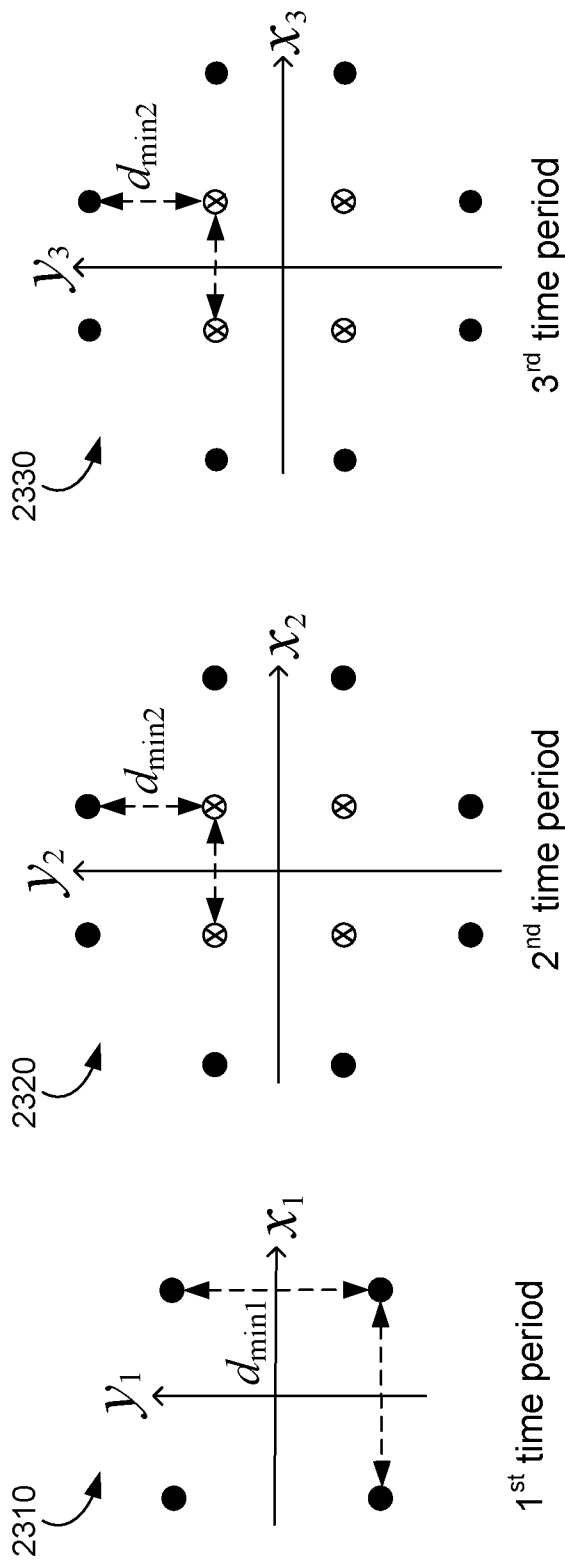


FIG. 23: (28/3)-ary QAM Constellation with 3TD

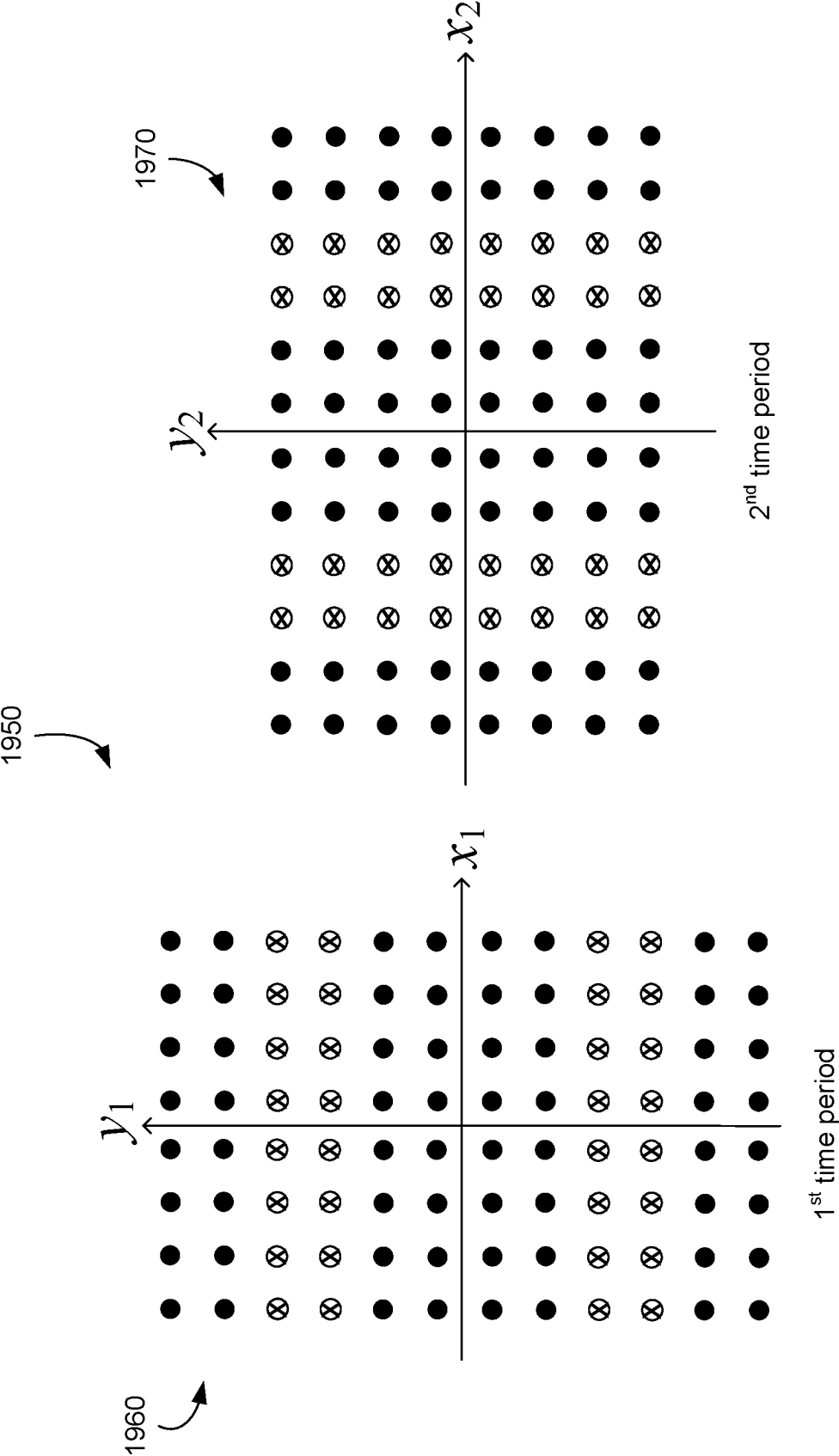


FIG. 19B: 96-ary QAM Constellation with 2TD

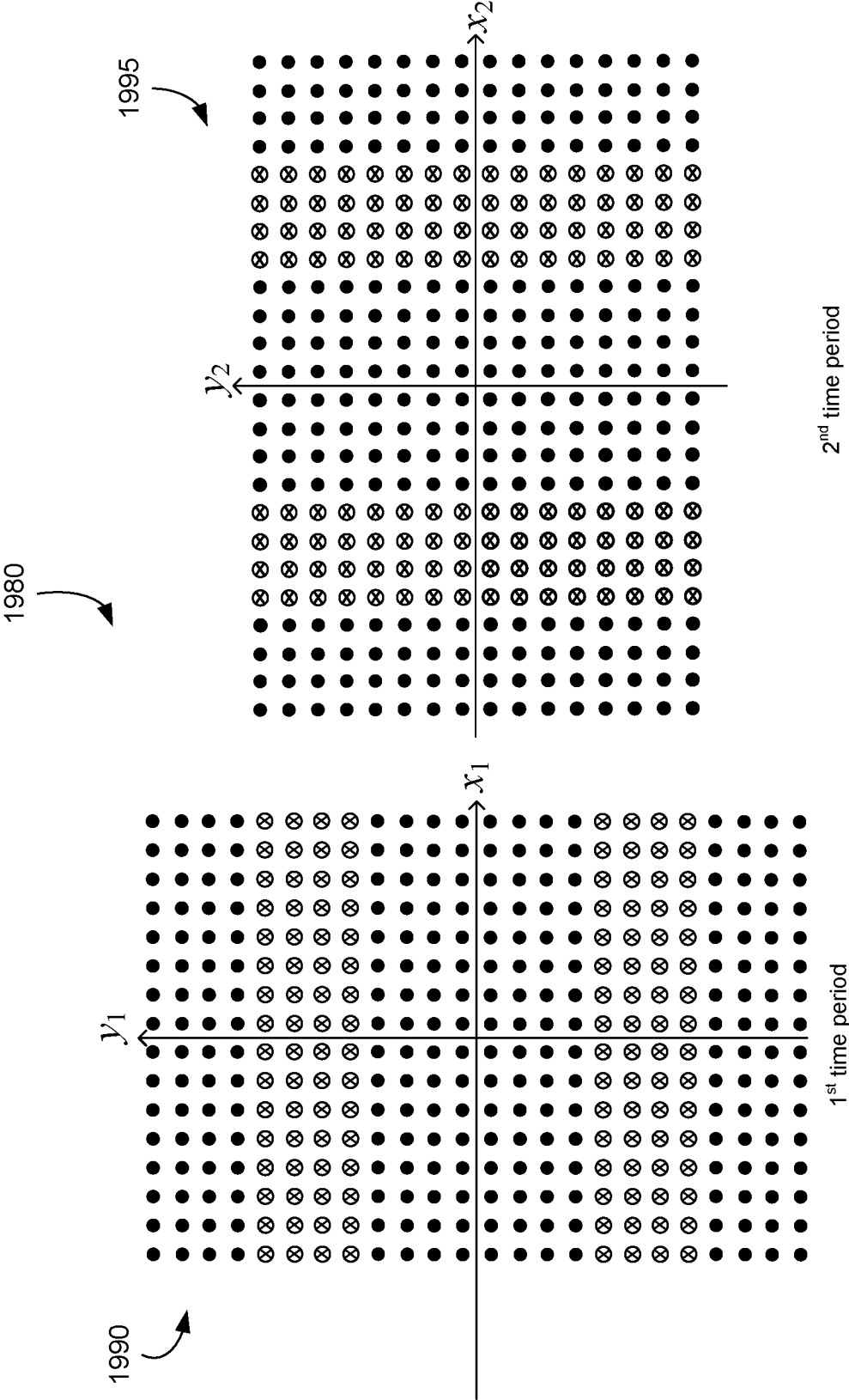
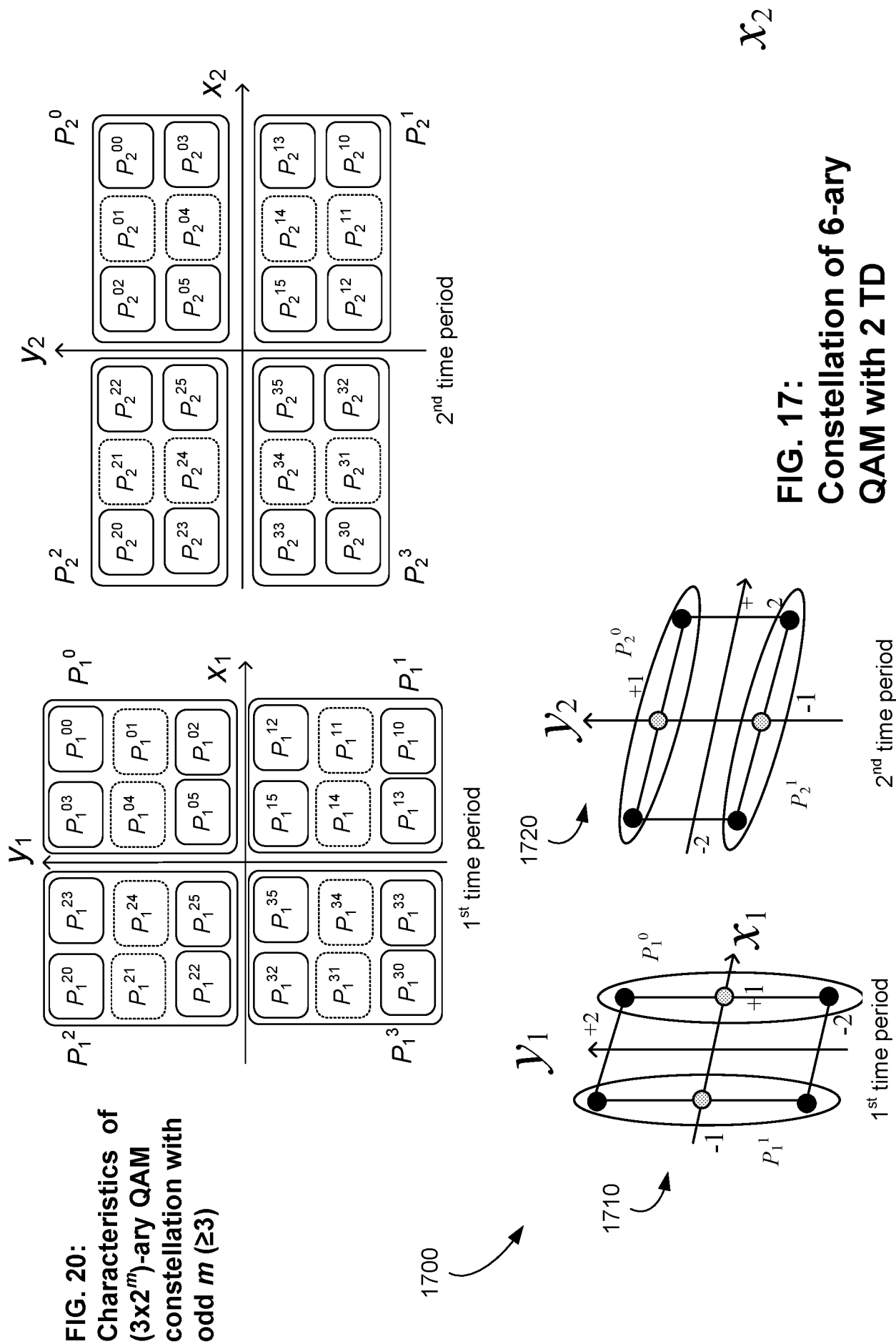


FIG. 19C: 384-ary QAM Constellation with 2TD



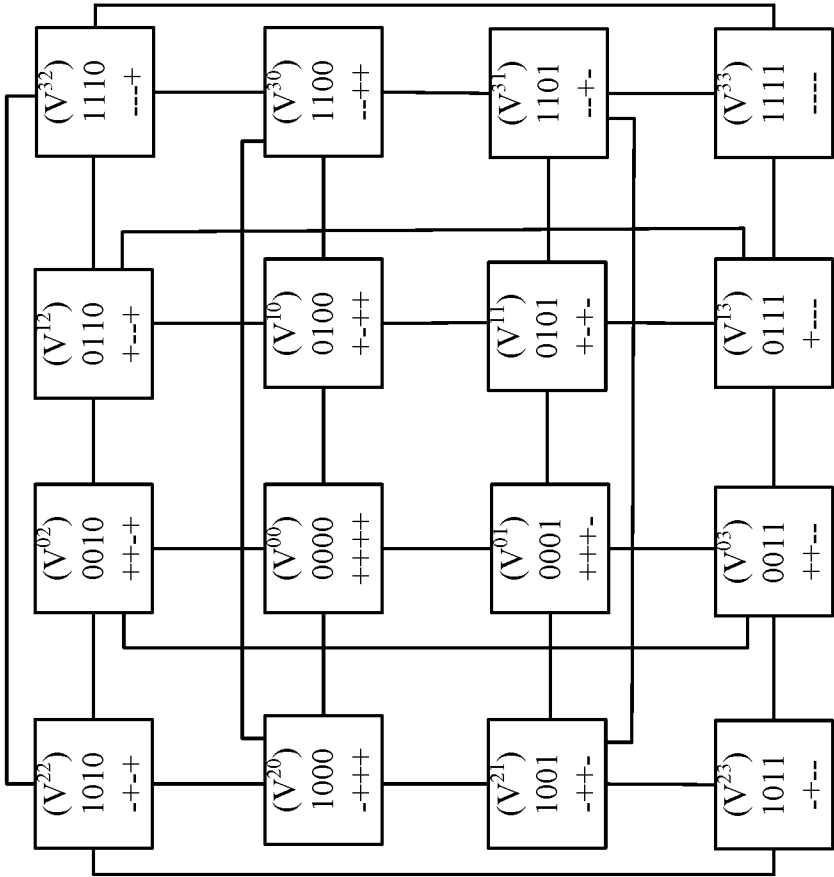
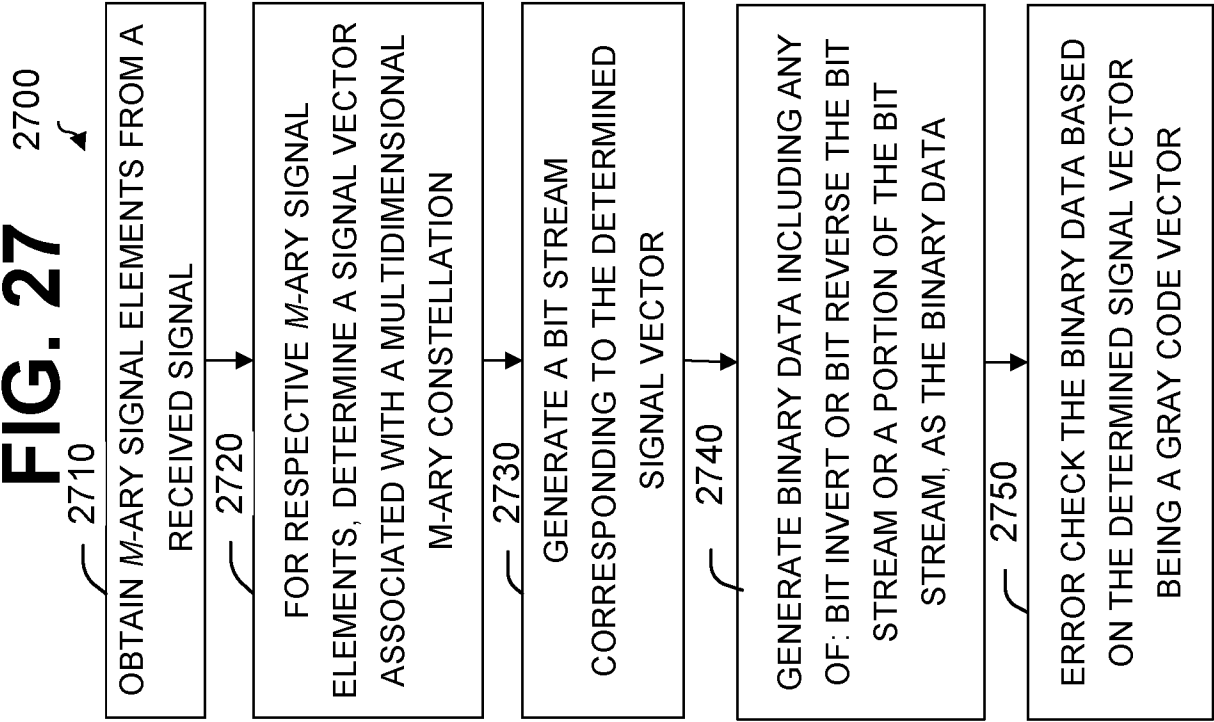


FIG. 21: Gray code allocation among SV subset V^{ij}

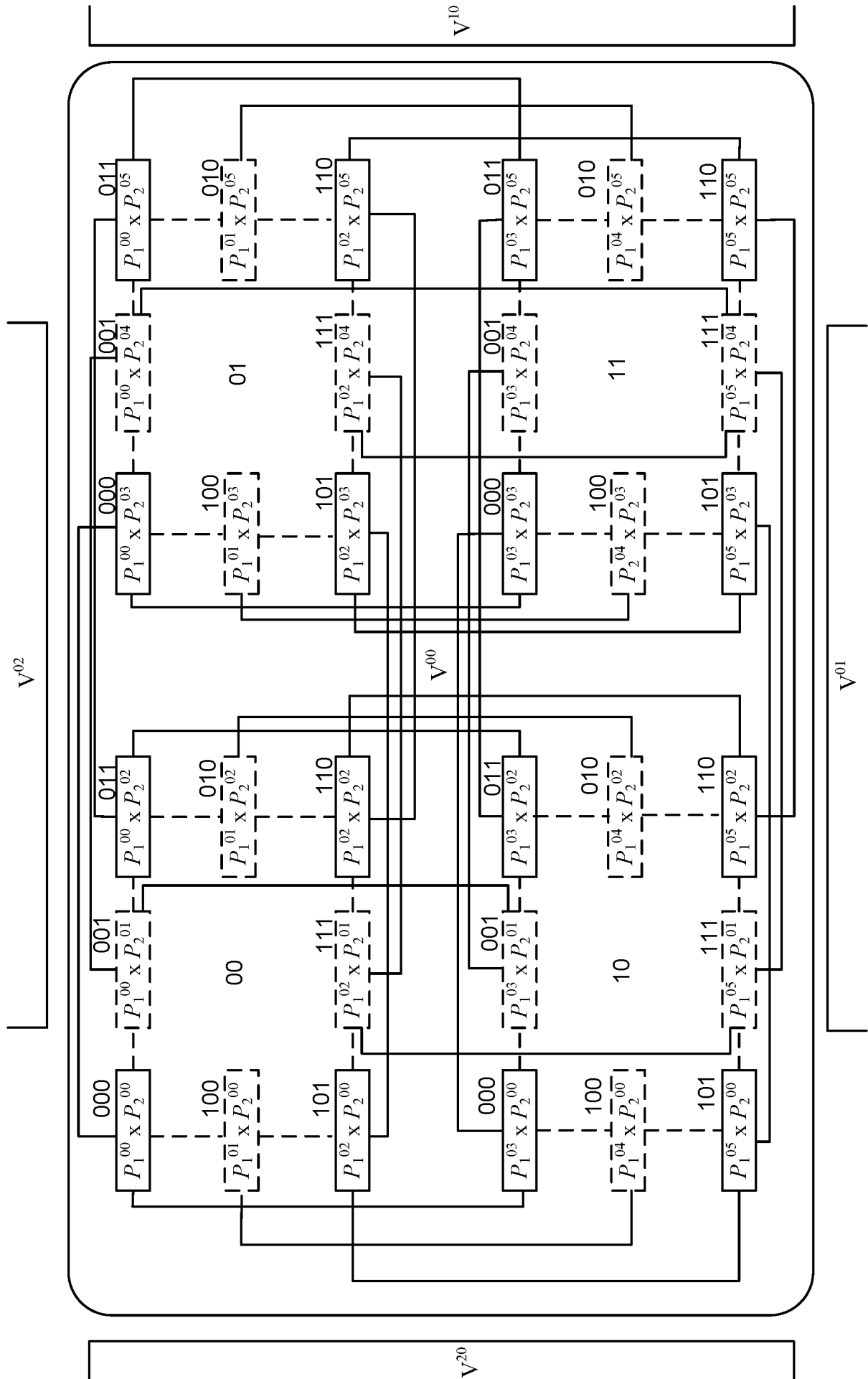


FIG. 22: Gray code allocation among SV subset ($P_1^{i_{1j1}} \times P_1^{i_{1j1}}$)

FIG. 24
2400

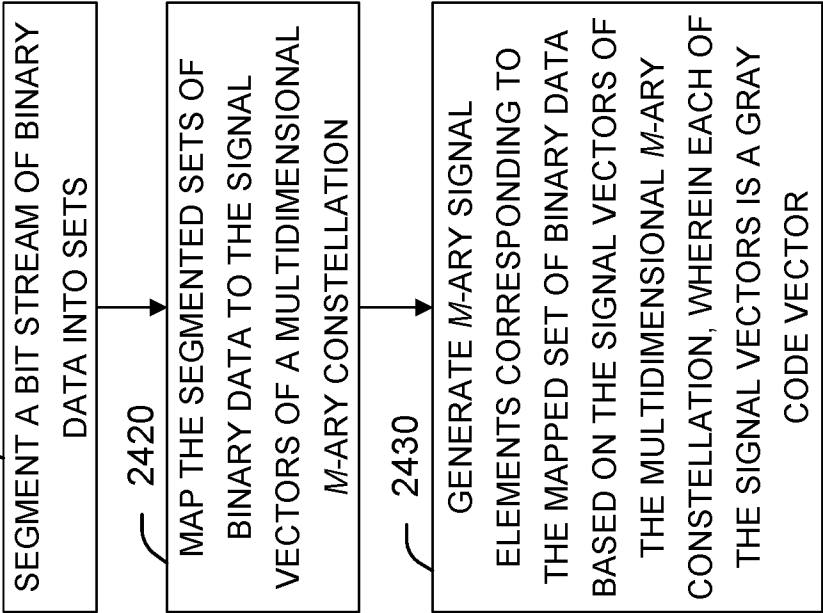


FIG. 25
2500

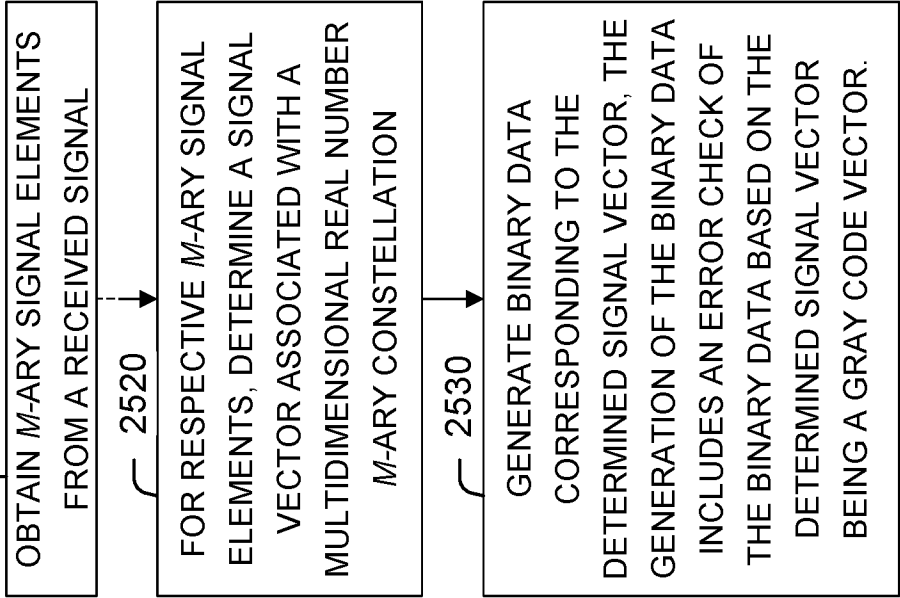
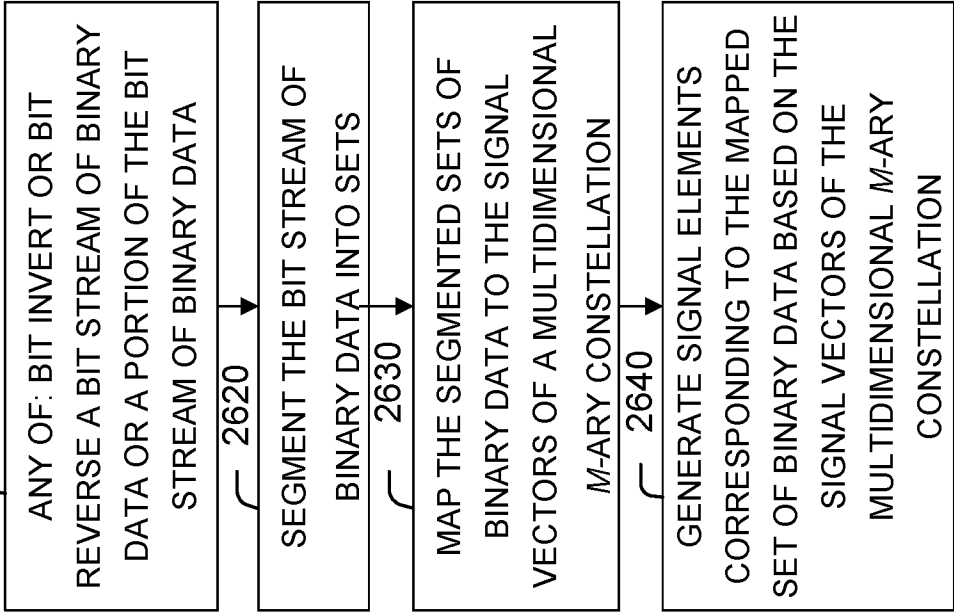
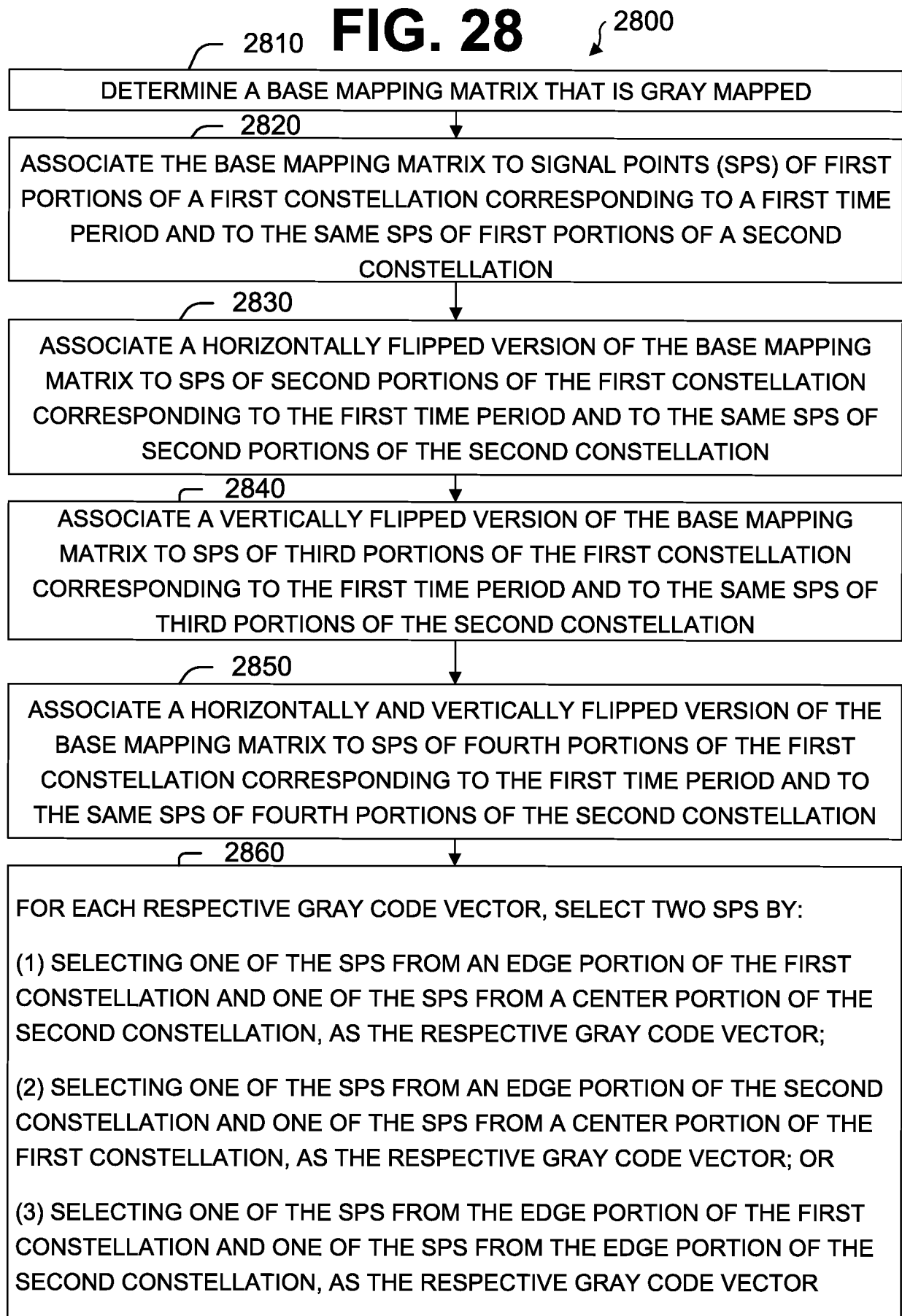


FIG. 26
2600



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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/031495

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H04L27/34 H04L1/06
 ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 H04L

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	XIANG ZHOU ET AL: "High Spectral Efficiency 400 Gb/s Transmission Using PDM Time-Domain Hybrid 32 64 QAM and Training-Assisted Carrier Recovery", JOURNAL OF LIGHTWAVE TECHNOLOGY, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 31, no. 7, 1 April 2013 (2013-04-01), pages 999-1005, XP011492657, ISSN: 0733-8724, DOI: 10.1109/JLT.2013.2243643 Sections II. and III.; figure 2	1-6, 8-10, 12-15, 17-22, 24-26, 28-33
X	US 2016/049999 A1 (TAHERZADEH BOROUJENI MAHMOUD [CA] ET AL) 18 February 2016 (2016-02-18) paragraph [0047] - paragraph [0059] figures 5-9	1-15, 17-33
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

17 July 2017

Date of mailing of the international search report

18/09/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
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 Fax: (+31-70) 340-3016

Authorized officer

Chave, Julien

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/031495

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WEI-REN PENG ET AL: "Hybrid QAM transmission techniques for single-carrier ultra-dense WDM systems", OPTOELECTRONICS AND COMMUNICATIONS CONFERENCE (OECC), 2011 16TH, IEEE, 4 July 2011 (2011-07-04), pages 824-825, XP032051358, ISBN: 978-1-61284-288-2 Section 2.; figure 1 -----	1-6, 8-10, 12-15, 17-22, 24-26, 28-33
X	CURRI V ET AL: "Time-division hybrid modulation formats: Tx operation strategies and countermeasures to nonlinear propagation", OFC 2014, OSA, 9 March 2014 (2014-03-09), pages 1-3, XP032633416, DOI: 10.1109/OFC.2014.6886929 Section 2. -----	1-6, 8-10, 12-15, 17-22, 24-26, 28-33

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/031495

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-15, 17-33

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15, 17-33

a multidimensional real number M-ary constellation for more granularity in link adaptation, ie allowing any bit rate /symbol.

2. claims: 16, 34

Determination of a Gray mapping associated to a given multidimensional real M-ary constellation for improved SNR.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/031495

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
US 2016049999	A1	18-02-2016	CN 106576024 A	19-04-2017
			EP 3172853 A1	31-05-2017
			KR 20170042680 A	19-04-2017
			US 2016049999 A1	18-02-2016
			WO 2016023517 A1	18-02-2016
