(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 March 2018 (15.03.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/048498 A1

(51) International Patent Classification:
H04L 27/26 (2006.01) *H04L 5/00* (2006.01)

(21) International Application Number:
PCT/US2017/040085

(22) International Filing Date:
29 June 2017 (29.06.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/385,902 09 September 2016 (09.09.2016) US

(71) Applicant: **INTEL CORPORATION** [US/US]; 2200 Mission College Boulevard, Santa Clara, California 95054 (US).

(72) Inventors: **LOMAYEV, Artyom**; Turgeneva str 30, Nizhny Novgorod, 603024 (RU). **GAGIEV, Yaroslav P.**; 9 Delovaya Str. Room 313, Nizhny Novgorod, 603163 (RU). **MALTSEV, Alexander**; 1-7 Verchne-Pecherskay Str., Nizhny Novgorod, 603163 (RU). **GENOSSAR, Michael**; 62 Binyamin, 71724 Modiin (IL). **CORDEIRO, Carlos**; 15168 NW Twinflower Drive, Portland, Oregon 97229 (US).

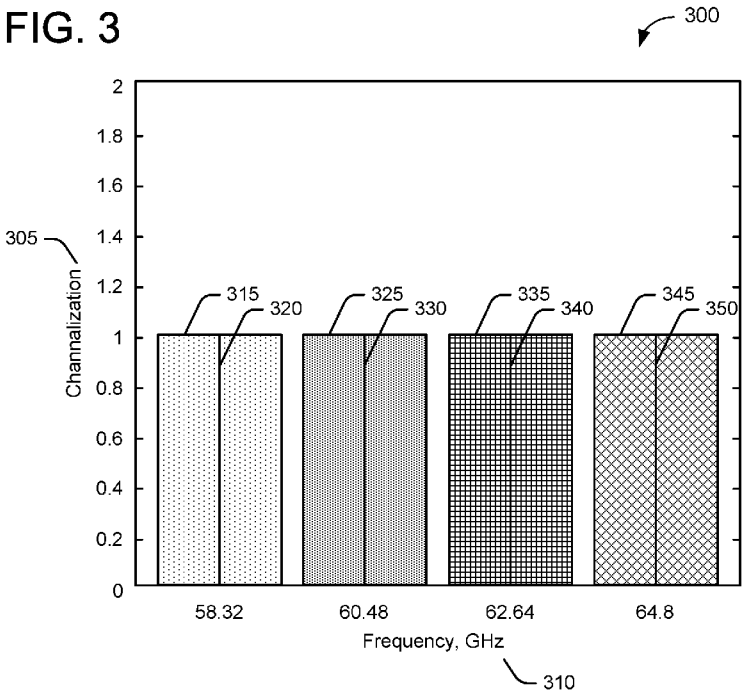
(74) Agent: **GRIFFIN, III, Malvern U.** et al.; Eversheds Sutherland (US) LLP, 999 Peachtree Street NE, Suite 2300, Atlanta, Georgia 30309 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: SIGNAL SPECTRA FOR WIRELESS NETWORKS

FIG. 3



(57) Abstract: In various embodiments, this disclosure describes various signal spectrum definitions for use in wireless networks. For example, the disclosure describes enhanced directional multi gigabit (EDMG) orthogonal frequency-division multiplexing (OFDM) signal spectrum definitions, for example, for use in connection with single input single output (SISO) transmission with channel bonding. In one embodiment, the OFDM signal spectrum can include data, pilot, zero direct current (DC) and zero guard band (GB) subcarriers. In another embodiment, the data and pilot subcarriers can define the total number of occupied subcarriers in the OFDM signal spectrum.

WO 2018/048498 A1

[Continued on next page]

UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*

SIGNAL SPECTRA FOR WIRELESS NETWORKS

CROSS REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/385,902, filed on September 9, 2016, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure generally relates to systems and methods for wireless communications and, more particularly, systems and methods to signal spectra for wireless communication.

BACKGROUND

[0003] Various standards, for example, Institute of Electrical and Electronics Engineers (IEEE) 802.11ay, are being developed for the millimeter (mm) wave (for example, 60 GHz) frequency band of the spectrum. For example, IEEE 802.11ay is one such standard. IEEE 802.11ay is related to the IEEE 802.11ad standard, also known as WiGig. IEEE 802.11ay seeks, in part, to increase the transmission data rate between two or more devices in a network.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 shows an exemplary network environment in accordance with the systems and methods disclosed herein.

[0005] FIG. 2 shows an example diagram of Directional Multi Gigabit (DMG) orthogonal frequency-division multiplexing (OFDM) spectrum definition for two adjacent channels, in accordance with example embodiments of the disclosure.

[0006] FIG. 3 shows an example of DMG OFDM spectrum definition for four adjacent channels, in accordance with example embodiments of the disclosure.

[0007] FIGs. 4A-4B show example tables showing OFDM signal spectrum parameters for channel bonding transmission, in accordance with example embodiments of the disclosure.

[0008] FIG. 5 shows an example flow chart illustrating operation for a transmitting device used in connection with the spectrum definitions herein, in accordance with example embodiments of the disclosure.

[0009] FIG. 6 shows an example flow chart illustrating operation for a receiving device used in connection with the spectrum definitions herein, in accordance with example embodiments of the disclosure.

[0010] FIG. 7 illustrates a functional diagram of an example communication station that may be suitable for use as a user device, in accordance with one or more example embodiments of the disclosure.

[0011] FIG. 8 shows a block diagram of an example machine upon which any of one or more techniques (e.g., methods) may be performed, in accordance with one or more embodiments of the disclosure.

DETAILED DESCRIPTION

[0012] Example embodiments described herein provide certain systems, methods, and devices, for providing signaling information to Wi-Fi devices in various Wi-Fi networks, in accordance with IEEE 802.11 communication standards, including but not limited to IEEE 802.11ay.

[0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0014] As mentioned, various standards, for example, Institute of Electrical and Electronics Engineers (IEEE) 802.11ay, are being developed for the millimeter (mm) wave (for example, 60 GHz) frequency band of the spectrum. For example, IEEE 802.11ay is one such standard. IEEE 802.11ay is related to the IEEE 802.11ad standard, also known as WiGig. IEEE 802.11ay seeks, in part, to increase the transmission data rate between two or more devices in a network.

[0015] As used herein, in an embodiment, Orthogonal Frequency-Division Multiplexing (OFDM) can refer to a frequency-division multiplexing (FDM) scheme

used as a digital multi-carrier modulation method for network communication. In one embodiment, in OFDM, a number of closely spaced orthogonal subcarrier signals can be used to carry data on several parallel data streams or channels. Each subcarrier can be modulated with a conventional modulation scheme (for example, quadrature amplitude modulation or phase-shift keying) at a relatively low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

[0016] As used herein, in an embodiment, a subcarrier can refer to a sideband of a radio frequency carrier wave, which is modulated to send additional information over a communications channel in a network.

[0017] As used herein, in an embodiment, a Direct Current (DC) subcarrier can refer to a subcarrier that has no information sent on it. In one embodiment, the DC subcarrier can be used by a mobile device to locate the center of the OFDM frequency band.

[0018] As used herein, in an embodiment, pilot signals can refer to signals, usually at a predetermined frequency, transmitted over the communications system for example, for supervisory, control, equalization, continuity, synchronization, and/or reference purposes In one embodiment, the pilot subcarriers can be used to track a residual phase error associated with one or more subcarriers, for example, after frequency correction are implemented.

[0019] As used herein, in an embodiment, channel bonding (CB) can refer to a practice used in IEEE 802.11 implementations in which two adjacent channels within a given frequency band are combined to increase throughput between two or more wireless devices. Channel bonding can lead to increased throughput and provides for more functionality within Wi-Fi deployments. In IEEE 802.11n, CB can occur when two adjacent 20 MHz channels inside a specific frequency are joined to create one 40 MHz channel, doubling throughput between wireless devices. In fact, CB in this case can more than doubles channel size since guard bands are removed. Further, many Wi-Fi devices operate at the 2.4 GHz frequency since the first standardization of IEEE 802.11 in 1997. While many Wi-Fi devices can operate at both 2.4 GHz and 5 GHz frequency bands, 2.4 GHz is preferred in many applications due its greater range compared to 5 GHz. Moreover, since 2.4 GHz performs at a comparable slower speed, CB can be used to boost device performance.

[0020] In one embodiment, this disclosure describes definitions and parameters for use in connection with an OFDM signal spectrum. In another embodiment, this disclosure extends

the definitions and parameters for use in connection with an OFDM signal spectrum having channel bonding. In one embodiment, the number of data subcarriers, pilot subcarriers, direct current (DC) subcarriers, and guard band (GB) subcarriers for use in connection with an OFDM signal spectrum are described in this disclosure. Further, as mentioned, this disclosure describes OFDM signal spectrum definition for networks implementing single input single output (SISO) transmissions with channel bonding. The systems and methods described herein can be implemented, in some embodiments, with directional antennas, for example, phase antenna arrays (PAAs).

[0021] In one embodiment, for channel bonding used in connection with an EDMG OFDM spectrum, the subcarrier spacing can be used as the EDMG OFDM spectrum defined, for example, in one or more legacy standards (for example, with legacy 802.11ad standards). In one embodiment, such standards can specify a spectrum approximately equal to $\Delta f = 5.1563$ MHz. In one embodiment, the DFT size for use in connection with channel bonding can be defined as $512*N_{CB}$, where $N_{CB} = 2, 3, 4$ for 2, 3, and 4 channels accordingly. In one embodiment, the number of total occupied subcarriers for channel bonding can be defined in a way that edge spectrum subcarriers (that is, subcarriers having a frequency on the edge of the spectrum) do not exceed the boundaries of another transmission in a nearby frequency range. In one embodiment, a center frequency for channel bonding transmission can be selected based at least in part on a number of factors, including, but not limited to, subcarrier spacing, channel bonding factor, and/or definitions and/or recommendations described by one or more standards. In one embodiment, the number of data subcarriers can be a predetermined number and can serve to support interleaving over the low-density parity-check (LDPC) codewords, for example, for higher order modulations. In one embodiment, low-density parity-check (LDPC) codes can refer to linear error correcting codes that can be used for transmitting a message over a noisy transmission channel.

[0022] In one embodiment, the number of DC subcarriers can be fixed, for example, at $N_{DC} = 3$, independent of the channel bonding factor being used for channel bonding. In another embodiment, the number of DC subcarriers can be modified based at least in part on the channel bonding factor N_{CB}; further, the remaining subcarriers (that is, the subcarriers that are not DC subcarriers) can be divided between the left and right guard bands (GBs).

[0023] In one embodiment, channel bonding can be performed; thereafter one or

more GB subcarriers that have a frequency between the channels and DC subcarriers can be reused for the data subcarrier and/or pilot subcarrier transmission. In one embodiment, a predetermined number of extra subcarriers, for example, 66 extra subcarriers, can be used for channel bonding of two channels, 66*2=132 extra subcarriers can be used for channel bonding of three channels, and 66*3=198 subcarriers can be used for channel bonding of four channels. In various embodiments, a general formula for the total number of occupied subcarriers N_{total} can be written as: $N_{total} = 352 * N_{CB} + Ng * (N_{CB} - 1) = (352 + Ng) * N_{CB} – Ng$; where $Ng = 66$ and N_{CB} can be equal to 2, 3, or 4.

[0024] In one embodiment, the following parameters and OFDM signal spectrum definition can be implemented: the total number of occupied subcarriers: $N_{total} = 418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$; the number of pilot subcarriers: $N_{pilots} = 16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$. The number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of DC subcarriers, $N_{DC} = 3$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0025] In an embodiment, the number of DC subcarriers can be based at least in part on the channel bonding factor N_{CB}. In one embodiment, the following parameters and OFDM signal spectrum definition can be implemented: the total number of occupied subcarriers: $N_{total} = 416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$; the number of pilots: $N_{pilots} = 14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; $N_{DC} = 3+2*(N_{CB}-1)$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0026] FIG. 1 is a network diagram illustrating an example network environment, according to some example embodiments of the present disclosure. Wireless network 100 may include one or more devices 120 and one or more access point(s) (AP) 102, which may communicate in accordance with IEEE 802.11 communication standards, including IEEE

802.11ay. The device(s) 120 may be mobile devices that are non-stationary and do not have fixed locations.

[0027] The user device(s) 120 (e.g., 124, 126, or 128) may include any suitable processor-driven user device including, but not limited to, a desktop user device, a laptop user device, a server, a router, a switch, an access point, a smartphone, a tablet, wearable wireless device (e.g., bracelet, watch, glasses, ring, etc.) and so forth. In some embodiments, the user devices 120 and AP 102 may include one or more computer systems similar to that of the functional diagram of FIG. 5 and/or the example machine/system of FIG. 6, to be discussed further.

[0028] Returning to FIG. 1, any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP 102 may be configured to communicate with each other via one or more communications networks 130 and/or 135 wirelessly or wired. Any of the communications networks 130 and/or 135 may include, but not limited to, any one of a combination of different types of suitable communications networks such as, for example, broadcasting networks, cable networks, public networks (e.g., the Internet), private networks, wireless networks, cellular networks, or any other suitable private and/or public networks. Further, any of the communications networks 130 and/or 135 may have any suitable communication range associated therewith and may include, for example, global networks (e.g., the Internet), metropolitan area networks (MANs), wide area networks (WANs), local area networks (LANs), or personal area networks (PANs). In addition, any of the communications networks 130 and/or 135 may include any type of medium over which network traffic may be carried including, but not limited to, coaxial cable, twisted-pair wire, optical fiber, a hybrid fiber coaxial (HFC) medium, microwave terrestrial transceivers, radio frequency communication mediums, white space communication mediums, ultra-high frequency communication mediums, satellite communication mediums, or any combination thereof.

[0029] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP 102 may include one or more communications antennae. Communications antenna may be any suitable type of antenna corresponding to the communications protocols used by the user device(s) 120 (e.g., user devices 124, 124 and 128), and AP 102. Some non-limiting examples of suitable communications antennas include Wi-Fi antennas, Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards compatible antennas, directional antennas, non-directional antennas, dipole antennas, folded dipole antennas, patch

antennas, multiple-input multiple-output (MIMO) antennas, or the like. The communications antenna may be communicatively coupled to a radio component to transmit and/or receive signals, such as communications signals to and/or from the user devices 120.

[0030] Any of the user devices 120 (e.g., user devices 124, 126, 128), and AP 102 may include any suitable radio and/or transceiver for transmitting and/or receiving radio frequency (RF) signals in the bandwidth and/or channels corresponding to the communications protocols utilized by any of the user device(s) 120 and AP 102 to communicate with each other. The radio components may include hardware and/or software to modulate and/or demodulate communications signals according to pre-established transmission protocols. The radio components may further have hardware and/or software instructions to communicate via one or more Wi-Fi and/or Wi-Fi direct protocols, as standardized by the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. In certain example embodiments, the radio component, in cooperation with the communications antennas, may be configured to communicate via 2.4 GHz channels (e.g. 802.11b, 802.11g, 802.11n), 5 GHz channels (e.g. 802.11n, 802.11ac), or 60 GHZ channels (e.g. 802.11ad). In some embodiments, non-Wi-Fi protocols may be used for communications between devices, such as Bluetooth, dedicated short-range communication (DSRC), Ultra-High Frequency (UHF) (e.g. IEEE 802.11af, IEEE 802.22), white band frequency (e.g., white spaces), or other packetized radio communications. The radio component may include any known receiver and baseband suitable for communicating via the communications protocols. The radio component may further include a low noise amplifier (LNA), additional signal amplifiers, an analog-to-digital (A/D) converter, one or more buffers, and digital baseband.

[0031] Typically, when an AP (e.g., AP 102) establishes communication with one or more user devices 120 (e.g., user devices 124, 126, and/or 128), the AP may communicate in the downlink direction by sending data frames (e.g., 142). The data frames may be preceded by one or more preambles that may be part of one or more headers. These preambles may be used to allow the user device to detect a new incoming data frame from the AP. A preamble may be a signal used in network communications to synchronize transmission timing between two or more devices (e.g., between the APs and user devices).

[0032] In various embodiments, the disclosed systems and methods can be used in connection with the mmWave (60 GHz) band, which may be related to the IEEE 802.11ad standard also known as WiGig. IEEE 802.11ay may be used to increase the

transmission data rate in wireless networks, for example, by using one or more Multiple Input Multiple Output (MIMO) and/or channel bonding techniques.

[0033] Various standards, for example, Institute of Electrical and Electronics Engineers (IEEE) 802.11ay, are being developed for the millimeter (mm) wave (for example, 60 GHz) frequency band of the spectrum. For example, IEEE 802.11ay is one such standard. IEEE 802.11ay is related to the IEEE 802.11ad standard, also known as WiGig. IEEE 802.11ay seeks, in part, to increase the transmission data rate between two or more devices in a network, for example, by implementing Multiple Input Multiple Output (MIMO) techniques.

[0034] As mentioned, this disclosure describes enhanced directional multi gigabit (EDMG) orthogonal frequency-division multiplexing (OFDM) signal spectrum definitions, for example, for use in connection with single input single output (SISO) transmission with channel bonding. In one embodiment, the OFDM signal spectrum can include data, pilot, zero direct current (DC) and zero guard band (GB) subcarriers. In another embodiment, the data and pilot subcarriers can define the total number of occupied subcarriers in the OFDM signal spectrum.

[0035] In one embodiment, this disclosure describes OFDM signal spectrum definitions, and extends the definitions for channel bonding. In one embodiment, the number of data, pilot, DC, and GB subcarriers are also described in this disclosure. Further, as mentioned, this disclosure describes OFDM signal spectrum definition for SISO transmission with channel bonding. The systems and methods described herein can be particularly useful when practiced with directional antennas, for example, phase antenna arrays (PAAs).

[0036] In one embodiment, the following parameters of the directional multi gigabit (DMG) OFDM signal spectrum can be used: total number of occupied subcarriers: N_{total} = 352; data and pilot subcarriers: N_{data} = 336, N_{pilot} = 16; number of DCs: N_{DC} = 3; left and right GBs: N_L = 79, N_R = 78; subcarrier spacing: Δf = 5.1563 MHz; channels spacing: 2.16 GHz; and discrete Fourier transform (DFT) size: 512 pt.

[0037] FIG. 2 shows an example diagram 200 of channels for use in connection with OFDM spectrum transmissions, in accordance with example embodiments of the disclosure. In one embodiment, the diagram 200 has an x-axis 210 representing frequency, and a y-axis 205 representing channelization. In one embodiment, the diagram 200 shows channels 215 and 225 spaced by approximately 2.16 GHz, with a

first carrier 220 at a frequency of approximately Fc1 = 58.32 GHz and a second carrier 230 at a frequency of approximately Fc2 = 60.48 GHz, in accordance with example embodiments of the disclosure.

[0038] In one embodiment, the EDMG OFDM spectrum can be defined in accordance with the following: For channel bonding the EDMG OFDM spectrum the same subcarrier spacing as the EDMG OFDM spectrum in one or more legacy standards (for example, with legacy 802.11ad standards), which can be approximately equal to Δf = 5.1563 MHz; The DFT size in case of channel bonding can be defined as $512*N_{CB}$, where N_{CB} = 2, 3, 4 in case of 2, 3, and 4 channels accordingly; The number of total occupied subcarriers for channel bonding can be defined in a way that the edge spectrum subcarriers do not exceed the boundaries of the duplicate spectrum transmission. The center frequency for channel bonding transmission can be selected based at least in part on a number of factors, including, but not limited to, subcarrier spacing, channel bonding factor, and/or one or more standards; The number of data subcarriers can be a predetermined number and can serve to support interleaving over the LDPC codewords, for example, for higher order modulations.

[0039] In one embodiment, the number of DC subcarriers can be equal to N_{DC} = 3 regardless of the channel bonding factor. In another embodiment, the N_{DC} can be changed based at least in part on the channel bonding factor N_{CB}; the remaining subcarriers can be divided between the left and right guard bands (GBs).

[0040] FIG. 3 shows an example diagram 300 of channels for use in connection with OFDM spectrum transmissions, in accordance with example embodiments of the disclosure. In one embodiment, the diagram 300 has an x-axis 310 representing frequency, and a y-axis 305 representing channelization. In one embodiment, the diagram 300 shows four approximately 2.16 GHz channels 315, 325, 335, and 345 which can, in some embodiments, be described and/or defined in accordance with one or more legacy standards. In one embodiment, channel 315 have respective center frequency 320 approximately equal to Fc1 = 58.32 GHz, channel 325 have respective center frequency 330 approximately equal to Fc2 = 60.48 GHz, channel 335 have respective center frequency 340 approximately equal to Fc3 =62.64 GHz, and channel 345 have respective center frequency 350 approximately equal to Fc4 = 64.8 GHz.

[0041] In one embodiment, channel bonding can be first performed, then one or more Guard Band (GB) subcarriers between the channels 315, 325, 335, and 345 and

DC subcarriers can be reused for the data subcarrier and/or pilot subcarrier transmission. In one embodiment, there can be a predetermined number of extra subcarriers, for example, 66 extra subcarriers, for channel bonding of two channels, 66*2=132 extra subcarriers for channel bonding of three channels, and 66*3=198 subcarriers for channel bonding of four channels.

[0042] In various embodiments, a general formula for the total number of occupied subcarriers can be written as: $N_{total} = 352 * N_{CB} + Ng * (N_{CB} - 1) = (352 + Ng) * N_{CB} – Ng$; where $Ng = 66$ and N_{CB} can be equal to 2, 3, or 4.

[0043] FIG. 4A shows an example table showing OFDM signal spectrum parameters for channel bonding transmission, in accordance with example embodiments of the disclosure.

[0044] In one embodiment, the channel bonding factors are represented in table 400: that is, for CB = 1 in element 405, CB = 2 in element 410, CB = 3 in element 415, and CB = 4 in element 420. Further row 425 represents number of data subcarriers, row 430 represents the number of pilot subcarriers, row 435 in table 400 represents the total number of occupied subcarriers, row 440 represents number of DC subcarriers, row 445 represents the number of left GB subcarriers, row 450 represents number of right GB subcarriers, and row 455 represents the frequency separation between subcarriers.

[0045] With reference to FIG. 4A, in a first embodiment, the number of DC subcarriers may not grow with the channel bonding factor N_{CB}, and the following parameters summarized in table 400 for OFDM signal spectrum definition can be defined as follows: the total number of occupied subcarriers: $N_{total} = 418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$; the number of pilot subcarriers: $N_{pilots} = 16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$. The number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of DC subcarriers, $N_{DC} = 3$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0046] In one embodiment, for a CB = 1, the N_{data} can be equal to 336, for a CB = 2, the N_{data} can be equal to 732, for a CB = 3, the N_{data} can be equal to 1134, and for a CB = 4, the N_{data} can be equal to 1536.

[0047] In one embodiment, for a CB = 1, the N_{pilots} can be equal to 16, for a CB = 2, the N_{pilots} can be equal to 38, for a CB = 3, the N_{pilots} can be equal to 54, and for a CB = 4, the N_{pilots} can be equal to 70.

[0048] In one embodiment, for a CB = 1, the N_{total} can be equal to 352, for a CB = 2, the N_{total} can be equal to 770, for a CB = 3, the N_{total} can be equal to 1188, and for a CB = 4, the N_{total} can be equal to 1606.

[0049] In one embodiment, for a CB = 1, the N_{DC} can be equal to 3, for a CB = 2, the N_{DC} can be equal to 3, for a CB = 3, the N_{DC} can be equal to 3, and for a CB = 4, the N_{DC} can be equal to 3.

[0050] In one embodiment, for a CB = 1, the N_L can be equal to 79, for a CB = 2, the N_L can be equal to 126, for a CB = 3, the N_L can be equal to 173, and for a CB = 4, the N_L can be equal to 220.

[0051] In one embodiment, for a CB = 1, the N_R can be equal to 78, for a CB = 2, the N_R can be equal to 125, for a CB = 3, the N_R can be equal to 172, and for a CB = 4, the N_R can be equal to 219.

[0052] In one embodiment, for a CB = 1, the frequency separation Δf can be equal to approximately 5.1563 MHz, for a CB = 2, the Δf can be equal to approximately 5.1563 MHz, for a CB = 3, the Δf can be equal to approximately 5.1563 MHz, and for a CB = 4, the Δf can be equal to approximately 5.1563 MHz.

[0053] FIG. 4B shows another example table showing OFDM signal spectrum parameters for channel bonding transmission, in accordance with example embodiments of the disclosure. In this embodiment, the number of DC subcarriers can be proportional to the channel bonding factor N_{CB}.

[0054] In one embodiment, the channel bonding factors are represented in table 401: that is, for CB = 1 in element 402, CB = 2 in element 404, CB = 3 in element 406, and CB = 4 in element 408. Further row 412 in table 400 represents the number of data subcarriers, row 414 represents the number of pilot subcarriers, row 416 represents the total number of occupied subcarriers, row 418 represents number of DC subcarriers, row 422 represents the number of left GB subcarriers, row 424 represents the number of right GB subcarriers, and row 426 represents the frequency separation between subcarriers.

[0055] With reference to FIG. 4B, as mentioned, in a second embodiment, the

number of DC subcarriers can be proportional to the channel bonding factor N_{CB}. In one embodiment, the following parameters and OFDM signal spectrum definition can be implemented: the total number of occupied subcarriers: $N_{total} = 416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$; the number of pilots: $N_{pilots} = 14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; $N_{DC} = 3+2*(N_{CB}-1)$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0056] In one embodiment, for a CB = 1, the N_{data} can be equal to 336, for a CB = 2, the N_{data} can be equal to 732, for a CB = 3, the N_{data} can be equal to 1134, and for a CB = 4, the N_{data} can be equal to 1536.

[0057] In one embodiment, for a CB = 1, the N_{pilots} can be equal to 16, for a CB = 2, the N_{pilots} can be equal to 36, for a CB = 3, the N_{pilots} can be equal to 50, and for a CB = 4, the N_{pilots} can be equal to 64.

[0058] In one embodiment, for a CB = 1, the N_{total} can be equal to 352, for a CB = 2, the N_{total} can be equal to 768, for a CB = 3, the N_{total} can be equal to 1184, and for a CB = 4, the N_{total} can be equal to 1600.

[0059] In one embodiment, for a CB = 1, the N_{DC} can be equal to 3, for a CB = 2, the N_{DC} can be equal to 5, for a CB = 3, the N_{DC} can be equal to 7, and for a CB = 4, the N_{DC} can be equal to 9.

[0060] In one embodiment, for a CB = 1, the N_L can be equal to 79, for a CB = 2, the N_L can be equal to 126, for a CB = 3, the N_L can be equal to 173, and for a CB = 4, the N_L can be equal to 220.

[0061] In one embodiment, for a CB = 1, the N_R can be equal to 78, for a CB = 2, the N_R can be equal to 125, for a CB = 3, the N_R can be equal to 172, and for a CB = 4, the N_R can be equal to 219.

[0062] In one embodiment, for a CB = 1, the frequency separation Δf can be equal to approximately 5.1563 MHz, for a CB = 2, the Δf can be equal to approximately 5.1563 MHz, for a CB = 3, the Δf can be equal to approximately 5.1563 MHz, and for a CB = 4, the Δf can be equal to approximately 5.1563 MHz.

[0063] Various embodiments may be implemented fully or partially in software and/or firmware. This software and/or firmware may take the form of instructions contained in or on a non-transitory computer-readable storage medium. Those instructions may then be read and executed by one or more processors to enable performance of the operations described herein. The instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing information in a form readable by one or more computers, such as but not limited to read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; a flash memory, etc.

[0064] FIG. 5 shows an example flow chart illustrating operation for a transmitting device used in connection with the spectrum definitions herein, in accordance with example embodiments of the disclosure.

[0065] In block 505, the device can determine data for transmission to a second device.

[0066] This determination of the data to send may be made, for example, based on a user input to the device, a predetermined schedule of data transmissions on the network, changes in network conditions, and the like.

[0067] In block 510, the device can determine a signal spectrum for a communication channel on a network, between the device and the second device.

[0068] In one embodiment, the network further comprises single input single output (SISO) transmission with channel bonding. In one embodiment, the signal spectrum comprises an orthogonal frequency-division multiplexing (OFDM) signal spectrum. In one embodiment, the OFDM signal spectrum comprises an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. In one embodiment, a number of occupied subcarriers in the OFDM signal spectrum is based at least in part on a channel bonding factor.

[0069] In block 515, the device can determine one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel.

[0070] In one embodiment, a number of occupied subcarriers is equal to $418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$; the number

of the one or more data subcarriers is equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to 3; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where N_{CB} = 2, 3, 4.

[0071] In one embodiment, a number of occupied subcarriers is equal to $416*N_{CB}$-64, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $14*N_{CB} + 8$, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to $3+2*(N_{CB}-1)$ where N_{CB} = 2, 3, 4; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where N_{CB} = 2, 3, 4.

[0072] In block 520, the device can establish the communication channel between the device and the second device based at least in part on the determined signal spectrum.

[0073] The establishment of the communications channels may further involve the transmission of one or more data packets (for example, one or more Request to Send (RTS)) to notify the second device to establish the communications channel. The establishment of the communications channels may be performed in accordance with one or more wireless and/or network standards.

[0074] In block 525, the device can send, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0075] In one embodiment, the data may be encapsulated in a data frame that is sent from the device to the second device. In one embodiment, the data may be sent at a predetermined time based at least in part on a predetermined schedule of communication between the devices of the network. In another embodiment, a first data may be first sent by the device, a period of time may elapse, and the device may repeat some or all of the procedures described in connection with any one or more of the previous blocks, and resend second data. In one embodiment during, or after the transmission of the data, the device may receive information from the receiving device, indicative of a change to be performed by the transmitting device in sending data and/or guard intervals. For example, the information may indicate to increase and/or decrease the amount of data transmitted, to retransmit one or more packets of data, to send one or more packets of data at a

predetermined time, and the like.

[0076] FIG. 6 shows an example flow chart illustrating operation for a receiving device used in connection with the spectrum definitions herein, in accordance with example embodiments of the disclosure.

[0077] In block 605, the device can receive data from a second device.

[0078] This reception of the data may be, for example, based on a user input to the device, a predetermined schedule of data transmissions on the network, changes in network conditions, and the like.

[0079] In block 610, the device can receive a signal spectrum for a communication channel on a network, between the device and the second device.

[0080] In one embodiment, the network further comprises single input single output (SISO) transmission with channel bonding. In one embodiment, the signal spectrum comprises an orthogonal frequency-division multiplexing (OFDM) signal spectrum. In one embodiment, the OFDM signal spectrum comprises an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. In one embodiment, a number of occupied subcarriers in the OFDM signal spectrum can be based at least in part on a channel bonding factor.

[0081] In block 615, the device can determine one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel.

[0082] In one embodiment, a number of occupied subcarriers is equal to $418*N_{CB}$-66, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $16*N_{CB}$ + 6, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to 3; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where N_{CB} = 2, 3, 4.

[0083] In one embodiment, a number of occupied subcarriers is equal to $416*N_{CB}$-64, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $14*N_{CB}$ + 8, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to $3+2*(N_{CB}-1)$ where N_{CB} = 2, 3, 4; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2,

3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$.

[0084] In block 620, the device can establish the communication channel between the device and the second device based at least in part on the determined signal spectrum.

[0085] The establishment of the communications channels may further involve the transmission of one or more data packets (for example, one or more Request to Send (RTS)) to notify the second device to establish the communications channel. The establishment of the communications channels may be performed in accordance with one or more wireless and/or network standards.

[0086] In block 625, the device can receive, from the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0087] In one embodiment, the data may be encapsulated in a data frame that is sent from the device to the second device. In one embodiment, the data may be sent at a predetermined time based at least in part on a predetermined schedule of communication between the devices of the network. In another embodiment, a first data may be first received by the device, a period of time may elapse, and the device may repeat some or all of the procedures described in connection with any one or more of the previous blocks, and receive second data. In one embodiment during, or after the transmission/reception of the data, the device may receive information from the transmitting device, indicative of a change to be performed by the receiving device in receiving data and/or guard intervals. For example, the information may indicateto retransmit one or more packets of data, to send one or more packets of data at a predetermined time, and the like.

[0088] FIG. 7 shows a functional diagram of an exemplary communication station 700 in accordance with some embodiments. In one embodiment, FIG. 7 illustrates a functional block diagram of a communication station that may be suitable for use as an AP 102 (FIG. 1) or communication station user device 120 (FIG. 1) in accordance with some embodiments. The communication station 700 may also be suitable for use as a handheld device, mobile device, cellular telephone, smartphone, tablet, netbook, wireless terminal, laptop computer, wearable computer device, femtocell, High Data Rate (HDR) subscriber station, access point, access terminal, or other personal communication system (PCS) device.

[0089] The communication station 700 may include communications circuitry 702 and a transceiver 710 for transmitting and receiving signals to and from other communication

stations using one or more antennas 701. The communications circuitry 702 may include circuitry that can operate the physical layer communications and/or medium access control (MAC) communications for controlling access to the wireless medium, and/or any other communications layers for transmitting and receiving signals. The communication station 700 may also include processing circuitry 706 and memory 708 arranged to perform the operations described herein. In some embodiments, the communications circuitry 702 and the processing circuitry 706 may be configured to perform operations detailed in FIGs. 1, 2, 3, 4A and 4B.

[0090] In accordance with some embodiments, the communications circuitry 702 may be arranged to contend for a wireless medium and configure frames or packets for communicating over the wireless medium. The communications circuitry 702 may be arranged to transmit and receive signals. The communications circuitry 702 may also include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 706 of the communication station 700 may include one or more processors. In other embodiments, two or more antennas 701 may be coupled to the communications circuitry 702 arranged for sending and receiving signals. The memory 708 may store information for configuring the processing circuitry 706 to perform operations for configuring and transmitting message frames and performing the various operations described herein. The memory 708 may include any type of memory, including non-transitory memory, for storing information in a form readable by a machine (e.g., a computer). For example, the memory 708 may include a computer-readable storage device may, read-only memory (ROM), random- access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices and other storage devices and media.

[0091] In some embodiments, the communication station 700 may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), a wearable computer device, or another device that may receive and/or transmit information wirelessly.

[0092] In some embodiments, the communication station 700 may include one or more antennas 701. The antennas 701 may include one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas, or other types of antennas suitable for transmission of RF signals. In some embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated for spatial diversity and the different channel characteristics that may result between each of the antennas and the antennas of a transmitting station.

[0093] In some embodiments, the communication station 700 may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0094] Although the communication station 700 is illustrated as having several separate functional elements, two or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may include one or more microprocessors, DSPs, field- programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio- frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of the communication station 700 may refer to one or more processes operating on one or more processing elements.

[0095] Certain embodiments may be implemented in one or a combination of hardware, firmware, and software. Other embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory memory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and

media. In some embodiments, the communication station 700 may include one or more processors and may be configured with instructions stored on a computer-readable storage device memory.

[0096] FIG. 8 illustrates a block diagram of an example of a machine 800 or system upon which any one or more of the techniques (e.g., methodologies) discussed herein may be performed. In other embodiments, the machine 800 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 800 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 800 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environments. The machine 1000 may be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, wearable computer device, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine, such as a base station. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), or other computer cluster configurations.

[0097] Examples, as described herein, may include or may operate on logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations when operating. A module includes hardware. In an example, the hardware may be specifically configured to carry out a specific operation (e.g., hardwired). In another example, the hardware may include configurable execution units (e.g., transistors, circuits, etc.) and a computer readable medium containing instructions where the instructions configure the execution units to carry out a specific operation when in operation. The configuring may occur under the direction of the executions units or a loading mechanism. Accordingly, the execution units are communicatively coupled to the computer-readable medium when the device is operating. In this example, the execution units may be a member of more than one module. For example, under operation, the execution units may be configured by a first set of instructions to implement a first module at one point in time and reconfigured by a second set of instructions to implement a second module at a second point in time.

[0098] The machine (e.g., computer system) 800 may include a hardware processor 802 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 1004 and a static memory 806, some or all of which may communicate with each other via an interlink (e.g., bus) 808. The machine 800 may further include a power management device 832, a graphics display device 810, an alphanumeric input device 812 (e.g., a keyboard), and a user interface (UI) navigation device 814 (e.g., a mouse). In an example, the graphics display device 810, alphanumeric input device 812, and UI navigation device 814 may be a touch screen display. The machine 800 may additionally include a storage device (i.e., drive unit) 816, a signal generation device 818 (e.g., a speaker), a signal spectrum device 819, a network interface device/transceiver 820 coupled to antenna(s) 830, and one or more sensors 828, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 800 may include an output controller 834, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate with or control one or more peripheral devices (e.g., a printer, card reader, etc.)).

[0099] The storage device 816 may include a machine readable medium 822 on which is stored one or more sets of data structures or instructions 824 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 824 may also reside, completely or at least partially, within the main memory 804, within the static memory 806, or within the hardware processor 802 during execution thereof by the machine 800. In an example, one or any combination of the hardware processor 802, the main memory 804, the static memory 806, or the storage device 816 may constitute machine-readable media.

[0100] The signal spectrum device 819 may be configured to determine, by the device, data for transmission to a second device; determine, by the device, a signal spectrum for a communication channel on a network, between the device and a second device; cause to establish, by the device, the communication channel between the device and a second device based at least in part on the determined signal spectrum; and cause to send, by the device, to the second device, the data. Further, the network can include Single Input Single Output (SISO) transmission with channel bonding. The signal spectrum can include orthogonal frequency-division multiplexing (OFDM) signal spectrum. The orthogonal frequency-division multiplexing (OFDM) signal spectrum can include an enhanced directional multi

gigabit (EDMG) OFDM signal spectrum. The OFDM signal spectrum can include one or more of a data subcarrier, a pilot subcarrier, a zero direct current (DC) subcarrier, and a zero guard band (GB) subcarrier. A number of occupied subcarriers in the OFDM signal spectrum can be based at least in part on one or more of the data subcarrier or the pilot subcarrier. It is understood that the above are only a subset of what the signal spectrum device 819 may be configured to perform and that other functions included throughout this disclosure may also be performed by the Guard Interval Device 819.

[0101] While the machine-readable medium 822 is illustrated as a single medium, the term "machine-readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 824.

[0102] The term “machine-readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 800 and that cause the machine 800 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding, or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories and optical and magnetic media. In an example, a massed machine-readable medium includes a machine-readable medium with a plurality of particles having resting mass. Specific examples of massed machine-readable media may include non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), or Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD- ROM disks.

[0103] The instructions 824 may further be transmitted or received over a communications network 826 using a transmission medium via the network interface device/transceiver 820 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communications networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards

known as WiMax®), IEEE 802.15.4 family of standards, and peer-to-peer (P2P) networks, among others. In an example, the network interface device/transceiver 820 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 826. In an example, the network interface device/transceiver 820 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding, or carrying instructions for execution by the machine 800 and includes digital or analog communications signals or other intangible media to facilitate communication of such software. The operations and processes described and shown above may be carried out or performed in any suitable order as desired in various implementations. Additionally, in certain implementations, at least a portion of the operations may be carried out in parallel. Furthermore, in certain implementations, less than or more than the operations described may be performed.

[0104] In one embodiment, this disclosure describes definitions and parameters for use in connection with an OFDM signal spectrum. In another embodiment, this disclosure extends the definitions and parameters for use in connection with an OFDM signal spectrum having channel bonding. In one embodiment, the number of data subcarriers, pilot subcarriers, direct current (DC) subcarriers, and guard band (GB) subcarriers for use in connection with an OFDM signal spectrum are described in this disclosure. Further, as mentioned, this disclosure describes OFDM signal spectrum definition for networks implementing single input single output (SISO) transmissions with channel bonding. The systems and methods described herein can be implemented, in some embodiments, with directional antennas, for example, phase antenna arrays (PAAs).

[0105] In one embodiment, for channel bonding used in connection with an EDMG OFDM spectrum, the subcarrier spacing can be used as the EDMG OFDM spectrum defined, for example, in one or more legacy standards (for example, with legacy 802.11ad standards). In one embodiment, such standards can specify a spectrum approximately equal to $\Delta f = 5.1563$ MHz. In one embodiment, the DFT size for use in connection with channel bonding can be defined as $512*N_{CB}$, where $N_{CB} = 2, 3, 4$ for 2, 3, and 4 channels accordingly. In one embodiment, the number of total occupied subcarriers for channel bonding can be defined in a way that edge spectrum subcarriers

(that is, subcarriers having a frequency on the edge of the spectrum) do not exceed the boundaries of another transmission in a nearby frequency range. In one embodiment, a center frequency for channel bonding transmission can be selected based at least in part on a number of factors, including, but not limited to, subcarrier spacing, channel bonding factor, and/or definitions and/or recommendations described by one or more standards. In one embodiment, the number of data subcarriers can be a predetermined number and can serve to support interleaving over the low-density parity-check (LDPC) codewords, for example, for higher order modulations. In one embodiment, low-density parity-check (LDPC) codes can refer to linear error correcting codes that can be used for transmitting a message over a noisy transmission channel.

[0106] In one embodiment, the number of DC subcarriers can be fixed, for example, at $N_{DC} = 3$, independent of the channel bonding factor being used for channel bonding. In another embodiment, the number of DC subcarriers can be modified based at least in part on the channel bonding factor N_{CB}; further, the remaining subcarriers (that is, the subcarriers that are not DC subcarriers) can be divided between the left and right guard bands (GBs).

[0107] In one embodiment, channel bonding can be performed; thereafter one or more GB subcarriers that have a frequency between the channels and DC subcarriers can be reused for the data subcarrier and/or pilot subcarrier transmission. In one embodiment, a predetermined number of extra subcarriers, for example, 66 extra subcarriers, can be used for channel bonding of two channels, 66*2=132 extra subcarriers can be used for channel bonding of three channels, and 66*3=198 subcarriers can be used for channel bonding of four channels. In various embodiments, a general formula for the total number of occupied subcarriers N_{total} can be written as: $N_{total} = 352 * N_{CB} + Ng * (N_{CB} - 1) = (352 + Ng) * N_{CB} – Ng$; where $Ng = 66$ and N_{CB} can be equal to 2, 3, or 4.

[0108] In one embodiment, the following parameters and OFDM signal spectrum definition can be implemented: the total number of occupied subcarriers: $N_{total} = 418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$; the number of pilot subcarriers: $N_{pilots} = 16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$. The number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of DC subcarriers, $N_{DC} = 3$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same

parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0109] In one embodiment, for a CB = 1, the N_{data} can be equal to 336, for a CB = 2, the N_{data} can be equal to 732, for a CB = 3, the N_{data} can be equal to 1134, and for a CB = 4, the N_{data} can be equal to 1536.In one embodiment, for a CB = 1, the N_{pilots} can be equal to 16, for a CB = 2, the N_{pilots} can be equal to 38, for a CB = 3, the N_{pilots} can be equal to 54, and for a CB = 4, the N_{pilots} can be equal to 70. In one embodiment, for a CB = 1, the N_{total} can be equal to 352, for a CB = 2, the N_{total} can be equal to 770, for a CB = 3, the N_{total} can be equal to 1188, and for a CB = 4, the N_{total} can be equal to 1606. In one embodiment, for a CB = 1, the N_{DC} can be equal to 3, for a CB = 2, the N_{DC} can be equal to 3, for a CB = 3, the N_{DC} can be equal to 3, and for a CB = 4, the N_{DC} can be equal to 3. In one embodiment, for a CB = 1, the N_L can be equal to 79, for a CB = 2, the N_L can be equal to 126, for a CB = 3, the N_L can be equal to 173, and for a CB = 4, the N_L can be equal to 220. In one embodiment, for a CB = 1, the N_R can be equal to 78, for a CB = 2, the N_R can be equal to 125, for a CB = 3, the N_R can be equal to 172, and for a CB = 4, the N_R can be equal to 219.

In one embodiment, for a CB = 1, the frequency separation Δf can be equal to approximately 5.1563 MHz, for a CB = 2, the Δf can be equal to approximately 5.1563 MHz, for a CB = 3, the Δf can be equal to approximately 5.1563 MHz, and for a CB = 4, the Δf can be equal to approximately 5.1563 MHz.

[0110] In an embodiment, the number of DC subcarriers can be based at least in part on the channel bonding factor N_{CB}. In one embodiment, the following parameters and OFDM signal spectrum definition can be implemented: the total number of occupied subcarriers: $N_{total} = 416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$; the number of pilots: $N_{pilots} = 14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of data subcarriers: $N_{data} = 402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; $N_{DC} = 3+2*(N_{CB}-1)$; the number of left GB subcarriers: $N_L = (94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; the number of right GB subcarriers: $N_R = (94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. In one embodiment, for $N_{CB} = 1$, the same parameters and OFDM signal spectrum definition can be used as described in one or more legacy standards (for example, an IEEE 802.11ad standard).

[0111] In one embodiment, for a CB = 1, the N_{data} can be equal to 336, for a CB = 2, the N_{data} can be equal to 732, for a CB = 3, the N_{data} can be equal to 1134, and for a CB = 4, the N_{data} can be equal to 1536. In one embodiment, for a CB = 1, the N_{pilots} can be

equal to 16, for a CB = 2, the N_{pilots} can be equal to 36, for a CB = 3, the N_{pilots} can be equal to 50, and for a CB = 4, the N_{pilots} can be equal to 64. In one embodiment, for a CB = 1, the N_{total} can be equal to 352, for a CB = 2, the N_{total} can be equal to 768, for a CB = 3, the N_{total} can be equal to 1184, and for a CB = 4, the N_{total} can be equal to 1600. In one embodiment, for a CB = 1, the N_{DC} can be equal to 3, for a CB = 2, the N_{DC} can be equal to 5, for a CB = 3, the N_{DC} can be equal to 7, and for a CB = 4, the N_{DC} can be equal to 9. In one embodiment, for a CB = 1, the N_L can be equal to 79, for a CB = 2, the N_L can be equal to 126, for a CB = 3, the N_L can be equal to 173, and for a CB = 4, the N_L can be equal to 220. In one embodiment, for a CB = 1, the N_R can be equal to 78, for a CB = 2, the N_R can be equal to 125, for a CB = 3, the N_R can be equal to 172, and for a CB = 4, the N_R can be equal to 219. In one embodiment, for a CB = 1, the frequency separation Δf can be equal to approximately 5.1563 MHz, for a CB = 2, the Δf can be equal to approximately 5.1563 MHz, for a CB = 3, the Δf can be equal to approximately 5.1563 MHz, and for a CB = 4, the Δf can be equal to approximately 5.1563 MHz.

[0112] According to example embodiments of the disclosure, there may be a device. The device may include memory and processing circuitry configured to determine, by the device, data for transmission to a second device; determine, by the device, a signal spectrum for a communication channel on a network, between the device and the second device; determine, by the device, one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel; cause to establish, by the device, the communication channel between the device and the second device based at least in part on the determined signal spectrum; and cause to send, by the device, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0113] The implementations may include one or more of the following features. The network may further comprise single input single output (SISO) transmission with channel bonding. The signal spectrum may comprise an orthogonal frequency-division multiplexing (OFDM) signal spectrum. The OFDM signal spectrum may comprise an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. A number of occupied subcarriers in the OFDM signal spectrum may be based at least in part on a channel bonding factor. A number of occupied subcarriers may be equal to $418*N_{CB}-66$, where N_{CB} = 2, 3, 4 and represents a

channel bonding factor; the number of the one or more pilot subcarriers may be equal to $16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers may be equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers may be equal to 3; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. A number of occupied subcarriers may be equal to $416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers may be equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers may be equal to $3+2*(N_{CB}-1)$ where $N_{CB} = 2, 3, 4$; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers may be equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. The device may further include a transceiver configured to transmit and receive wireless signals and an antenna coupled to the transceiver.

[0114] According to example embodiments of the disclosure, there may be a non-transitory computer-readable medium storing computer-executable instructions which, when executed by a processor, cause the processor to perform operations. The operations may include determining, by the processor, data for transmission by a first device to a second device; determining, by the processor, a signal spectrum for a communication channel on a network, between the device and the second device; determining, by the processor, one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel; causing to establish, by the processor, the communication channel between the device and the second device based at least in part on the determined signal spectrum; and causing to send, by the processor, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0115] The implementation may include one or more of the following features. The network may further comprise single input single output (SISO) transmission with channel bonding. The signal spectrum may comprise an orthogonal frequency-division multiplexing (OFDM) signal spectrum. The OFDM signal spectrum may comprise an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. A number of occupied subcarriers in the OFDM signal spectrum may be based at least in part on a channel bonding factor. A number

of occupied subcarriers may be equal to $418*N_{CB}$-66, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $16*N_{CB}$ + 6, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers may be equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers may be equal to 3; the number of left one or more GB subcarriers may be equal to ($94*N_{CB}$ + 64)/2, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers may be equal to ($94*N_{CB}$ + 62)/2, where N_{CB} = 2, 3, 4. A number of occupied subcarriers is equal to $416*N_{CB}$-64, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $14*N_{CB}$ + 8, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers may be equal to $402*N_{CB}$-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers may be equal to $3+2*(N_{CB}-1)$ where N_{CB} = 2, 3, 4; the number of left one or more GB subcarriers may be equal to ($94*N_{CB}$ + 64)/2, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers may be equal to ($94*N_{CB}$ + 62)/2, where N_{CB} = 2, 3, 4.

[0116] According to example embodiments there may be a method. The method may include determining data for transmission to a second device; determining a signal spectrum for a communication channel on a network, between the device and the second device; determining one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel; establishing the communication channel between the device and the second device based at least in part on the determined signal spectrum; and sending to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0117] The implementation may include one or more of the following features. The network may further comprise single input single output (SISO) transmission with channel bonding. The signal spectrum may comprise an orthogonal frequency-division multiplexing (OFDM) signal spectrum. The OFDM signal spectrum may comprise an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. A number of occupied subcarriers in the OFDM signal spectrum may be based at least in part on a channel bonding factor. A number of occupied subcarriers may be equal to $418*N_{CB}$-66, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $16*N_{CB}$ + 6, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers may be

equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers may be equal to 3; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers may be equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. A number of occupied subcarriers is equal to $416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers may be equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers may be equal to $3+2*(N_{CB}-1)$ where $N_{CB} = 2, 3, 4$; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers may be equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$.

[0118] According to example embodiments of the disclosure, there may be an apparatus. The apparatus may include means for determining data for transmission to a second device; means for determining a signal spectrum for a communication channel on a network, between the device and the second device; means for determining one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel;

[0119] means for establishing the communication channel between the device and the second device based at least in part on the determined signal spectrum; and means for sending to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

[0120] The implementation may include one or more of the following features. The network may further comprise single input single output (SISO) transmission with channel bonding. The signal spectrum may comprise an orthogonal frequency-division multiplexing (OFDM) signal spectrum. The OFDM signal spectrum may comprise an enhanced directional multi gigabit (EDMG) OFDM signal spectrum. A number of occupied subcarriers in the OFDM signal spectrum may be based at least in part on a channel bonding factor. A number of occupied subcarriers may be equal to $418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers may be equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers

may be equal to 3; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers may be equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$. A number of occupied subcarriers is equal to $416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers may be equal to $14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers may be equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers may be equal to $3+2*(N_{CB}-1)$ where $N_{CB} = 2, 3, 4$; the number of left one or more GB subcarriers may be equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers may be equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$.

[0121] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. The terms "computing device", "user device", "communication station", "station", "handheld device", "mobile device", "wireless device" and "user equipment" (UE) as used herein refers to a wireless communication device such as a cellular telephone, smartphone, tablet, netbook, wireless terminal, laptop computer, a femtocell, High Data Rate (HDR) subscriber station, access point, printer, point of sale device, access terminal, or other personal communication system (PCS) device. The device may be either mobile or stationary.

[0122] As used within this document, the term "communicate" is intended to include transmitting, or receiving, or both transmitting and receiving. This may be particularly useful in claims when describing the organization of data that is being transmitted by one device and received by another, but only the functionality of one of those devices is required to infringe the claim. Similarly, the bidirectional exchange of data between two devices (both devices transmit and receive during the exchange) may be described as 'communicating', when only the functionality of one of those devices is being claimed. The term "communicating" as used herein with respect to a wireless communication signal includes transmitting the wireless communication signal and/or receiving the wireless communication signal. For example, a wireless communication unit, which is capable of communicating a wireless communication signal, may include a wireless transmitter to transmit the wireless communication signal to at least one other wireless communication unit, and/or a wireless communication receiver to receive the wireless communication signal from at least one other wireless communication unit.

[0123] The term "access point" (AP) as used herein may be a fixed station. An access point may also be referred to as an access node, a base station, or some other similar terminology known in the art. An access terminal may also be called a mobile station, user equipment (UE), a wireless communication device, or some other similar terminology known in the art. Embodiments disclosed herein generally pertain to wireless networks. Some embodiments can relate to wireless networks that operate in accordance with one of the IEEE 802.11 standards.

[0124] Some embodiments may be used in conjunction with various devices and systems, for example, a Personal Computer (PC), a desktop computer, a mobile computer, a laptop computer, a notebook computer, a tablet computer, a server computer, a handheld computer, a handheld device, a Personal Digital Assistant (PDA) device, a handheld PDA device, an on-board device, an off-board device, a hybrid device, a vehicular device, a non-vehicular device, a mobile or portable device, a consumer device, a non-mobile or non-portable device, a wireless communication station, a wireless communication device, a wireless Access Point (AP), a wired or wireless router, a wired or wireless modem, a video device, an audio device, an audio-video (A/V) device, a wired or wireless network, a wireless area network, a Wireless Video Area Network (WVAN), a Local Area Network (LAN), a Wireless LAN (WLAN), a Personal Area Network (PAN), a Wireless PAN (WPAN), and the like.

[0125] Some embodiments may be used in conjunction with one way and/or two-way radio communication systems, cellular radio-telephone communication systems, a mobile phone, a cellular telephone, a wireless telephone, a Personal Communication Systems (PCS) device, a PDA device which incorporates a wireless communication device, a mobile or portable Global Positioning System (GPS) device, a device which incorporates a GPS receiver or transceiver or chip, a device which incorporates an RFID element or chip, a Multiple Input Multiple Output (MIMO) transceiver or device, a Single Input Multiple Output (SIMO) transceiver or device, a Multiple Input Single Output (MISO) transceiver or device, a device having one or more internal antennas and/or external antennas, Digital Video Broadcast (DVB) devices or systems, multi-standard radio devices or systems, a wired or wireless handheld device, e.g., a Smartphone, a Wireless Application Protocol (WAP) device, or the like.

[0126] Some embodiments may be used in conjunction with one or more types of wireless communication signals and/or systems following one or more wireless

communication protocols, for example, Radio Frequency (RF), Infra Red (IR), Frequency-Division Multiplexing (FDM), Orthogonal FDM (OFDM), Time-Division Multiplexing (TDM), Time-Division Multiple Access (TDMA), Extended TDMA (E-TDMA), General Packet Radio Service (GPRS), extended GPRS, Code-Division Multiple Access (CDMA), Wideband CDMA (WCDMA), CDMA 2000, single-carrier CDMA, multi-carrier CDMA, Multi-Carrier Modulation (MDM), Discrete Multi-Tone (DMT), Bluetooth®, Global Positioning System (GPS), Wi-Fi, Wi-Max, ZigBeeTM, Ultra-Wideband (UWB), Global System for Mobile communication (GSM), 2G, 2.5G, 3G, 3.5G, 4G, Fifth Generation (5G) mobile networks, 3GPP, Long Term Evolution (LTE), LTE advanced, Enhanced Data rates for GSM Evolution (EDGE), or the like. Other embodiments may be used in various other devices, systems, and/or networks.

[0127] Certain aspects of the disclosure are described above with reference to block and flow diagrams of systems, methods, apparatuses, and/or computer program products according to various implementations. It will be understood that one or more blocks of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and the flow diagrams, respectively, can be implemented by computer-executable program instructions. Likewise, some blocks of the block diagrams and flow diagrams may not necessarily need to be performed in the order presented, or may not necessarily need to be performed at all, according to some implementations.

[0128] These computer-executable program instructions may be loaded onto a special-purpose computer or other particular machine, a processor, or other programmable data processing apparatus to produce a particular machine, such that the instructions that execute on the computer, processor, or other programmable data processing apparatus create means for implementing one or more functions specified in the flow diagram block or blocks. These computer program instructions may also be stored in a computer-readable storage media or memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable storage media produce an article of manufacture including instruction means that implement one or more functions specified in the flow diagram block or blocks. As an example, certain implementations may provide for a computer program product, comprising a computer-readable storage medium having a computer-readable program code or program instructions implemented therein, said computer-readable program code adapted to be executed to implement one or more functions specified in the flow diagram block or blocks. The

computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational elements or steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide elements or steps for implementing the functions specified in the flow diagram block or blocks.

[0129] Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, can be implemented by special-purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special-purpose hardware and computer instructions.

[0130] Conditional language, such as, among others, "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain implementations could include, while other implementations do not include, certain features, elements, and/or operations. Thus, such conditional language is not generally intended to imply that features, elements, and/or operations are in any way required for one or more implementations or that one or more implementations necessarily include logic for deciding, with or without user input or prompting, whether these features, elements, and/or operations are included or are to be performed in any particular implementation.

[0131] Many modifications and other implementations of the disclosure set forth herein will be apparent having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the disclosure is not to be limited to the specific implementations disclosed and that modifications and other implementations are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

CLAIMS

What is claimed is:

1. A device, comprising:

at least one memory that stores computer-executable instructions; and

at least one processor of the one or more processors configured to access the at least one memory, wherein the at least one processor of the one or more processors is configured to execute the computer-executable instructions to:

determine, by the device, data for transmission to a second device;

determine, by the device, a signal spectrum for a communication channel on a network, between the device and the second device;

determine, by the device, one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel;

cause to establish, by the device, the communication channel between the device and the second device based at least in part on the determined signal spectrum; and

cause to send, by the device, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

2. The device of claim 1, wherein the network further comprises single input single output (SISO) transmission with channel bonding.

3. The device of claim 1, wherein the signal spectrum comprises an orthogonal frequency-division multiplexing (OFDM) signal spectrum.

4. The device of claim 3, wherein the OFDM signal spectrum comprises an enhanced directional multi gigabit (EDMG) OFDM signal spectrum.

5. The device of claim 3, wherein a number of occupied subcarriers in the OFDM signal spectrum is based at least in part on a channel bonding factor.

6. The device of claim 1, wherein a number of occupied subcarriers is equal to

418*N_{CB}-66, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to 16*N_{CB} + 6, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to 402*N_{CB}-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to 3; the number of left one or more GB subcarriers is equal to (94*N_{CB} + 64)/2, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to (94*N_{CB} + 62)/2, where N_{CB} = 2, 3, 4.

7. The device of claim 1, wherein a number of occupied subcarriers is equal to 416*N_{CB}-64, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to 14*N_{CB} + 8, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to 402*N_{CB}-72, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to 3+2*(N_{CB}-1) where N_{CB} = 2, 3, 4; the number of left one or more GB subcarriers is equal to (94*N_{CB} + 64)/2, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to (94*N_{CB} + 62)/2, where N_{CB} = 2, 3, 4.

8. The device of claim 1, further comprising a transceiver configured to transmit and receive wireless signals and an antenna coupled to the transceiver.

9. A non-transitory computer-readable medium storing computer-executable instructions which, when executed by a processor, cause the processor to perform operations comprising:

determine, by the processor, data for transmission by a first device to a second device;

determine, by the processor, a signal spectrum for a communication channel on a network, between the device and the second device;

determine, by the processor, one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel;

cause to establish, by the processor, the communication channel between the device and the second device based at least in part on the determined signal spectrum;

and

cause to send, by the processor, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

10. The non-transitory computer-readable medium of claim 9, wherein the network further comprises single input single output (SISO) transmission with channel bonding.

11. The non-transitory computer-readable medium of claim 9, wherein the signal spectrum comprises an orthogonal frequency-division multiplexing (OFDM) signal spectrum.

12. The non-transitory computer-readable medium of claim 11, wherein the OFDM signal spectrum comprises an enhanced directional multi gigabit (EDMG) OFDM signal spectrum.

13. The non-transitory computer-readable medium of claim 11, wherein a number of occupied subcarriers in the OFDM signal spectrum is based at least in part on a channel bonding factor.

14. The non-transitory computer-readable medium of claim 9, wherein a number of occupied subcarriers is equal to $418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers is equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers is equal to 3; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$.

15. The non-transitory computer-readable medium of claim 9, wherein a number of occupied subcarriers is equal to $416*N_{CB}-64$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $14*N_{CB} + 8$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers is equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers is equal to $3+2*(N_{CB}-1)$ where $N_{CB} = 2, 3, 4$; the number of left one or

more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where $N_{CB} = 2, 3, 4$; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where $N_{CB} = 2, 3, 4$.

16. A method, comprising:

determine data for transmission to a second device;

determine a signal spectrum for a communication channel on a network, between the device and the second device;

determine one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel;

establish the communication channel between the device and the second device based at least in part on the determined signal spectrum; and

send to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel.

17. The method of claim 16, wherein the network further comprises single input single output (SISO) transmission with channel bonding.

18. The method of claim 16, wherein the signal spectrum comprises an orthogonal frequency-division multiplexing (OFDM) signal spectrum.

19. The method of claim 18, wherein the OFDM signal spectrum comprises an enhanced directional multi gigabit (EDMG) OFDM signal spectrum.

20. The method of claim 18, wherein a number of occupied subcarriers in the OFDM signal spectrum is based at least in part on a channel bonding factor.

21. The method of claim 16, wherein a number of occupied subcarriers is equal to $418*N_{CB}-66$, where $N_{CB} = 2, 3, 4$ and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $16*N_{CB} + 6$, where $N_{CB} = 2, 3, 4$; the number of the one or more data subcarriers is equal to $402*N_{CB}-72$, where $N_{CB} = 2, 3, 4$; the number of the one or more DC subcarriers is equal to 3; the

number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where N_{CB} = 2, 3, 4.

22. The method of claim 16, wherein a number of occupied subcarriers is equal to $416*N_{CB}-64$, where N_{CB} = 2, 3, 4 and represents a channel bonding factor; the number of the one or more pilot subcarriers is equal to $14*N_{CB} + 8$, where N_{CB} = 2, 3, 4; the number of the one or more data subcarriers is equal to $402*N_{CB}-72$, where N_{CB} = 2, 3, 4; the number of the one or more DC subcarriers is equal to $3+2*(N_{CB}-1)$ where N_{CB} = 2, 3, 4; the number of left one or more GB subcarriers is equal to $(94*N_{CB} + 64)/2$, where N_{CB} = 2, 3, 4; and the number of right one or more GB subcarriers is equal to $(94*N_{CB} + 62)/2$, where N_{CB} = 2, 3, 4.

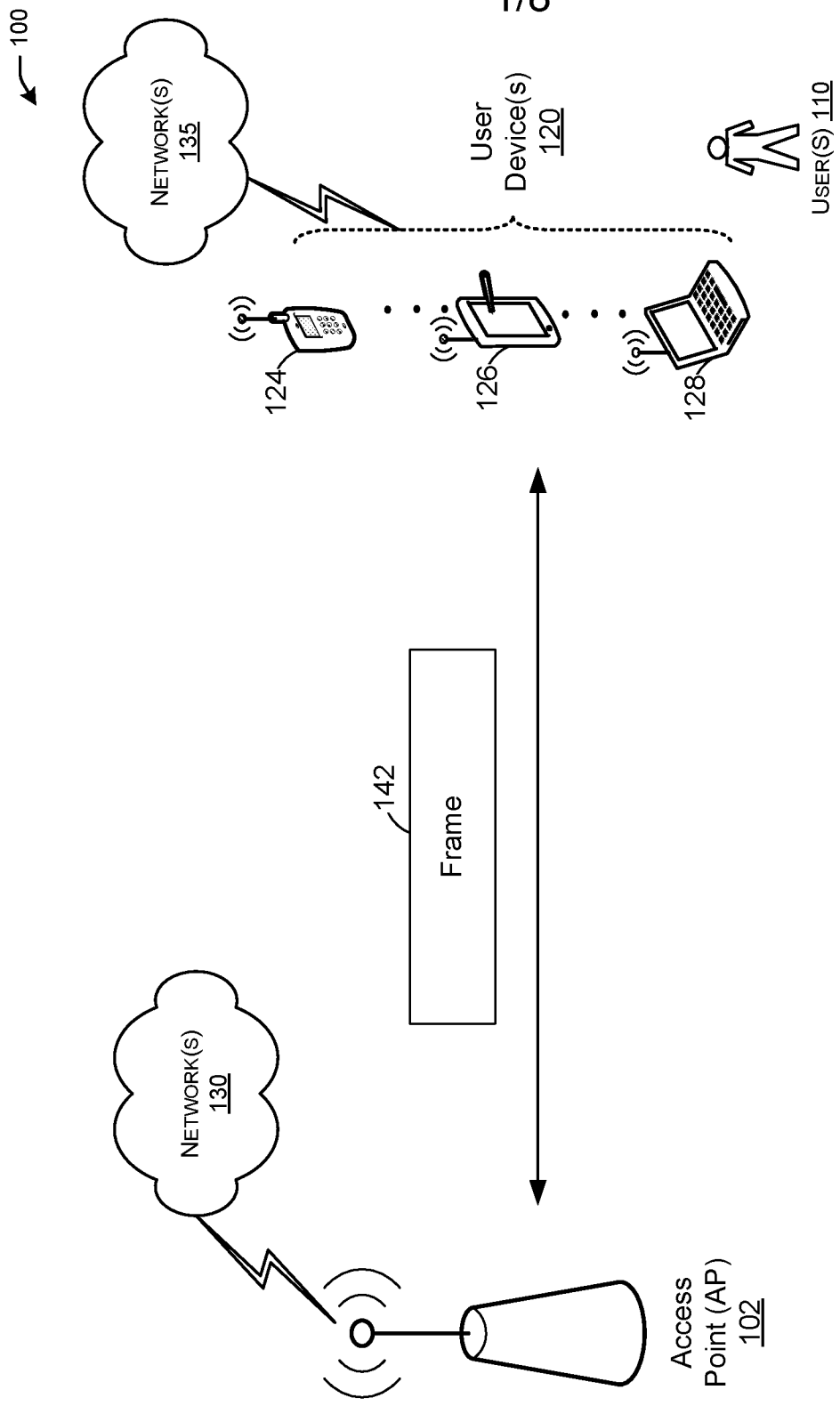

100
NETWORK(S)
135
User
Device(s)
120
USER(S) 110
124
126
128
142
Frame
NETWORK(S)
130
Access
Point (AP)
102

FIG. 1

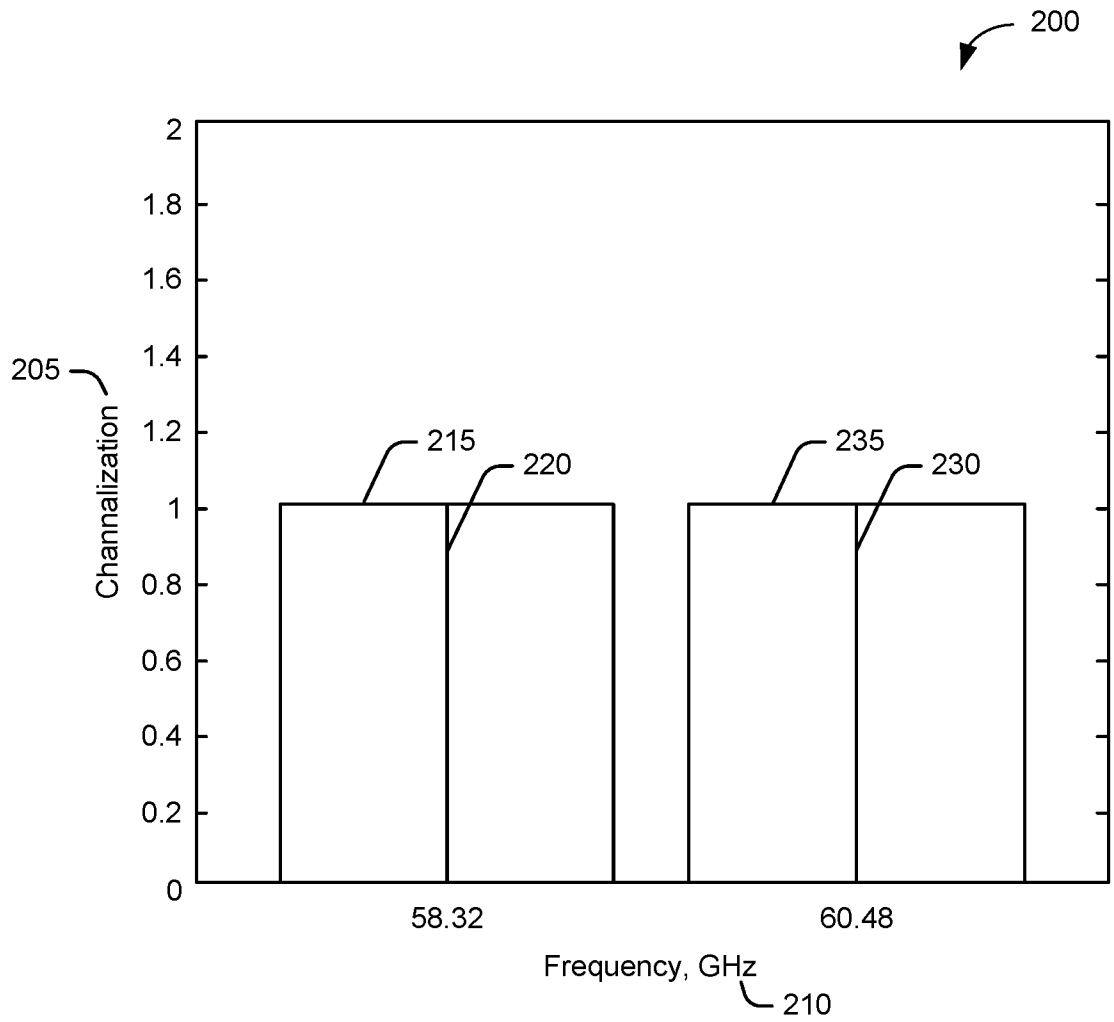

200
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
205
Channalization
215
220
235
230
58.32
60.48
Frequency, GHz
210

FIG. 2

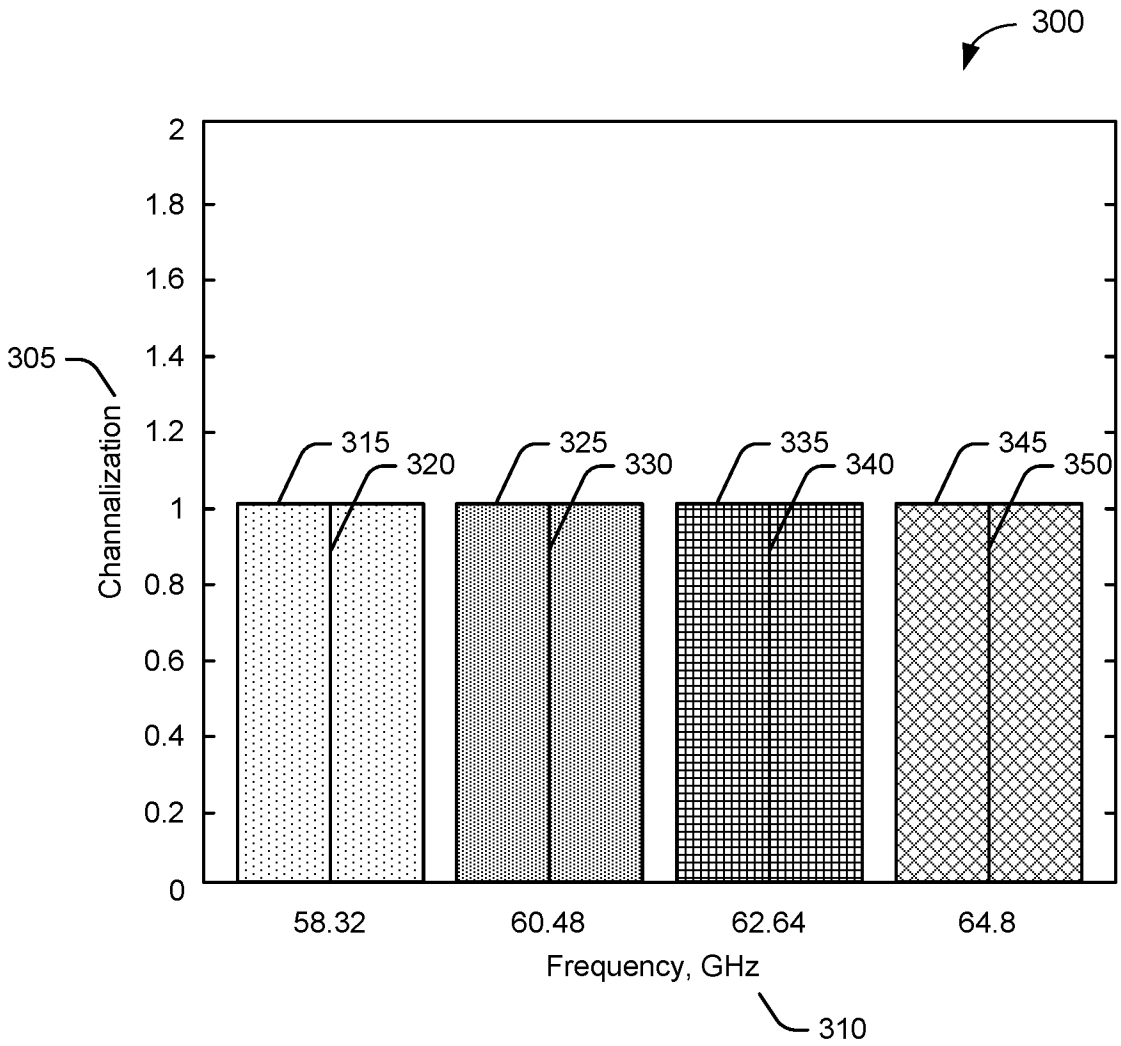
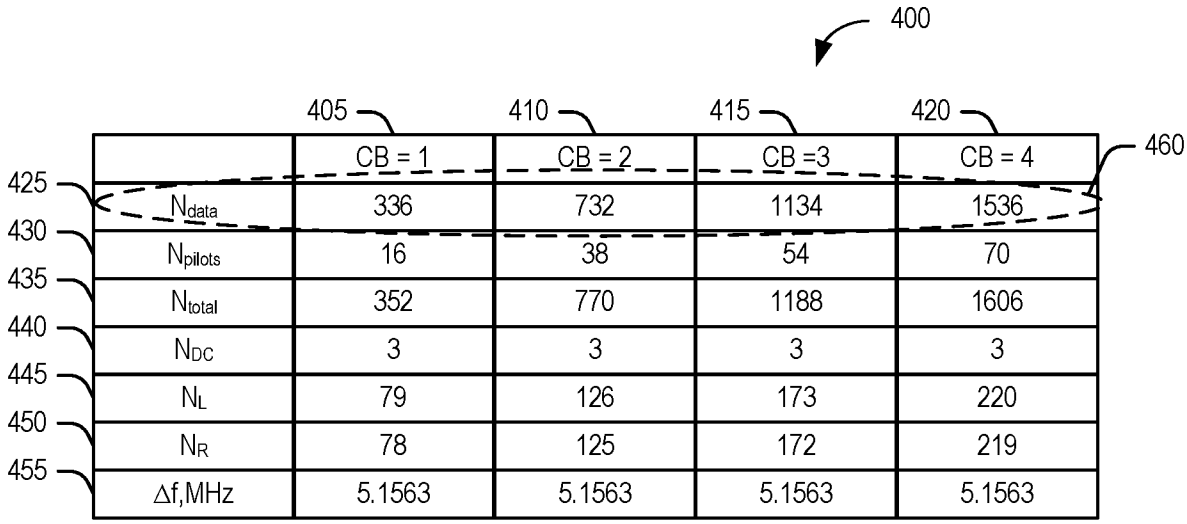
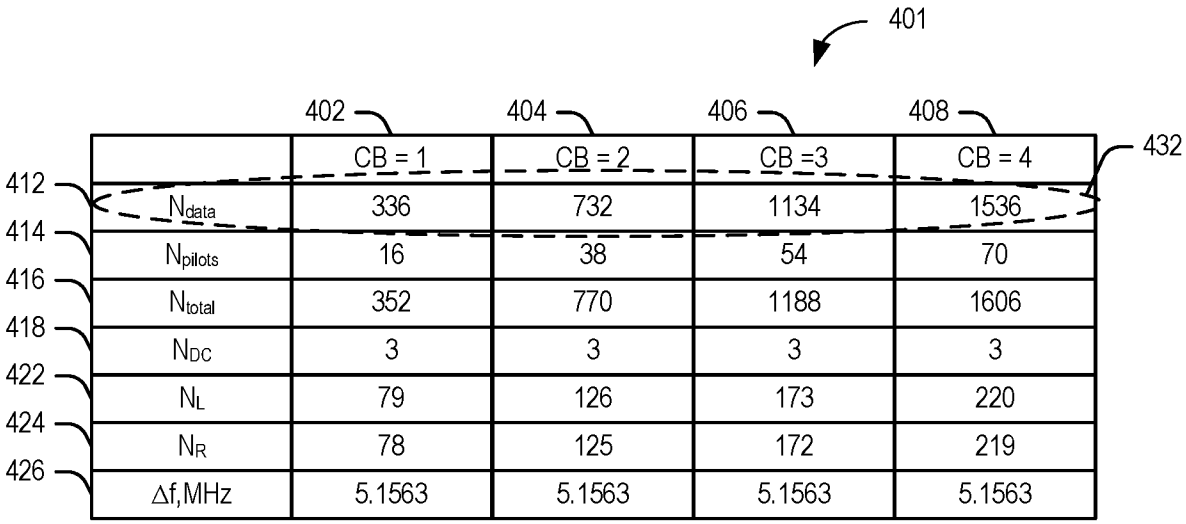

300
305
Channalization
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
315
320
325
330
335
340
345
350
58.32
60.48
62.64
64.8
Frequency, GHz
310

FIG. 3



	CB = 1	CB = 2	CB =3	CB = 4
N_{data}	336	732	1134	1536
N_{pilots}	16	38	54	70
N_{total}	352	770	1188	1606
N_{DC}	3	3	3	3
N_L	79	126	173	220
N_R	78	125	172	219
Δf,MHz	5.1563	5.1563	5.1563	5.1563

FIG. 4A



	CB = 1	CB = 2	CB =3	CB = 4
N_{data}	336	732	1134	1536
N_{pilots}	16	38	54	70
N_{total}	352	770	1188	1606
N_{DC}	3	3	3	3
N_L	79	126	173	220
N_R	78	125	172	219
Δf,MHz	5.1563	5.1563	5.1563	5.1563

FIG. 4B

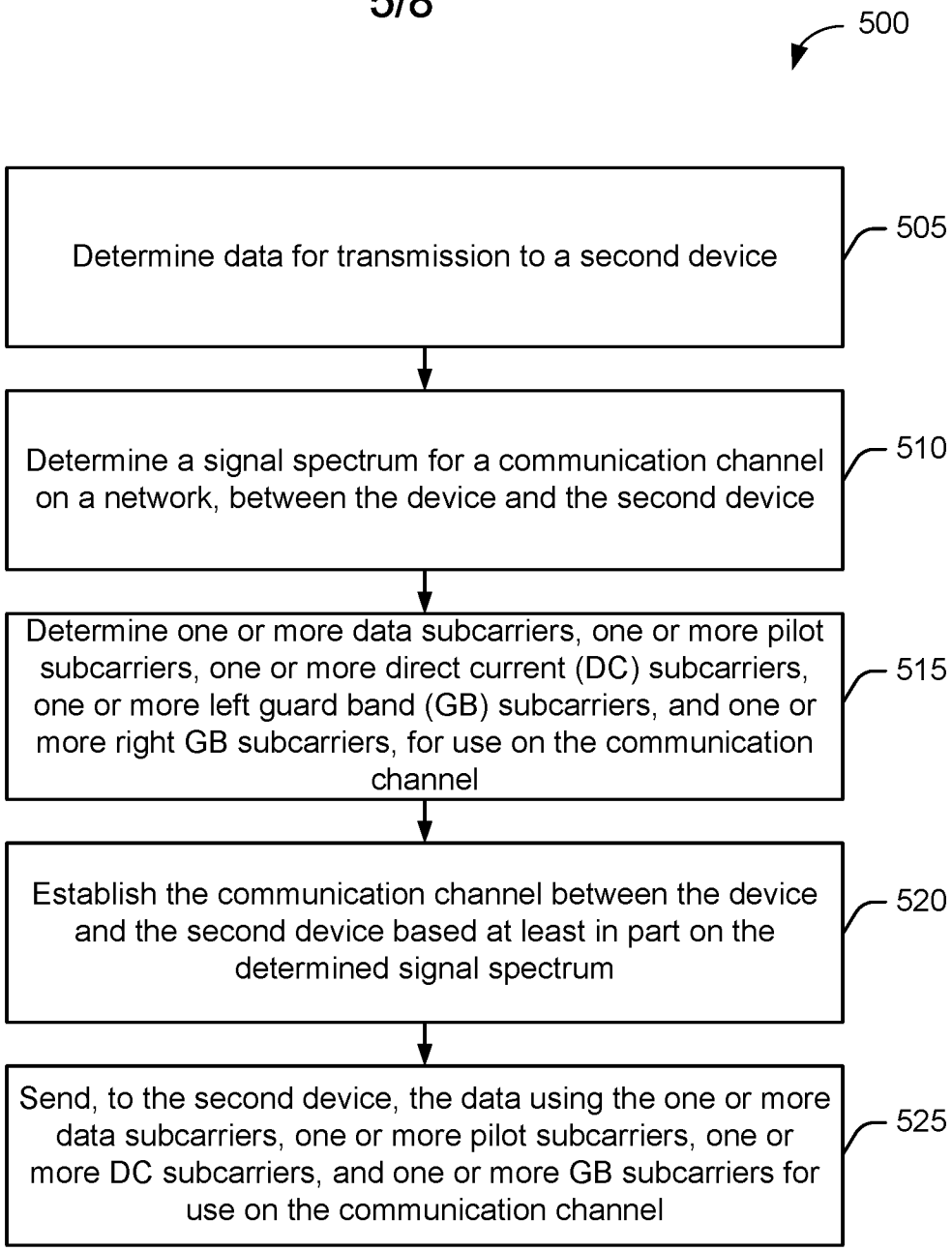

500
Determine data for transmission to a second device
505
Determine a signal spectrum for a communication channel on a network, between the device and the second device
510
Determine one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel
515
Establish the communication channel between the device and the second device based at least in part on the determined signal spectrum
520
Send, to the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel
525

FIG. 5

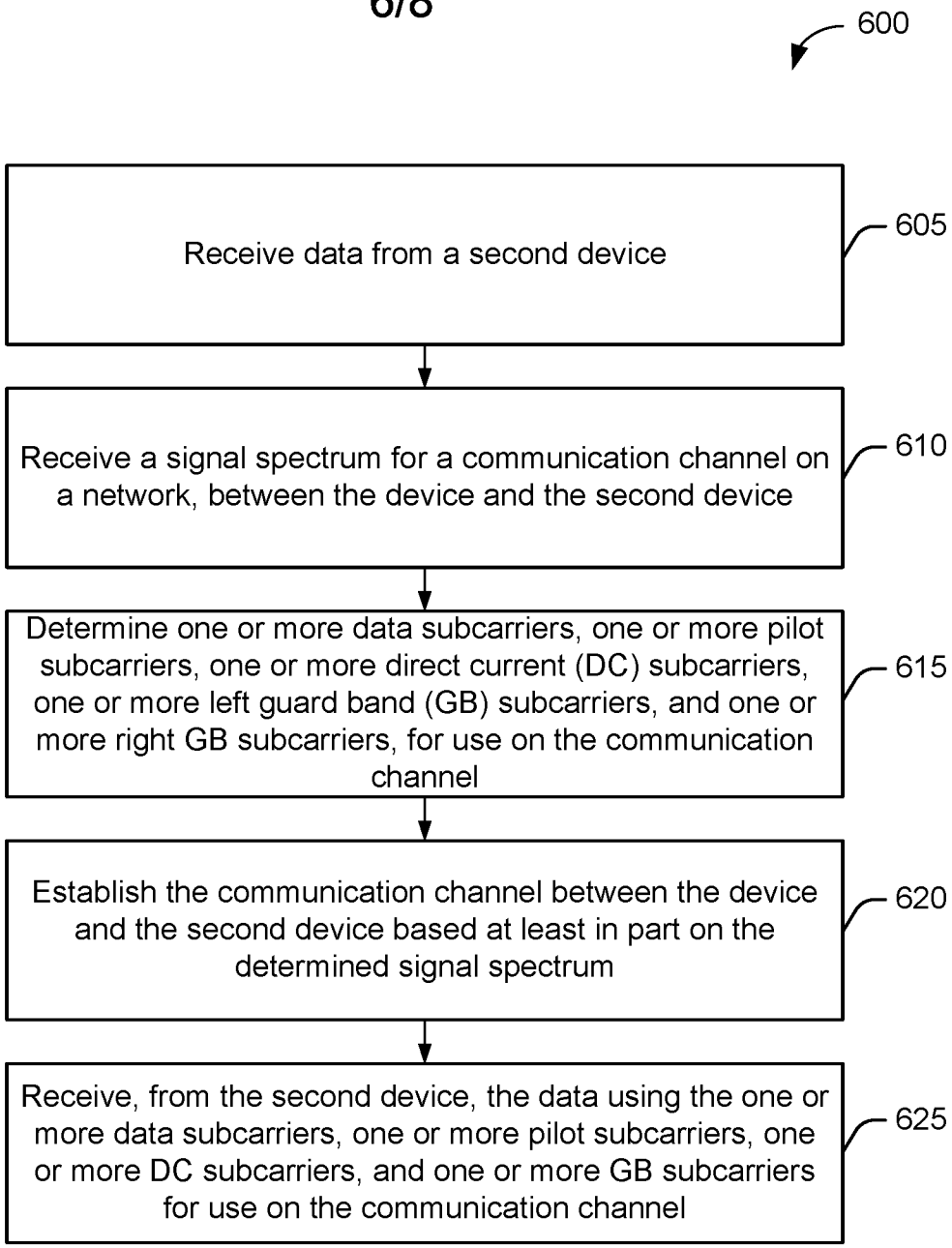

600
Receive data from a second device
605
Receive a signal spectrum for a communication channel on a network, between the device and the second device
610
Determine one or more data subcarriers, one or more pilot subcarriers, one or more direct current (DC) subcarriers, one or more left guard band (GB) subcarriers, and one or more right GB subcarriers, for use on the communication channel
615
Establish the communication channel between the device and the second device based at least in part on the determined signal spectrum
620
Receive, from the second device, the data using the one or more data subcarriers, one or more pilot subcarriers, one or more DC subcarriers, and one or more GB subcarriers for use on the communication channel
625

FIG. 6

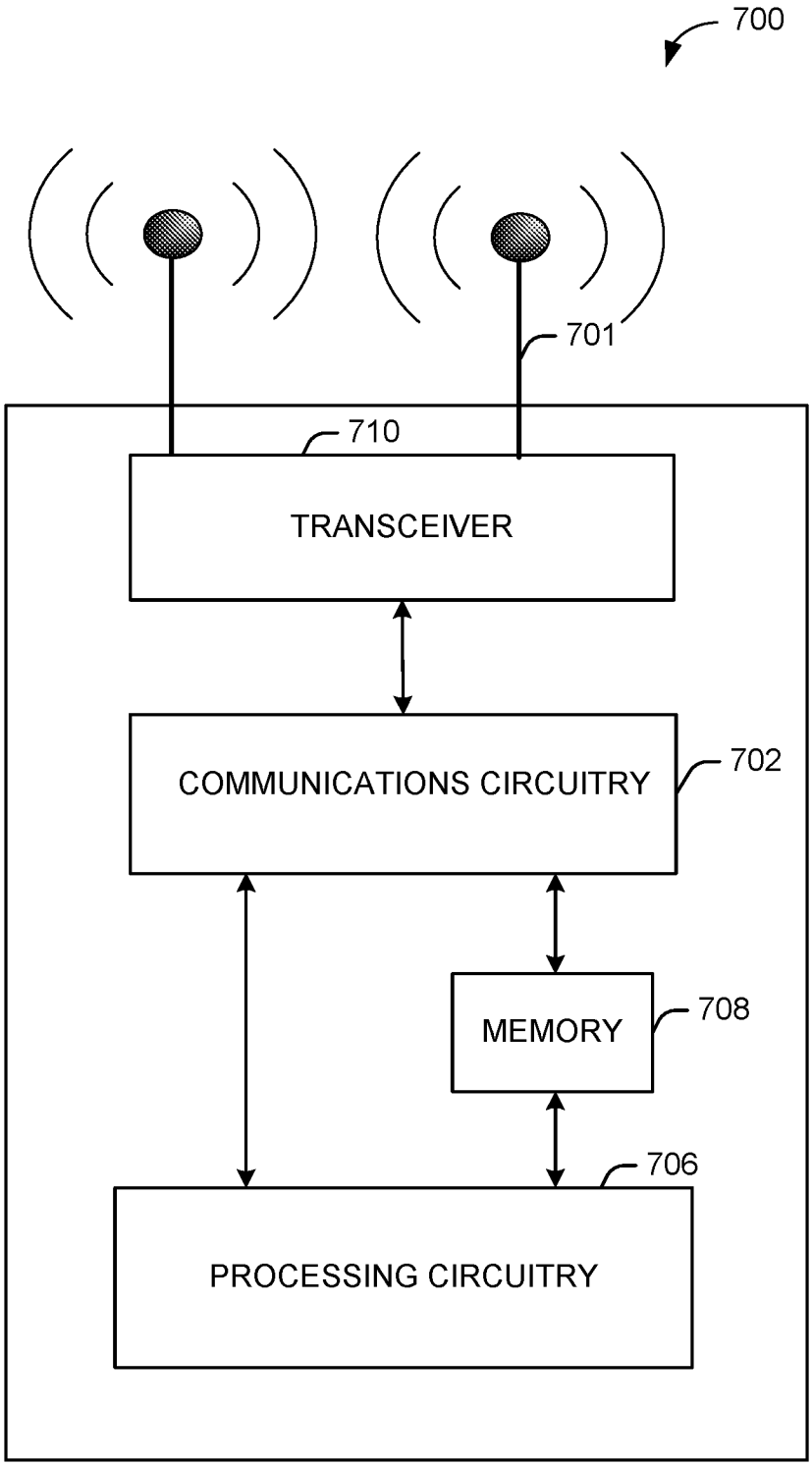

700
701
710
TRANSCEIVER
COMMUNICATIONS CIRCUITRY
702
MEMORY
708
706
PROCESSING CIRCUITRY

FIG. 7

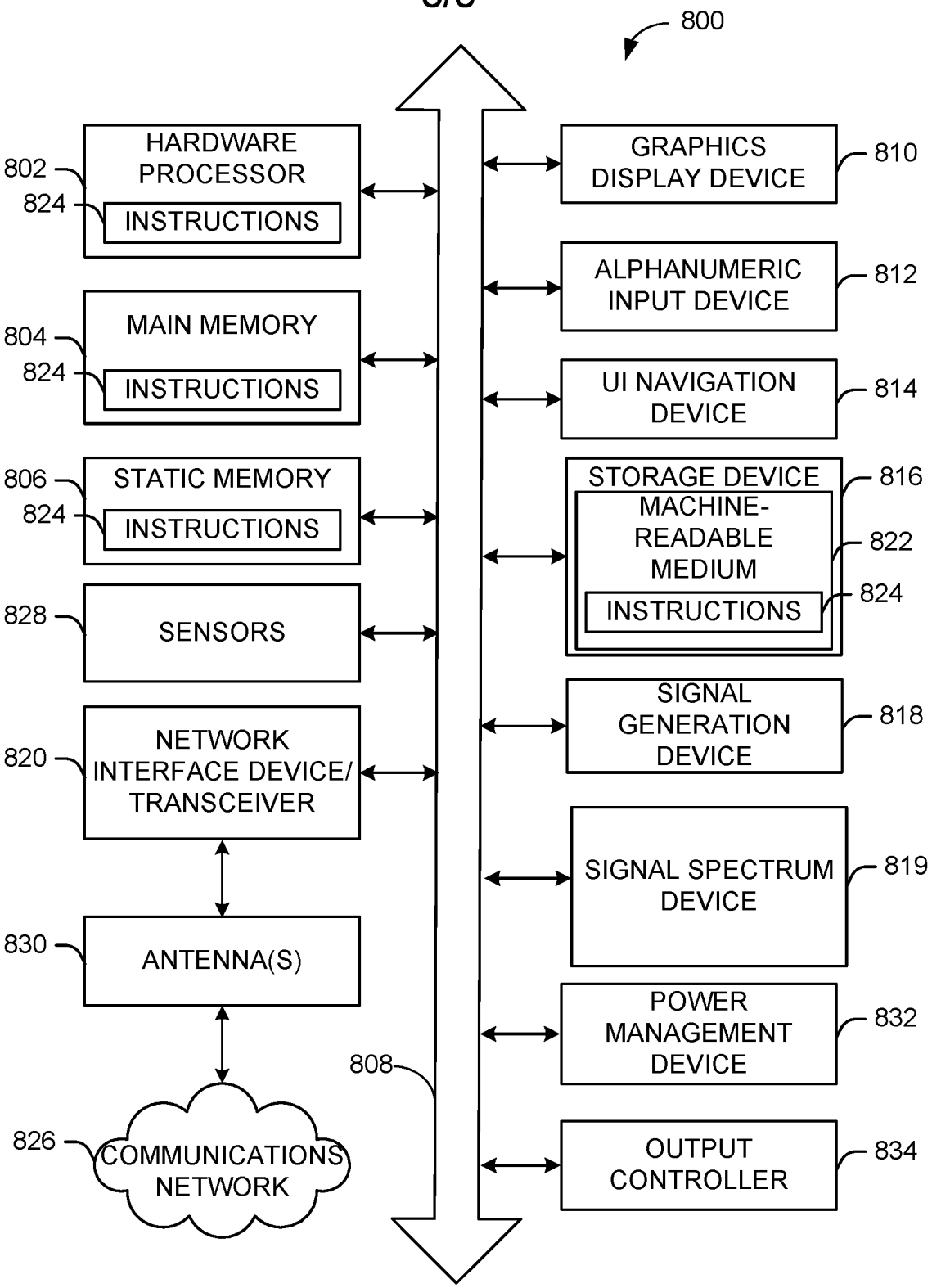

800
HARDWARE PROCESSOR
802
824
INSTRUCTIONS
MAIN MEMORY
804
824
INSTRUCTIONS
STATIC MEMORY
806
824
INSTRUCTIONS
828
SENSORS
NETWORK INTERFACE DEVICE/ TRANSCEIVER
820
830
ANTENNA(S)
826
COMMUNICATIONS NETWORK
808
GRAPHICS DISPLAY DEVICE
810
ALPHANUMERIC INPUT DEVICE
812
UI NAVIGATION DEVICE
814
STORAGE DEVICE
816
MACHINE-READABLE MEDIUM
822
INSTRUCTIONS
824
SIGNAL GENERATION DEVICE
818
SIGNAL SPECTRUM DEVICE
819
POWER MANAGEMENT DEVICE
832
OUTPUT CONTROLLER
834

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/040085

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/26(2006.01)i, H04L 5/00(2006.01)i

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 27/26; H04L 5/00; H04J 1/00; H04W 56/00; H04W 74/06; H04L 27/20; H04W 72/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: signal spectrum, subcarrier, direct current, guard band

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013-0070623 A1 (JIN YOUNG CHUN et al.) 21 March 2013 See paragraphs [0045], [0088]; and figure 11.	1-22
A	US 2016-0057736 A1 (SAMSUNG ELECTRONICS CO., LTD.) 25 February 2016 See paragraphs [0538], [0541]; claim 1; and figure 38.	1-22
A	US 2015-0271814 A1 (LG ELECTRONICS INC.) 24 September 2015 See paragraphs [0053]-[0164]; and figures 1-20.	1-22
A	US 2016-0249332 A1 (HUAWEI TECHNOLOGIES CO., LTD.) 25 August 2016 See paragraphs [0026]-[0097]; and figures 1-16.	1-22
A	US 2013-0089067 A1 (SAMSUNG ELECTRONICS CO., LTD.) 11 April 2013 See paragraphs [0046]-[0137]; and figures 1A-15.	1-22

☐ 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
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 October 2017 (26.10.2017)	**26 October 2017 (26.10.2017)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
LEE, Dal Kyong
Telephone No. +82-42-481-8440

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/040085

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013-0070623 A1	21/03/2013	KR 10-1751060 B1	28/06/2017
		KR 10-2011-0070795 A	24/06/2011
		US 8867393 B2	21/10/2014
		WO 2011-074895 A2	23/06/2011
		WO 2011-074895 A3	27/10/2011
US 2016-0057736 A1	25/02/2016	KR 10-2016-0023519 A	03/03/2016
		WO 2016-028130 A1	25/02/2016
US 2015-0271814 A1	24/09/2015	US 9554381 B2	24/01/2017
		WO 2014-046516 A1	27/03/2014
US 2016-0249332 A1	25/08/2016	US 2016-0241425 A1	18/08/2016
		WO 2016-130970 A1	18/08/2016
		WO 2016-130987 A1	18/08/2016
US 2013-0089067 A1	11/04/2013	EP 2764745 A1	13/08/2014
		KR 10-2013-0037507 A	16/04/2013
		US 8964689 B2	24/02/2015
		WO 2013-051907 A1	11/04/2013