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(54) Title: DISTRIBUTING MULTIPLE-INPUT, MULTIPLE-OUTPUT (MIMO) COMMUNICATIONS STREAMS TO REMOTE UNITS IN A DISTRIBUTED COMMUNICATION SYSTEM (DCS) TO SUPPORT CONFIGURATION OF INTERLEAVED MIMO COMMUNICATIONS SERVICES

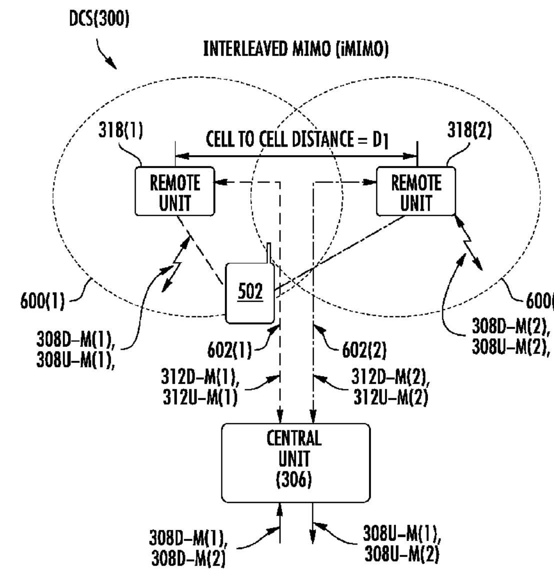

FIG. 6

(57) Abstract: Distributed communications systems (DCSs) supporting configuring or reconfiguring the distribution of MIMO communications streams to designated remote units in the DCS to provide interleaved MIMO cell bonding of remote units are disclosed. In one example, the DCS includes different physical layers that are maintained from the central unit to the remote units. In this manner, the central unit can be configured or reconfigured to distribute separate MIMO communications streams to the desired physical layers in the DCS to support distributing MIMO communications streams to the desired remote units to provide the desired interleaved MIMO communications services. In this manner, interleaved MIMO communications services can be configured for a DCS using an existing infrastructure of remote units having substantially non-overlapping remote coverage areas, by directing the MIMO communications

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streams over the configured physical layers to be provided to the desired remote units to facilitate interleaved MIMO cell bonding of remote units.

DISTRIBUTING MULTIPLE-INPUT, MULTIPLE-OUTPUT (MIMO) COMMUNICATIONS STREAMS TO REMOTE UNITS IN A DISTRIBUTED COMMUNICATION SYSTEM (DCS) TO SUPPORT CONFIGURATION OF INTERLEAVED MIMO COMMUNICATIONS SERVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. App. No. 15/689,629, filed August 29, 2017, which priority under 35 U.S.C. § 119 of U.S. Provisional App. No. 62/513,045 filed on May 31, 2017, and Provisional App. No. 62/513,051, filed on May 31, 2017, the contents of which are relied upon and incorporated herein by reference in their entireties.

BACKGROUND

[0002] The disclosure relates generally to distributed communications systems (DCSs), such as distributed antenna systems (DAS) for example, capable of distributing wireless radio-frequency (RF) communications services over wired communications mediums to remote units to provide remote communications coverage areas for distributing the RF communications services to wireless client devices.

[0003] Wireless customers are increasingly demanding wireless communications services, such as cellular communications services and Wi-Fi services. Thus, small cells, and more recently Wi-Fi services, are being deployed indoors. At the same time, some wireless customers use their wireless communication devices in areas that are poorly serviced by conventional cellular networks, such as inside certain buildings or areas where there is little cellular coverage. One response to the intersection of these two concerns has been the use of wireless distributed communications systems (DCSs), such as distributed antenna systems (DASs). DASs include remote antenna units (RAUs) configured to receive and transmit communications signals to client devices within the antenna range of the RAUs. DASs can be particularly useful when deployed inside buildings or other indoor environments where the wireless communication devices may not otherwise be able to effectively receive radio frequency (RF) signals from a source.

[0004] In this regard, **FIG. 1** illustrates a wireless DCS **100** that is configured to distribute communications services to remote coverage areas **102(1)-102(N)**, where 'N' is the number of remote coverage areas. The wireless DCS **100** in **FIG. 1** is provided in the form of a DAS **104**. The DAS **104** can be configured to support a variety of communications services that can include cellular communications services, wireless communications services, such as RF identification (RFID) tracking, Wireless Fidelity (Wi-Fi), local area network (LAN), and wireless LAN (WLAN), wireless solutions (Bluetooth, Wi-Fi Global Positioning System (GPS) signal-based, and others) for location-based services, and combinations thereof, as examples. The remote coverage areas **102(1)-102(N)** are created by and centered on remote units **106(1)-106(N)** communicatively coupled to a central unit **108** (e.g., a head-end controller, a central unit, or a head-end unit). The central unit **108** may be communicatively coupled to a source transceiver **110**, such as for example, a base transceiver station (BTS) or a baseband unit (BBU). In this regard, the central unit **108** receives downlink communications signals **112D** from the source transceiver **110** to be distributed to the remote units **106(1)-106(N)**. The downlink communications signals **112D** can include data communications signals and/or communication signaling signals, as examples. The central unit **108** is configured with filtering circuits and/or other signal processing circuits that are configured to support a specific number of communications services in a particular frequency bandwidth (i.e., frequency communications bands). The downlink communications signals **112D** are communicated by the central unit **108** over a communications link **114** over their frequency to the remote units **106(1)-106(N)**.

[0005] With continuing reference to **FIG. 1**, the remote units **106(1)-106(N)** are configured to receive the downlink communications signals **112D** from the central unit **108** over respective communications links **114(1)-114(N)**. The downlink communications signals **112D** are configured to be distributed to the respective remote coverage areas **102(1)-102(N)** of the remote units **106(1)-106(N)**. The remote units **106(1)-106(N)** are also configured with filters and other signal processing circuits that are configured to support all or a subset of the specific communications services (i.e., frequency communications bands) supported by the central unit **108**. In a non-limiting example, the communications links **114(1)-114(N)** may be a wired communications link, a wireless communications link, or an optical fiber-based communications link. Each of the remote units **106(1)-106(N)** may include an RF transmitter/receiver **116(1)-116(N)** and a respective antenna **118(1)-118(N)** operably connected to the RF transmitter/receiver **116(1)-116(N)** to wirelessly distribute the communications services to a wireless client device **120** within the respective remote coverage areas **102(1)-102(N)**. The remote units **106(1)-106(N)** are also configured to receive uplink communications signals **112U** from the wireless client device **120** in the respective remote coverage areas **102(1)-102(N)** to be distributed to the source transceiver **110**.

[0006] One problem that can exist with wireless communication systems, including the system **100** in **FIG. 1**, is the multi-path (fading) nature of signal propagation. This simply means that local maxima and minima of desired signals can exist over a picocell coverage area. A receiver antenna located at a maximum location will have better performance or signal-to-noise ratio (SNR) than a receiver antenna located in a minimum position. Signal processing techniques can be employed to improve the SNR of wireless data transmission in such wireless communication systems. For example, spatial diversity can be utilized in instances involving many access points. Other signal processing techniques include multiple-input, multiple-output (MIMO) techniques for increasing bit rates or beam forming for SNR, or wireless distance improvement. MIMO is the use of multiple antennas at both a transmitter and receiver to increase data throughput and link range without additional bandwidth or increased transmit power. MIMO technology can be employed in DASs to increase the bandwidth up to twice the nominal bandwidth.

[0007] Even with the potential doubling of bandwidth in a DCS employing MIMO technology, a client device must still be within range of two MIMO antennas to realize the full benefits of increased bandwidth of MIMO technology. Ensuring uniform MIMO coverage may be particularly important for newer cellular standards, such as Long Term Evolution (LTE), where increased bandwidth requirements are expected by users of client devices in all coverage areas.

[0008] MIMO communications services require at least two (2) communications streams being distributed in a given coverage area. For example, to provide MIMO communications services in the DAS **104** in **FIG. 1**, remote units **106(1)-106(N)** in the DAS **104** can be co-located. For example, **FIG. 2** illustrates the DAS **104** in **FIG. 1** with co-located remote units **106(1), 106(2)** and co-located remote units **106(3), 106(4)**. The co-located remote units **106(1), 106(2)** are separated a distance $\mathbf{D_1}$ from the other co-located remote units **106(3), 106(4)** such that two distinct MIMO coverage areas **204(1), 204(2)** are formed by the respective co-located remote units **106(1), 106(2)** and co-located remote units **106(3), 106(4)**. Each remote unit **106(1)-106(4)** has a respective radio **202(1)-202(4)** configured to distribute a communication stream including one or more communications bands. Each radio **202(1)-202(4)** may be configured to support the same communications bands, or a common subset of communications bands. Co-located remote units **106(1), 106(2)** provide the first MIMO coverage area **204(1)** by respectively receiving and distributing MIMO communications streams **200(1), 200(2)**. Co-located remote units **106(3), 106(4)** provide the second MIMO coverage area **204(2)** by also respectively receiving and distributing MIMO communications streams **200(1), 200(2)**. As shown in **FIG. 2**, a wireless client device **120** located within the first MIMO coverage area **204(1)** will receive the MIMO communications streams **200(1), 200(2)** for a MIMO communications service from the co-located remote units **106(1), 106(2)**, because the wireless client device **120** will be in communications range of both remote units **106(1), 106(2)**. Similarly, if the wireless client device **120** were located in the second MIMO coverage area **204(2)** in range of both remote units **106(3), 106(4)**, the wireless client device **120** would receive MIMO communications streams **200(1), 200(2)** for a MIMO communications service through remote units **106(3), 106(4)**. If however, the wireless client device **120** were located in a coverage area outside or on the edge of the first and second MIMO coverage areas **204(1), 204(2)**, the wireless client device **120** may still be in communication range of at least one of the remote units **106(1)-106(4)** to receive one of the MIMO communications streams **200(1)** or **200(2)**. However, the wireless client device **120** may not be in communication range with sufficient signal-to-noise (SNR) ratio of another remote unit **106(1)-106(4)**, to receive the other MIMO communications streams **200(2)** or **200(1)**. Thus, in this example, the wireless client device **120** would only receive single input, single output (SISO) communications services in the DAS **104**.

[0009] Providing co-located remote units **106(1)-106(N)** in the DAS **104** can increase the MIMO coverage areas **204** provided in the DAS **104** to reduce or eliminate non-MIMO coverage areas where only SISO communications services are available. However, providing co-located remote units **106(1)-106(N)** increases the number of remote units **106(1)-106(N)** in the DAS **104** for the number of MIMO coverage areas **204** provided. For example, as shown in **FIG. 2**, two (2) remote units **106(1), 106(2)** are required to be co-located to form the single MIMO coverage area **204(1)**. If a 4x4 MIMO communications service is desired, then four (4) remote units **106(1)-106(N)** would be required to be co-located to form a single MIMO coverage area **204**. Providing an increased number of remote units **106(1)-106(N)** to provide MIMO communications services in the DAS **104** adds complexity and associated cost by requiring support of a greater number of remote units **106(1)-106(N)** to as well as increased costs associated with providing additional communications links **114(1)-114(N)** for each MIMO coverage area **204**.

[0010] No admission is made that any reference cited herein constitutes prior art. Applicant expressly reserves the right to challenge the accuracy and pertinency of any cited documents.

SUMMARY

[0011] Embodiments disclosed herein include distributing multiple-input, multiple-output (MIMO) communications streams to remote units in a distributed communication system (DCS) to support configuration of interleaved MIMO communications services. MIMO communication services involve use of multiple antennas at both a transmitter and receiver to increase data throughput and link range to increase bandwidth up to twice nominal bandwidth. Related circuits, systems, and methods are also disclosed. In this regard, in exemplary aspects disclosed herein, DCSs are disclosed that are capable of distributing MIMO communications streams for a MIMO communications service in remote coverage areas between remote units and client devices in wireless communication range of remote units. The DCS can be configured to distribute a separate MIMO communications stream to each of multiple remote units, which in turn distribute the received MIMO communications stream in a remote MIMO coverage area to provide MIMO communications services to client devices in the remote coverage area. In this regard, an antenna of each remote unit radiates a respective received downlink MIMO communications stream received from the central unit in the overlapping MIMO coverage area. An antenna of each remote unit also receives a respective uplink MIMO communications stream received from a client device in the overlapping MIMO coverage area.

[0012] The remote units in the DCS configured to distribute MIMO communications streams for a MIMO communications service can be co-located with each other such that the remote coverage areas of each remote unit substantially overlap to form a remote MIMO coverage area. However, this requires providing multiple remote units for each desired remote MIMO coverage area, thereby increasing costs and complexity. In this regard, in aspects disclosed herein, to reduce the number of remote units in the DCS while still providing the desired remote MIMO coverage areas, the DCSs disclosed herein can be configured to provide interleaved MIMO communications services. Interleaved MIMO communications services involves configuring multiple adjacent remote units separated by a prescribed distance in the DCS and having respective, adjacent, substantially non-overlapping remote coverage areas to each receive a MIMO communications stream for a MIMO communications service to form a remote MIMO coverage area. By the multiple adjacent remote units being located at a prescribed distance from each other, each of their respective antennas are in essence "bonded" together through their distribution and reception of separate MIMO communications streams in the remote MIMO coverage area to form interleaved

MIMO cell bonded remote units. The size of the remote MIMO coverage area formed by the interleaved MIMO cell bonded remote units is a function of the distance between the interleaved MIMO cell bonded remote units, because this distance affects the signal quality level required by a client device to receive the MIMO communications streams from each of the interleaved MIMO cell bonded remote units. If a client device does not have acceptable and/or higher communications signal quality with an antenna of a single remote unit, the client device will engage in MIMO communications through the interleaved MIMO cell bonded remote units. If however, a client device has acceptable and/or higher communications signal quality with a subset of the antennas of the interleaved MIMO cell bonded remote units, the client device will engage in single-input, single-output (SISO) communications through a remote unit of the interleaved MIMO cell bonded remote units. More sparse and lower cost remote unit deployments can thus provide substantially uniform high-capacity MIMO DAS coverage.

[0013] In aspects disclosed herein, to provide the desired interleaved MIMO communications services, the DCS supports configuring or reconfiguring the distribution of MIMO communications streams to designated remote units in the DCS to provide interleaved MIMO cell bonding of remote units. In one example, the DCS includes different physical layers that are maintained from the central unit to the remote units. In this manner, the central unit can be configured or reconfigured to distribute separate MIMO communications streams to the desired physical layers in the DCS to support distributing MIMO communications streams to the desired remote units to provide the desired interleaved MIMO communications services. In this manner, interleaved MIMO communications services can be configured for a DCS using an existing infrastructure of remote units having substantially non-overlapping remote coverage areas, by directing the MIMO communications streams over the configured physical layers to be provided to the desired remote units to facilitate interleaved MIMO cell bonding of remote units.

[0014] To support configuration or reconfiguration of interleaved MIMO communications services, DCSs disclosed herein can also support simulating the interleaved MIMO performance of a DCS to determine possible interleaved MIMO communications service configurations to be presented to a technician or customer. In this regard, the interleaved MIMO performance of an existing DCS infrastructure is simulated. This simulation can involve the use of radio frequency (RF) simulation software program that may be resident in the DCS or located elsewhere, such as in the cloud or executed in a standalone computer system. The simulated interleaved MIMO performance of an existing DCS infrastructure is used to determine possible interleaved MIMO configurations in the DCS along with the associated configurations and changes needed to realize such possible interleaved MIMO configurations. For example, the simulation may involve creating a “heat” map of both SISO and interleaved MIMO remote coverage areas of the remote units in the DCS based on existing configurations for the remote units and the assigned routing of MIMO communications streams over the physical layers to the remote units. These possible interleaved MIMO communications service configurations can then be presented to a technician or customer to determine if any of the possible interleaved MIMO communications service configurations should be deployed in the DCS. For example, one possible interleaved MIMO communications service configuration may be to change the MIMO communications services supported by a DCS from 2x2 interleaved MIMO communications services to 4x4 interleaved MIMO communications services. If the possible interleaved MIMO communications service configurations should be deployed in the DCS, the DCS can be reconfigured to support the selected interleaved MIMO communications service configurations. If the infrastructure of the DCS is indicated as not being able to be changed, the possible interleaved MIMO communications service configurations presented will involve using the existing infrastructure of remote units and their locations, but with possible different physical layer assignments for distribution of MIMO communications streams to the remote units. If the infrastructure of the DCS is indicated as being able to be changed, the possible interleaved MIMO communications service configurations presented can also involve changing (e.g., adding to) the number and/or location of remote units along with possible different physical layer assignments for distribution of MIMO communications streams to the remote units.

[0015] In this regard, in one exemplary aspect, a distributed communications system (DCS) is disclosed. The DCS comprises a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units. The central unit is configured to distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration. The central unit is also configured to distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units. The plurality of remote units are each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers. Each remote unit among the plurality of remote units comprising at least one antenna is configured to distribute received uplink communications signals received over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit. Each remote unit among the plurality of remote units are also configured to distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna. The central unit is further configured to configure the routing configuration to assign a first multiple-input, multiple-output (MIMO) communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area, and assign a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

[0016] An additional aspect of the disclosure relates to a method of configuring a distributed communications system (DCS) for providing interleaved multiple-input, multiple-output (MIMO) communications services. The method comprises receiving an interleaved MIMO communications service configuration request from an external interface indicating if interleaved MIMO communications services are to be configured for a DCS. The DCS comprises a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units. The central unit is configured to distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration. The central unit is also configured to distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units. The plurality of remote units are each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers. Each remote unit among the plurality of remote units comprising at least one antenna and is configured to distribute received uplink communications signals received over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit and distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna. The method further comprises determining from the received interleaved MIMO communications service configuration request if the plurality of remote units in the DCS are to remain existing or be redesigned. In response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned, the central unit is configured to determine an existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units, the method further comprises determining an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units. The method further comprises sending the determined interleaved MIMO routing configuration to the external interface. The method further comprises storing the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration. The method further comprises assigning a first MIMO communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area. The method further comprises assigning a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

[0017] An additional aspect of the disclosure relates to non-transitory computer-readable medium having stored thereon computer executable instructions which, when executed by a processor, cause the processor to receive an interleaved multiple-input, multiple-output (MIMO) communications service configuration request from an external interface indicating if interleaved MIMO communications services are to be configured for a distributed communications system (DCS). The DCS comprises a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units. The central unit is configured to distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration. The central unit is also configured to distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units. The plurality of remote units are each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers. Each remote unit among the plurality of remote units comprises at least one antenna and is configured to distribute received uplink communications signals over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit and distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna. The processor is also configured to determine from the received interleaved MIMO communications service configuration request if the plurality of remote units in the DCS are to remain existing or be redesigned. In response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned, the processor determines the existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units; determines an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units; sends the determined interleaved MIMO routing configuration to the external interface; and stores the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration. The processor is also configured to assign a first MIMO communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area; and assign a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

[0018] Additional features and advantages will be set forth in the detailed description which follows and, in part, will be readily apparent to those skilled in the art from the description or recognized by practicing the embodiments as described in the written description and claims hereof, as well as the appended drawings.

[0019] It is to be understood that both the foregoing general description and the following detailed description are merely exemplary and are intended to provide an overview or framework to understand the nature and character of the claims.

[0020] The accompanying drawings are included to provide a further understanding of the disclosure, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s), and together with the description serve to explain principles and operation of the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] **FIG. 1** is a schematic diagram of an exemplary wireless distributed communications system (DCS) in the form of a distributed antenna system (DAS);

[0022] **FIG. 2** is schematic diagram of two MIMO coverage areas formed in the DAS of **FIG. 1** by respective co-located remote units;

[0023] **FIG. 3** is a schematic diagram of an exemplary optical fiber-based DCS in the form of a DAS configured to distribute communications signals between a central unit and a plurality of remote units, and that can include one or more power distribution systems configured to distribute power to a plurality of remote units and provide a safety power disconnect of the power source to remote units;

[0024] **FIG. 4A** is a partially schematic cut-away diagram of an exemplary building infrastructure in which a DCS in **FIG. 3** can be provided;

[0025] **FIG. 4B** is a more detailed schematic diagram of the DCS in **FIG. 4A**;

[0026] **FIG. 5A** is a schematic diagram of a DCS configured to support co-located MIMO communications services with client devices;

[0027] **FIG. 5B** is a schematic of a downlink path and uplink path and related components of the remote unit in the DCS of **FIG. 5A**;

[0028] **FIG. 6** is a schematic diagram of exemplary adjacent remote units in a DCS, such as the DCS in **FIGS. 5A** and **5B**, having exemplary substantially non-overlapping remote coverage areas and located a defined distance from each other to be capable of being interleaved MIMO cell bonded together to support interleaved MIMO communications services;

[0029] **FIG. 7** is a schematic diagram of exemplary adjacent remote units in a DCS, such as the DCS in **FIGS. 5A** and **5B**, located a defined distance from each other to show both traditional and interleaved MIMO cell bonding to support both SISO and interleaved MIMO communications services;

[0030] **FIG. 8** is a graph illustrating an exemplary percentage of remote coverage area of the remote units in **FIG. 7** supporting MIMO communications services as a function of distance between the remote units for both traditional and interleaved MIMO cell bonding;

[0031] **FIGS. 9A-9C** are schematic diagrams illustrating different, exemplary SISO, 2x2, and 4x4 interleaved MIMO cell bonding configurations that can be configured and/or re-configured in the DCS in **FIG. 5A** based on configuring and/or re-configuring the distribution of MIMO communications streams to designated remote units in the DCS;

[0032] **FIG. 10A** is a schematic diagrams illustrating the DCS in **FIGS. 5A** and 5**B** configured to support distribution of SISO communications streams to remote units to support SISO communication services;

[0033] **FIG. 10B** is a schematic diagram of a building layout employing the DCS in **FIG. 10A** configured to support distribution of SISO communications streams to remote units to support SISO communication services;

[0034] **FIG. 11A** is a schematic diagram illustrating the DCS in **FIG. 10A** re-configured to support interleaved distribution of MIMO communications streams to remote units to provide 2x2 interleaved MIMO communication services;

[0035] **FIGS. 11B** and **11C** are schematic diagrams of exemplary building layouts employing the DCS in **FIG. 11A** configured to support interleaved distribution of MIMO communications streams to remote units to provide 2x2 interleaved MIMO communication services;

[0036] **FIG. 12** is a schematic diagram illustrating the DCS in **FIG. 11A** re-configured to support interleaved distribution of MIMO communications streams to remote units to provide 4x4 interleaved MIMO communication services;

[0037] **FIG. 13** is a flowchart illustrating an exemplary process of configuring and/or re-configuring the DCS in **FIGS. 5A** and 5**B** to support interleaved MIMO communications services based on the existing remote units deployed in the DCS and their installed locations to achieve a desired interleaved MIMO communications services performance in the DCS;

[0038] **FIG. 14** is a flowchart illustrating an exemplary process of configuring and/or re-configuring the DCS in **FIGS. 5A** and 5**B** to support interleaved MIMO communications services based on the existing remote units deployed in the DCS and with repositioning installed locations of remote units and/or adding MIMO communications streams to achieve a desired interleaved MIMO communications services performance in the DCS;

[0039] **FIGS. 15A** and **15B** are diagrams of exemplary graphical user interfaces (GUI) that facilitate configuring and/or reconfiguring distribution of MIMO communications streams in a DCS, such as the DCS in **FIGS. 5A** and **5B** and according to any of the exemplary interleaved MIMO communications services discussed herein, displayed on a display in a computer system in response to a processor executing of software instructions; and

[0040] **FIG. 16** is a schematic diagram of an exemplary computer system that can be included in any component in a DCS, including but not limited to the DCS in **FIGS. 5A** and **5B,** wherein the computer system includes a processor that is configured to software execute instructions to support configuring and/or reconfiguring distribution of MIMO communications streams in a DCS, such as the DCS in **FIGS. 5A** and **5B**.

DETAILED DESCRIPTION

[0041] Embodiments disclosed herein include distributing multiple-input, multiple-output (MIMO) communications streams to remote units in a distributed communication system (DCS) to support configuration of interleaved MIMO communications services. MIMO communication services involve use of multiple antennas at both a transmitter and receiver to increase data throughput and link range to increase bandwidth up to twice nominal bandwidth. Related circuits, systems, and methods are also disclosed. In this regard, in exemplary aspects disclosed herein, DCSs are disclosed that are capable of distributing MIMO communications streams for a MIMO communications service in remote coverage areas between remote units and client devices in wireless communication range of remote units. The DCS can be configured to distribute a separate MIMO communications stream to each of multiple remote units, which in turn distribute the received MIMO communications stream in a remote MIMO coverage area to provide MIMO communications services to client devices in the remote coverage area. In this regard, an antenna of each remote unit radiates a respective received downlink MIMO communications stream received from the central unit in the overlapping MIMO coverage area. An antenna of each remote unit also receives a respective uplink MIMO communications stream received from a client device in the overlapping MIMO coverage area.

[0042] The remote units in the DCS configured to distribute MIMO communications streams for a MIMO communications service can be co-located with each other such that the remote coverage areas of each remote unit substantially overlap to form a remote MIMO coverage area. However, this requires providing multiple remote units for each desired remote MIMO coverage area, thereby increasing costs and complexity. In this regard, in aspects disclosed herein, to reduce the number of remote units in the DCS while still providing the desired remote MIMO coverage areas, the DCSs disclosed herein can be configured to provide interleaved MIMO communications services. Interleaved MIMO communications services involves configuring multiple adjacent remote units separated by a prescribed distance in the DCS and having respective, adjacent, substantially non-overlapping remote coverage areas to each receive a MIMO communications stream for a MIMO communications service to form a remote MIMO coverage area. By the multiple adjacent remote units being located at a prescribed distance from each other, each of their respective antennas are in essence “bonded” together through their distribution and reception of separate MIMO communications streams in the remote MIMO coverage area to form interleaved MIMO cell bonded remote units. The size of the remote MIMO coverage area formed by the interleaved MIMO cell bonded remote units is a function of the distance between the interleaved MIMO cell bonded remote units, because this distance affects the signal quality level required by a client device to receive the MIMO communications streams from each of the interleaved MIMO cell bonded remote units. If a client device does not have acceptable and/or higher communications signal quality with an antenna of a single remote unit, the client device will engage in MIMO communications through the interleaved MIMO cell bonded remote units. If however, a client device has acceptable and/or higher communications signal quality with a subset of the antennas of the interleaved MIMO cell bonded remote units, the client device will engage in single-input, single-output (SISO) communications through a remote unit of the interleaved MIMO cell bonded remote units. More sparse and lower cost remote unit deployments can thus provide substantially uniform high-capacity MIMO DAS coverage.

[0043] In aspects disclosed herein, to provide the desired interleaved MIMO communications services, the DCS supports configuring or reconfiguring the distribution of

MIMO communications streams to designated remote units in the DCS to provide interleaved MIMO cell bonding of remote units. In one example, the DCS includes different physical layers that are maintained from the central unit to the remote units. In this manner, the central unit can be configured or reconfigured to distribute separate MIMO communications streams to the desired physical layers in the DCS to support distributing MIMO communications streams to the desired remote units to provide the desired interleaved MIMO communications services. In this manner, interleaved MIMO communications services can be configured for a DCS using an existing infrastructure of remote units having substantially non-overlapping remote coverage areas, by directing the MIMO communications streams over the configured physical layers to be provided to the desired remote units to facilitate interleaved MIMO cell bonding of remote units.

[0044] To support configuration or reconfiguration of interleaved MIMO communications services, DCSs disclosed herein can also support simulating the interleaved MIMO performance of a DCS to determine possible interleaved MIMO communications service configurations to be presented to a technician or customer. In this regard, the interleaved MIMO performance of an existing DCS infrastructure is simulated. This simulation can involve the use of radio frequency (RF) simulation software program that may be resident in the DCS or located elsewhere, such as in the cloud or executed in a standalone computer system. The simulated interleaved MIMO performance of an existing DCS infrastructure is used to determine possible interleaved MIMO configurations in the DCS along with the associated configurations and changes needed to realize such possible interleaved MIMO configurations. For example, the simulation may involve creating a “heat” map of both SISO and interleaved MIMO remote coverage areas of the remote units in the DCS based on existing configurations for the remote units and the assigned routing of MIMO communications streams over the physical layers to the remote units. These possible interleaved MIMO communications service configurations can then be presented to a technician or customer to determine if any of the possible interleaved MIMO communications service configurations should be deployed in the DCS. For example, one possible interleaved MIMO communication service configuration may be to change the MIMO communications services supported by a DCS from 2x2 interleaved MIMO communications services to 4x4 interleaved MIMO communications services. If the possible interleaved MIMO communications service configurations should be deployed in the DCS, the DCS can be reconfigured to support the selected interleaved MIMO communications service configurations. If the infrastructure of the DCS is indicated as not being able to be changed, the possible interleaved MIMO communications service configurations presented will involve using the existing infrastructure of remote units and their locations, but with possible different physical layer assignments for distribution of MIMO communications streams to the remote units. If the infrastructure of the DCS is indicated as being able to be changed, the possible interleaved MIMO communications service configurations presented can also involve changing (e.g., adding to) the number and/or location of remote units along with possible different physical layer assignments for distribution of MIMO communications streams to the remote units.

[0045] Before discussing examples distributing MIMO communications streams to remote units in a DCS to support configuration and/or reconfiguration of interleaved MIMO communications services starting at **FIG. 6**, an exemplary DCS is described in regards to **FIGS. 3-5B**.

[0046] In this regard, **FIG. 3** is a schematic diagram of such an exemplary DCS **300** in the form of a distributed antenna system (DAS) **302**. A DAS is a system that is configured to distribute communications signals, including wireless communications signals, from a central unit to a plurality of remote units over physical communications media, to then be distributed from the remote units wirelessly to client devices in wireless communication range of a remote unit. The DAS **302** in this example is an optical fiber-based DAS that is comprised of three (3) main components. One or more interface circuits provided in the form of radio interface circuits **304(1)-304(T)** are provided in a central unit **306** to receive and process (e.g., filter, amplify, route) downlink electrical communications signals **308D(1)-308D(S)** prior to optical conversion into downlink optical communications signals. The downlink electrical communications signals **308D(1)-308D(S)** may be received from a base transceiver station (BTS) or baseband unit (BBU) as examples. The downlink electrical communications signals **308D(1)-308D(S)** may be analog signals or digital signals that can be sampled and processed as digital information. The radio interface circuits **304(1)-304(T)** provide both downlink and uplink interfaces for signal processing. The notations "1-S" and "1-T" indicate that any number of the referenced component, 1-S and 1-T, respectively, may be provided.

[0047] With continuing reference to **FIG. 3**, the central unit **306** is configured to accept the plurality of radio interface circuits **304(1)-304(T)** as modular components that can easily be installed and removed or replaced in a chassis. In one embodiment, the central unit **306** is configured to support up to twelve (12) radio interface circuits **304(1)-304(12)**. Each radio interface circuit **304(1)-304(T)** can be designed to support a particular type of radio source or range of radio sources (i.e., frequencies) to provide flexibility in configuring the central unit **306** and the DAS **302** to support the desired radio sources. For example, one radio interface circuit **304** may be configured to support the Personal Communication Services (PCS) radio band. Another radio interface circuit **304** may be configured to support the 700 MHz radio band. In this example, by inclusion of these radio interface circuits **304**, the central unit **306** could be configured to support and distribute communications signals, including those for the communications services and communications bands described above as examples.

[0048] The radio interface circuits **304(1)-304(T)** may be provided in the central unit **306** that support any frequencies desired, including but not limited to licensed US FCC and Industry Canada frequencies (824-849 MHz on uplink and 869-894 MHz on downlink), US FCC and Industry Canada frequencies (1850-1915 MHz on uplink and 1930-1995 MHz on downlink), US FCC and Industry Canada frequencies (1710-1755 MHz on uplink and 2110-2155 MHz on downlink), US FCC frequencies (698-716 MHz and 776-787 MHz on uplink and 728-746 MHz on downlink), EU R & TTE frequencies (880-915 MHz on uplink and 925-960 MHz on downlink), EU R & TTE frequencies (1710-1785 MHz on uplink and 1805-1880 MHz on downlink), EU R & TTE frequencies (1920-1980 MHz on uplink and 2110-2170 MHz on downlink), US FCC frequencies (806-824 MHz on uplink and 851-869 MHz on downlink), US FCC frequencies (896-901 MHz on uplink and 929-941 MHz on downlink), US FCC frequencies (793-805 MHz on uplink and 763-775 MHz on downlink), and US FCC frequencies (2495-2690 MHz on uplink and downlink).

[0049] With continuing reference to **FIG. 3**, the received downlink electrical communications signals **308D(1)-308D(S)** are provided to a plurality of optical interfaces provided in the form of optical interface circuits **310(1)-310(W)** in this embodiment to convert the downlink electrical communications signals **308D(1)-308D(S)** into downlink optical communications signals **312D(1)-312D(S)**. The notation "1-W" indicates that any number of the referenced component 1-W may be provided. The optical interface circuits **310** may include one or more optical interface components (OICs) that contain electrical-to-optical (E-O) converters **316(1)-316(W)** to convert the received downlink electrical communications signals **308D(1)-308D(S)** into the downlink optical communications signals **312D(1)-312D(S)**. The optical interface circuits **310** support the radio bands that can be provided by the radio interface circuits **304**, including the examples previously described above. The downlink optical communications signals **312D(1)-312D(S)** are communicated over a downlink optical fiber communications link **314D** to a plurality of remote units **318(1)-318(X)** provided in the form of remote antenna units in this example. The notation "1-X" indicates that any number of the referenced component 1-X may be provided. One or more of the downlink optical communications signals **312D(1)-312D(S)** can be distributed to each remote unit **318(1)-318(X)**. Thus, the distribution of the downlink optical communications signals **312D(1)-312D(S)** from the central unit **306** to the remote units **318(1)-318(X)** is in a point-to-multipoint configuration in this example.

[0050] With continuing reference to **FIG. 3**, the remote units **318(1)-318(X)** include optical-to-electrical (O-E) converters **320(1)-320(X)** configured to convert the one or more received downlink optical communications signals **312D(1)-312D(S)** back into the downlink electrical communications signals **308D(1)-308D(S)** to be wirelessly radiated through antennas **322(1)-322(X)** in the remote units **318(1)-318(X)** to user equipment (not shown) in the reception range of the antennas **322(1)-322(X)**. The optical interface circuits **310** may also include O-E converters **324(1)-324(W)** to convert received uplink optical communications signals **312U(1)-312U(X)** from the remote units **318(1)-318(X)** into the uplink electrical communications signals **326U(1)-326U(S)** as will be described in more detail below.

[0051] With continuing reference to **FIG. 3**, the remote units **318(1)-318(X)** are also configured to receive uplink electrical communications signals **328U(1)-328U(X)** received by the respective antennas **322(1)-322(X)** from client devices in wireless communication range of the remote units **318(1)-318(X)**. The uplink electrical communications signals **328U(1)-328U(S)** may be analog signals or digital signals that can be sampled and processed as digital information. The remote units **318(1)-318(X)** include E-O converters **329(1)-329(X)** to convert the received uplink electrical communications signals **328U(1)-328U(X)** into uplink optical communications signals **312U(1)-312U(X)**. The remote units **318(1)-318(X)** distribute the uplink optical communications signals **312U(1)-312U(X)** over an uplink optical fiber communication link **314U** to the optical interface circuits **310(1)-310(W)** in the central unit **306**. The O-E converters **324(1)-324(W)** convert the received uplink optical communications signals **312U(1)-312U(X)** into uplink electrical communications signals **326U(1)-326U(X)**, which are processed by the radio interface circuits **304(1)-304(T)** and provided as the uplink electrical communications signals **330U(1)-330U(X)** to a source transceiver such as a base transceiver station (BTS) or baseband unit (BBU).

[0052] Note that the downlink optical fiber communications link **314D** and the uplink optical fiber communications link **314U** coupled between the central unit **306** and the remote units **318(1)-318(X)** may be a common optical fiber communications link, wherein for example, wave division multiplexing (WDM) may be employed to carry the downlink optical communications signals **312D(1)-312D(S)** and the uplink optical communications signals **312U(1)-312U(X)** on the same optical fiber communications link. Alternatively, the downlink optical fiber communications link **314D** and the uplink optical fiber communications link **314U** coupled between the central unit **306** and the remote units **318(1)-318(X)** may be single, separate optical fiber communications links, wherein for example, wave division multiplexing (WDM) may be employed to carry the downlink optical communications signals **312D(1)-312D(S)** on one common downlink optical fiber and the uplink optical communications signals **312U(1)-312U(X)** carried on a separate, only uplink optical fiber. Alternatively, the downlink optical fiber communications link **314D** and the uplink optical fiber communications link **314U** coupled between the central unit **306** and the remote units **318(1)-318(X)** may be separate optical fibers dedicated to and providing a separate communications link between the central unit **306** and each remote unit **318(1)-318(X)**.

[0053] The DCS **300** in **FIG. 3** can be provided in an indoor environment as illustrated in **FIG. 4A**. **FIG. 4A** is a partially schematic cut-away diagram of a building infrastructure **332** employing the DCS **300**. **FIG. 4B** is a schematic diagram of the DCS **300** installed according to the building infrastructure **332** in **FIG. 4A**.

[0054] With reference to **FIG. 4A**, the building infrastructure **332** in this embodiment includes a first (ground) floor **334(1)**, a second floor **334(2)**, and a Fth floor **334(F)**, where ‘F’ can represent any number of floors. The floors **334(1)-334(F)** are serviced by the central unit **306** to provide antenna coverage areas **336** in the building infrastructure **332**. The antenna coverage area **336** is the distance in which wireless communications signals can be transmitted or otherwise distributed at a minimum signal-to-noise ratio (SNR) to achieve communications with a client device. The central unit **306** is communicatively coupled to a signal source **338**, such as a BTS or BBU, to receive the downlink electrical communications signals **308D(1)-308D(S)**. The central unit **306** is communicatively coupled to the remote units **318(1)-318(X)** to receive optical uplink communications signals **312U(1)-312U(X)** from the remote units **318(1)-318(X)** as previously described in **FIG. 3**. The downlink and uplink optical communications signals **312D(1)-312D(S), 312U(1)-312U(X)** are distributed between the central unit **306** and the remote units **318(1)-318(X)** over a riser cable **340** in this example. The riser cable **340** may be routed through interconnect units (ICUs) **342(1)-342(F)** dedicated to each floor **334(1)-334(F)** for routing the downlink and uplink optical communications signals **312D(1)-312D(S), 312U(1)-312U(X)** to the remote units **318(1)-318(X)**. The ICUs **342(1)-342(F)** may also include respective power distribution circuits **344(1)-344(F)** that include power sources as part of a power distribution system **350**, wherein the power distribution circuits **344(1)-344(F)** are configured to distribute power remotely to the remote units **318(1)-318(X)** to provide power for operating the power consuming components in the remote units **318(1)-318(X)**. For example, array cables **345(1)-345(F)** may be provided and coupled between the ICUs **342(1)-342(F)** that contain both optical fibers to provide the respective downlink and uplink optical fiber communications media **314D(1)-314D(F), 314U(1)-314U(F)** and power conductors **346(1)-346(F)** (e.g., electrical wire) to carry current from the respective power distribution circuits **344(1)-344(F)** to the remote units **318(1)-318(X)**.

[0055] With reference to the DCS **300** shown in **FIG. 4B**, the central unit **306** may include a power supply circuit **352** to provide power to the radio interface circuits **304(1)-304(T)**, the optical interface circuits **310(1)-310(W)**, and radio distribution circuits (RDCs) **354, 356**. The downlink electrical communications signals **308D(1)-308D(S)** and the uplink electrical communications signals **326U(1)-326U(S)** are routed from between the radio interface circuits **304(1)-304(T)** and the optical interface circuits **310(1)-310(W)** through RDCs **354, 356**. In one embodiment, the RDCs **354, 356** can support sectorization in the DCS **300**, meaning that only certain downlink electrical communications signals **308D(1)-308D(S)** are routed to certain radio interface circuits **304(1)-304(T)**. A power supply circuit **358** may also be provided to provide power to the optical interface circuits **310(1)-310(W)**. An external interface **360**, which may include web and network management system (NMS) interfaces, may also be provided to allow configuration and communication to the components of the central unit **306**. A microcontroller, microprocessor, or other control circuitry, called a head-end controller (HEC) **362** (e.g., a controller circuit or a microprocessor) may be included in central unit **306** to provide control operations for the central unit **306** and the DCS **300**.

[0056] The DCS **300** in **FIGS. 3-4B** can be configured to support MIMO communications services. In this regard, **FIG. 5A** is a schematic diagram of an exemplary the DCS **300** in **FIGS. 3-4B** illustrating the central unit **306** and a single remote unit **318** distributing MIMO communications streams to support 2x2 MIMO communications services.

MIMO communications involves the use of multiple antennas at both a transmitter and receiver to improve communication performance. Remote unit **318(1)** is shown in **FIG. 5A** and is used as an example to represent any of the remote units **318(1)-318(X)** in the DCS **300**. **FIG. 5B** is a schematic diagram illustrating more detail of a downlink path and uplink path and related components of the remote unit **318(1)** in the DAS **300** illustrated in **FIG. 5A** for supporting MIMO communications services. Common components illustrated for the DCS **300** in **FIGS. 5A** and **5B** and **FIGS. 3-4B** are shown with common element numbers with **FIGS. 5A** and **5B** and thus will not be re-described.

[0057] With reference to **FIG. 5A**, the central unit **306** is configured to receive electrical downlink MIMO communications signals **308D-M** from outside the DCS **300** in a signal processor **500**. The central unit **306** is also configured to distribute electrical uplink MIMO communications signals **308U-M**, received from a wireless client device **502**, to other systems. The signal processor **500** may be configured to provide the electrical downlink MIMO communications signals **308D-M** to a mixer **504**, which may be an IQ signal mixer in this example. The mixer **504** is configured to convert the electrical downlink MIMO communications signals **308D-M** to IQ signals in one example. The mixer **504** is driven by a frequency signal **506** that is provided by a local oscillator **508**. Frequency conversion is optional. In this embodiment, it is desired to up-convert the frequency of the electrical downlink MIMO communications signals **308D-M** to a higher frequency to provide electrical downlink MIMO communications signals **312D-M(E)** to provide for a greater bandwidth capability before distributing the electrical downlink MIMO communications signals **312D-M(E)** to the remote unit **318(1)**. For example, the up-conversion carrier frequency may be provided as an extremely high frequency (e.g., approximately 30 GHz to 300 GHz).

[0058] With continuing reference to **FIG. 5A**, because the communication medium between the central unit **306** and the remote unit **318(1)** is the optical fiber communications medium **314D, 314U** in this example, the electrical downlink MIMO communications signals **312D-M(E)** are converted to optical signals by an electro-optical converter **510**. The electro-optical converter **510** includes components to receive a light wave **512** from a light source **514**, such as a laser. The light wave **512** is modulated by the frequency oscillations in the electrical downlink MIMO communications signals **312D-M(E)** to provide optical downlink MIMO communications signals **312D-M(O)** over the downlink optical fiber **314D** to the remote unit **318(1)**. The electro-optical converter **510** may be provided so that the electrical downlink MIMO communications signals **312D-M(E)** are provided as radio-over-fiber (RoF) communications signals.

[0059] With continuing reference to **FIG. 5A**, the optical downlink MIMO communications signals **312D-M(O)** are received by an optical bi-directional amplifier **516**, which is then provided to a MIMO splitter circuit **518** in the remote unit **318(1)**. The MIMO splitter **518** is provided so that the optical downlink MIMO communications signals **312D-M(O)** can be split among two separate downlink communication paths **520(1)**, **520(2)** to be radiated over two separate MIMO antennas **322(1)(1)**, **322(1)(2)** provided in two separate MIMO transmitters **522(1), 522(2)** configured in MIMO configuration. The MIMO antennas **322(1)(1), 322(1)(2)** are configured to be bonded, meaning that both MIMO antennas **322(1)(1), 322(1)(2)** are co-located within the same remote unit **318(1)** to each provide substantially overlapping MIMO coverage areas designed to support MIMO communications with a particular wireless client device **502** in communications range of their MIMO coverage areas. The MIMO splitter circuit **518** in the remote unit **318(1)** is an optical splitter since the received optical downlink MIMO communications signals **312D-M(O)** are optical signals. In each downlink communication path **520(1)**, **520(2)**, downlink optical-to-electrical converters **524D(1)**, **524D(2)** are provided to convert the optical downlink MIMO communications signals **312D-M(O)(1), 312D-M(O)(2)** to electrical downlink MIMO communications signals **308D-M(1), 308D-M(2)**. The uplink path of the communications paths **520(1), 520(2)** in the remote unit **318(1)** is illustrated in **FIG. 5B**. As illustrated in **FIG. 5B**, uplink electrical-to-optical converters **524U(1)**, **524U(2)** are also provided in the remote unit **318(1)** to convert electrical uplink MIMO communications signals **308U-M(1), 308U-M(2)** received from the wireless client device **502** to optical uplink MIMO communications signals **312U-M(O)(1), 312U-M(O)(2)** to be communicated over the uplink optical fiber **314U(1), 314U(2)** to the central unit **306**.

[0060] With reference back to **FIG. 5A**, the wireless client device **502** includes two MIMO receivers **528(1), 528(2)** that include MIMO receiver antennas **530(1)**, **530(2)** also configured in MIMO configuration. The MIMO receiver antennas **530(1)**, **530(2)** are configured to receive the electrical downlink MIMO communications signals **308D-M(1)**, **308D-M(2)** wirelessly from the remote unit **318(1)**. Mixers **532(1)**, **532(2)** are provided and coupled to the MIMO receiver antennas **530(1)**, **530(2)**, respectively, in the wireless client device **502** to provide frequency conversion of the electrical downlink MIMO communications signals **308D-M(1), 308D-M(2)**. A local oscillator **534** is provided that is configured to provide oscillation signals **536(1)**, **536(2)** to the mixers **532(1)**, **532(2)**, respectively, for frequency conversion. In this embodiment, the electrical downlink MIMO communications signals **308D-M(1), 308D-M(2)** are down converted back to their native frequency as received by the central unit **306**. The down converted electrical downlink MIMO communications signals **308D-M(1)**, **308D-M(2)** are then provided to a signal analyzer **538** in the wireless client device **502** for any processing desired.

[0061] Even with the potential doubling of bandwidth in the DCS **300** in **FIGS. 5A** and **5B** by being configured to support MIMO communications services, the wireless client device **502** must still be within range of two antennas **322(1), 322(2)** of a remote unit **318** (e.g., antennas **322(1)(1), 322(1)(2)** of remote unit **318(1)**) to properly operate in MIMO configuration with increased bandwidth. Otherwise, the full benefits of increased bandwidth of MIMO technology provided in the DCS **300** may not be realized. Ensuring uniform MIMO coverage in coverage areas of the DCS **300** may be particularly important for newer cellular standards, such as Long Term Evolution (LTE), where increased bandwidth requirements are expected by users of client devices **502** in all coverage areas. Thus, it is desired to provide uniform coverage areas in a DCS, such as DCS **300**, particularly in the edges of MIMO coverage cells. However, as discussed above, providing traditional MIMO remote unit bonding between co-located remote units **318** in the DCS **300** in **FIGS. 5A** and **5B** may still provide non-uniform MIMO coverage areas unless a high density of remote units **318** are provided, thereby increasing cost and complexity.

[0062] In this regard, **FIG. 6** is a schematic diagram of exemplary adjacent remote units **318(1), 318(2)** in the DCS **300** in **FIGS. 5A** and **5B**, having exemplary substantially non-overlapping remote coverage areas **600(1), 600(2)** and located a defined distance $\mathbf{D_1}$ from each other to be capable of being interleaved MIMO cell bonded together to support interleaved MIMO communications services. For example, if a wireless client device **502** receives a downlink communications signal from a remote unit **318(1)**, **318(2)** greater than 12 dB for example, the wireless client device **502** may engage in SISO communications with a remote unit **318(1)**, **318(2)**. However, if a wireless client device **502** receives a downlink communications signal from a remote unit **318(1), 318(2)** less than 12 dB for example, the wireless client device **502** may engage in interleaved MIMO communications with the remote units **318(1), 318(2)**, which may be achievable at distance $\mathbf{D_1}$ such that the remote coverage areas **600(1), 600(2)** are substantially non-overlapping. Note that **FIG. 6** illustrates two remote units **318(1), 318(2)**, but the interleaved MIMO cell bonded remote units could be any of the remote units **318(1)-318(X)** in the DCS **300**.

[0063] In this example, the interleaved MIMO communication services are 2x2 MIMO communications services. Interleaved MIMO communications services in this example involves configuring the adjacent remote units **318(1), 318(2)** separated by the prescribed distance $\mathbf{D_1}$ in the DCS **300** to have respective, adjacent, substantially non-overlapping remote coverage areas **600(1), 600(2)** to each receive a MIMO communications stream **602(1), 602(2)**. The MIMO communications streams **602(1), 602(2)** are MIMO communications signals that are directed to the same wireless client device **502** to provide MIMO communications services. In this regard, the MIMO communications signals distributed by the central unit **306** to the respective remote units **318(1), 318(2)** include downlink optical MIMO communications signals **312D-M(1), 312D-M(2)** as also previously illustrated in **FIG. 5A**. The remote units **318(1), 318(2)** are configured to distribute the downlink optical MIMO communications signals **312D-M(1), 312D-M(2)** as downlink electrical MIMO communications signals **308D-M(1), 308D-M(2)** in the respective remote coverage areas **600(1), 600(2)** to a wireless client device **502**. The MIMO communications signals can also include uplink electrical MIMO communications signals **308U-M(1), 308U-M(2)** received by the remote units **318(1), 318(2)** from a wireless client device **502** to be distributed by the respective remote units **318(1), 318(2)** as uplink electrical MIMO communications signals **308U-M(1), 308U-M(2)** to the central unit **306**. The remote unit **318(1)** supports communicating the MIMO communications stream **602(1)** in its remote coverage area **600(1)**, and the remote unit **318(2)** supports communicating the MIMO communications streams **602(2)** in its respective remote coverage area **600(2)**. If a wireless client device **502** is outside of the remote coverage area **600(1), 600(2)** of one remote unit **318(1), 318(2)**, but not the other, the wireless client device **502** can still communicate with the in-range remote unit **318(1), 318(2)** for SISO communications services.

[0064] **FIG. 7** is a schematic diagram of the adjacent remote units **318(1)-318(4)** in the DCS **300** in **FIG. 6** to further describe interleaved MIMO cell bonding that occurs between the remote units **318(1)-318(4)** based on the distances $\mathbf{D_2}$ and $\mathbf{D_3}$ between the remote units **318(1)-318(4)**. Remote units **318(1), 318(3)** are co-located with each other at distance $\mathbf{D_2}$ such that their respective remote coverage areas **600(1), 600(3)** are substantially overlapping. Remote units **318(2), 318(4)** are shown co-located with each other by distance $\mathbf{D_2}$ (e.g., within 2 meters), which is also close enough to each other such that their respective remote coverage areas **600(2), 600(4)** are substantially overlapping to provide 100% MIMO coverage in this example. For example, area **604(1)** is underneath remote unit **318(3)**, which is in both remote coverage areas **600(1), 600(3)**. Area **604(2)** is between the remote units **318(1), 318(3)**, which is also in both remote coverage areas **600(1), 600(3)**. As an example, distance $\mathbf{D_2}$ of six (6) meters or less may provide for the remote units **318(1), 318(3)** to provide 100% MIMO coverage for client devices within their remote coverage areas **600(1), 600(3)** and provide for the remote units **318(2), 318(4)** to provide 100% MIMO coverage for client devices within their remote coverage areas **600(2), 600(4)**.

[0065] Alternatively, as another example, remote units **318(1), 318(2)** can be located a distance $\mathbf{D_3}$ (e.g., > 6 meters apart) still close enough to each other such that their respective remote coverage areas **600(2), 600(4)** are not substantially overlapping to still provide MIMO coverage even if less than 100% MIMO coverage. For example, assume that only remote units **318(1)** and **318(2)** were illustrated in **FIG. 7** and located a distance $\mathbf{D_3}$ apart from each other (e.g., >= 12 meters (m)), greater than distance $\mathbf{D_2}$ such that their respective remote coverage areas **600(1), 600(2)** are overlapping, but not substantially overlapping. At this distance $\mathbf{D_3}$, remote units **318(1), 318(2)** can still achieve interleaved MIMO cell bonding, but at a reduced MIMO coverage. For example, at distance $\mathbf{D_3}$ of approximately six (6) m to twenty-two (22) m, the remote units **318(1), 318(2)** with their remote coverage areas **600(1), 600(2)** may still provide 65% to 95% MIMO coverage through interleaved MIMO cell bonding even though their respective remote coverage areas **600(1), 600(2)** are substantially non-overlapping. This reduced MIMO coverage may be an acceptable tradeoff to provide MIMO coverage in a DCS, such as DCS **300**, with fewer remote units **318** deployed to save cost and/or complexity.

[0066] **FIG. 8** is a graph **800** that illustrates an exemplary percentage of the remote coverage area **600** for MIMO communications services as a function of distance $\mathbf{D_X}$ between the remote units **318(1)-318(X)**. Line **802** shows the percentage of remote coverage area **600** supporting MIMO communications services for a traditional MIMO communications service, such as between remote units **318(1), 318(3)** and between remote units **318(2), 318(4)** in **FIG. 7**. For example, according to line **802** in **FIG. 8**, approximately 80% of the remote coverage areas **600(1), 600(3)** support traditional MIMO communications services when the remote units **318(1), 318(3)** are located from each other at distance $\mathbf{D_2}$ within approximately six (6) meters.

[0067] With reference back to **FIG. 7,** it has been discovered that when remote units **318(1), 318(X)**, such as the remote units **318(1), 318(2)** are not co-located and located further away at prescribed distance $\mathbf{D_3}$ such that their respective remote coverage areas **600(1),**

600(2) are substantially non-overlapping, interleaved MIMO communications services can still be achieved. Interleaved MIMO cell bonding occurs between the remote units **318(1), 318(2)** by their remote coverage areas **600(1), 600(2)** overlapping, but not substantially overlapping in this example. For example, area **604(3)** is an area wherein the remote coverage areas **600(1), 600(2)** overlap at the cell edge of the remote coverage areas **600(1), 600(2)** of the remote units **318(1), 318(2)**. This is shown by example in the graph **800** in **FIG. 8**, where line **804** shows the percentage of remote coverage area **600** for MIMO communications services for an interleaved MIMO communications service, such as between remote units **318(1), 318(2)** in **FIG. 7**. For example, according to line **804** in **FIG. 8**, approximately 65% of the remote coverage areas **600(1), 600(2)** support MIMO communications services when the remote units **318(1), 318(2)** are located from each other at distance $\mathbf{D_3}$ within approximately eight (18) meters. SISO communications services are still supported by the remote units **318(1), 318(2)** even for the 35% of the remote coverage areas **600(1), 600(2)** that do not support MIMO communications services. The size of the remote coverage areas **600(1), 600(2)** supporting interleaved MIMO communications services formed by the interleaved MIMO cell bonding between the remote units **318(1), 318(2)** is a function of the distance $\mathbf{D_X}$ between the remote units **318(1), 318(2)**, because this distance affects the signal quality level required by a wireless client device to receive the MIMO communications streams **600(1), 600(2)**. If a wireless client device does not have an acceptable and/or higher communications signal quality with the antenna of a single remote unit **318(1), 318(2)**, the wireless client device will engage in SISO communications with the remote unit **318(1), 318(2)**. However, if a wireless client device does not have acceptable and/or higher communications signal quality with a single remote unit **318(1), 318(2)**, the wireless client device will engage in interleaved MIMO communications through the interleaved MIMO cell bonded remote units **318(1), 318(2)**.

[0068] Thus, interleaved MIMO cell bonding between the remote units **318(1), 318(2)** allows MIMO communications services to still be supported in the DCS **300** without having to necessarily co-locate the remote units **318(1), 318(2)**, or provide multiple radios in each remote unit **318(1), 318(2)** to achieve sufficient MIMO communication services, thus reducing cost and complexity. Thus, MIMO communications services can be provided in the DCS **300** with less remote units **318(1)-318(X)**. This also allows an existing infrastructure of installed remote units **318(1)-318(X)** configured to support SISO communications, to support interleaved MIMO communication services, based on a trade-off of the number of remote units **318(1)-318(X)** and distance **Dx** therebetween versus percentage of their remote coverage areas **600** that support MIMO communications services. More sparse and lower cost remote unit deployments can still provide substantially uniform high-capacity MIMO communications coverage.

[0069] An existing infrastructure of installed remote units in a DCS configured to support SISO communications, such as the remote units **318(1)-318(X)** in the DCS **300** in **FIGS. 5A** and **5B**, can be configured or re-configured to support interleaved MIMO communication services taking the example of **FIG. 6** if the DCS **300** can be configured or re-configured to route MIMO communications streams **602(1), 602(2)**. In this regard, **FIG. 9A** is a schematic diagram **900(1)** illustrating a configuration of the remote units **318(1)-318(X)** that can be provided in DCS **300** in **FIG. 5A** to support SISO communications streams to designated remote units **318(1)-318(X)** in the DCS **300**. Each circle 'A' represents a single remote unit **318** and its remote coverage area **600** receiving MIMO communications stream A. However, as shown in the schematic diagram **900(2)** in **FIG. 9B**, the same number of remote units **318(1)-318(X)** and their respective locations are provided, but the remote units **318(1)-318(X)** are configured to support 2x2 interleaved MIMO communications services. The MIMO communications streams 'A' and 'B' are routed to the remote units **318(1)-318(X)** interleaved to provide a 2x2 interleaved MIMO cell bonding configuration to support 2x2 interleaved MIMO communications services. Thus, by simply re-routing the MIMO communications streams 'A' and 'B' to the existing remote units **318(1)-318(X)** in **FIG. 9A**, the remote units **318(1)-318(X)** can be configured to migrate from only supporting SISO communications services to 2x2 interleaved MIMO communications services.

[0070] Even further, **FIG. 9C** is a schematic diagram **900(3)** illustrating an exemplary 4x4 interleaved MIMO cell bonding configuration that can be configured and/or re-configured in the DCS **300** in **FIG. 5A** based on configuring and/or re-configuring the distribution of MIMO communications streams **602** to designated remote units **318(1)-318(X)** in the DCS **300**. Again, the same number of remote units **318(1)-318(X)** and their respective locations are provided, but the remote units **318(1)-318(X)** are configured to support 4x4 interleaved MIMO communications services. The MIMO communications streams 'A', 'B', 'C', and 'D' are routed to the remote units **318(1)-318(X)** interleaved to provide a 4x4 interleaved MIMO cell bonding configuration to support 4x4 interleaved MIMO communications services. Thus, by simply re-routing the MIMO communications streams MIMO communications streams 'A', 'B', 'C', and 'D' to the existing remote units **318(1)-**

318(X) in **FIG. 9A** or **9B**, the remote units **318(1)-318(X)** can be configured to migrate from only supporting SISO communications services, or 2x2 interleaved MIMO communications services, to 4x4 interleaved MIMO communications services.

[0071] To configure or re-configure the DCS **300** to support the desired communications services, whether it be SISO communications services or interleaved MIMO communication services, the DCS **300** provides different physical layers that are maintained from the central unit **306** to the remote units **318(1)-318(X)**. In this manner, the central unit **306** can be configured or reconfigured to distribute communications signals, to the desired physical layers in the DCS **300** to in turn distribute the communications signals to the desired remote units **318(1)-318(X)** to provide the desired communications services. In this manner, as an example, interleaved MIMO communications services can be configured for the DCS **300** using an existing infrastructure of remote units **318(1)-318(X)** having substantially non-overlapping remote coverage areas **600(1)-600(X)**, by directing the MIMO communications streams over the configured physical layers to be provided to the desired remote units **318(1)-318(X)** to facilitate interleaved MIMO cell bonding of adjacent remote units **318(1)-318(X)**. For example, substantially non-overlapping coverage areas may mean that the coverage areas do not overlap by more than 70%, 60%, 50%, or less than 50% as examples.

[0072] In this regard, **FIG. 10A** is a schematic diagram illustrating the DCS **300** in **FIGS. 5A** and **5B** configured to support distribution of SISO communications streams to remote units **318(1)-318(X), 318(8)** (where 'X' = 8 in this example) to support SISO communication services. The remote units **318(1)-318(8)** are installed in the DCS **300** according to the desired locations and desired separation distances (e.g., between 12-15 meters) to provide the desired remote coverage areas. The central unit **306** is configured to receive downlink SISO communications signals **308D-S(A)-308D-S(C)** from a signal source, such as a base transceiver station (BTS) or baseband unit (BBU) as examples, where each downlink SISO communications signals **308D-S(A)-308D-S(C)** represents a particular communications band 'A', 'B', 'C' for a particular communications service. As previously discussed in regard to **FIG. 3**, the central unit **306** includes the radio interface circuits **304(1)-304(T)** that are configured receive and process the received downlink SISO communications signals **308D-S(A)-308D-S(C)**. As also discussed in regard to **FIG. 3**, in this example, the central unit **306** also includes the optical interface circuits **310(1)-310(W)** to convert the received downlink SISO communications signals **308D-S(A)-308D-S(C)** into optical downlink SISO communications signals **308D-S(A)-308D-S(C)**. A routing circuit **1000** is also provided, which may also be in the central unit **306**, to route the downlink SISO communications signals **308D-S(A)-308D-S(C)** to the desired remote units **318(1)-318(8), 318(X)** (where 'X' = 8 in this example) according to a routing configuration **1004** for the DCS **300**. In this regard, the DCS **300** includes physical layers **1002(1)-1002(8)** dedicated to each of the remote units **318(1)-318(8)**. Each physical layer **1002(1)-1002(8)** is dedicated to one remote unit **318(1)-318(8)** and maintained from the central unit **306** to the remote units **318(1)-318(8)** in a one-to-one connectivity in this example. In this example, the physical layers **1002(1)-1002(8)** are the dedicated communications links in the form of optical fiber communications links **314(1)-314(8)**. The physical layers **1002(1)-1002(8)** can be downlink physical layers only dedicated to carrying downlink communications signals to the remote units **318(1)-318(8)** or also configured to carry uplink communications signals from the remote units **318(1)-318(8)** to the central unit **306**. Each optical fiber communications link **314(1)-314(8)** can separate optical fiber communications links for carrying downlink and uplink communications signals separately as shown in **FIG. 3**, or a single optical fiber communications link for carrying uplink and downlink communications signals. For example, **FIG. 10B** is a schematic diagram illustrating a communications services layout **1006** of remote units **318(1)-318(8)** in the DCS **300** in **FIG. 10A** installed in a building **1008**. The remote units **318(1)-318(8)** are located in building **1008** according to the desired locations to provide the desired remote coverage areas.

[0073] With reference back to **FIG. 10A**, the routing circuit **1000** is configured to control the routing of the optical interface circuits **310(1)-310(W)** to the physical layers **1002(1)-1002(8)** according to the routing configuration **1004** to control which downlink SISO communications signals **308D-S(A)-308D-S(C)** are routed to the remote units **318(1)-318(8)**. The routing circuit **1000** controls the spatial deployment of communications signals to the remote units **318(1)-318(8)**. In this example, the HEC **362** as shown in **FIG. 4B** may be configured to program the routing configuration **1004** of the routing circuit **1000**. The routing configuration **1004** may be stored in a memory or other circuit settings. In this example, the routing configuration **1004** is configured to cause the routing circuit **1000** to route the downlink SISO communications signals **308D-S(A)** to remote units **318(1)-318(3),** the downlink SISO communications signals **308D-S(B)** to remote units **318(4)-318(6)**, and the downlink SISO communications signals **308D-S(C)** to remote units **318(7)-318(8)**. The remote units **318(1)-318(8)** are also configured to receive and distribute received respective uplink SISO communications signals **308U-S(A)(1)-308U-S(A)(3), 308U-S(B)(1)-308U-**

S(B)(3), 308U-S(C)(1)-308U-S(C)(2) over the respective dedicated physical layers **1002(1)-1002(8)** to the central unit **306** to be distributed back to a network, such as BTS or BBU. The routing circuit **1000** routes the received uplink SISO communications signals **308U-S(A)(1)-308U-S(A)(3), 308U-S(B)(1)-308U-S(B)(3), 308U-S(C)(1)-308U-S(C)(2)** from the dedicated physical layers **1002(1)-1002(8)** to particular radio interface circuits **304(1)-304(T)** according to the routing configuration **1004**.

[0074] It may be desired for DCS **300** in **FIG. 10A** to support MIMO communications services, such as 2x2 MIMO communications services. It may be desired to configure the DCS **300** in **FIG. 10A** to support MIMO communications without having to change the location of the remote units **318(1)-318(X)**. In this regard, by changing the routing configuration **1004** to provide for interleaved MIMO cell bonding between adjacent remote units **318(1)-318(8)** as previously discussed, it may be possible to re-configure the DCS **300** to support MIMO communications without having to change the location of the remote units **318(1)-318(8)** or with minimal relocating or providing of additional remote units **318(1)-318(8)**. This provides an upgrade path for customers of the DCS **300** in **FIG. 10A** should, for example, only SISO communications services be initially desired to be supported, but then MIMO communications services may be desired to be supported in the future.

[0075] In this regard, **FIG. 11A** is a schematic diagram illustrating the DCS **300** in **FIGS. 5A** and **5B** configured to support distribution of SISO communications streams to remote units **318(1)-318(X), 318(8)** (where ‘X’ = 8 in this example) to support MIMO communications services. The remote units **318(1)-318(8)** are installed in the DCS **300** according to the desired locations and desired separation distances (e.g., between 12-15 meters) to provide the desired remote coverage areas. The central unit **306** is configured to receive downlink MIMO communications signals **308D-M(A), 308D-M(B)** for MIMO communications streams ‘A’ and ‘B’, such as from a BTS or BBU as examples. Each downlink MIMO communications signals **308D-M(A), 308D-M(B)** represents a particular MIMO communications stream ‘A’, ‘B’ for a communications service. As previously discussed in regard to **FIG. 3**, the central unit **306** includes the radio interface circuits **304** that are configured to receive and process the received downlink MIMO communications signals **308D-M(A), 308D-M(B)**. This processing may include splitting the downlink MIMO communications signals **308D-M(A), 308D-M(B)** so that each can be deployed to multiple remote units **318(1)-318(8)** according to the routing configuration **1004**. As also discussed in regard to **FIG. 3**, in this example, the central unit **306** also includes the optical interface circuits **310** to convert the received downlink MIMO communications signals **308D-M(A), 308D-M(B)** into optical downlink MIMO communications signals **308D-M(A), 308D-M(B)**. The routing circuit **1000** is configured to route the downlink MIMO communications signals **308D-M(A), 308D-M(B)** to the desired remote units **318(1)-318(8), 318(X)** (where 'X' = 8 in this example) according to the routing configuration **1004** for the DCS **300**. In this regard, the DCS **300** includes the physical layers **1002(1)-1002(8)** dedicated to each of the remote units **318(1)-318(8)**. The physical layers **1002(1)-1002(8)** dedicated to each of the remote units **318(1)-318(8)** are maintained from the central unit **306** to the remote units **318(1)-318(8)**. In this example, the physical layers **1002(1)-1002(8)** are the dedicated communications links in the form of optical fiber communications links **314(1)-314(8)**. Each optical fiber communications link **314(1)-314(8)** can separate optical fiber communications links for carrying downlink and uplink communications signals separately as shown in **FIG. 3**, or a single optical fiber communications link for carrying uplink and downlink communications signals.

[0076] For example, **FIG. 11B** is a schematic diagram illustrating a communications services layout **1100** of sixteen (16) remote units **318(1)-318(16)** in the DCS **300** in **FIG. 11A** installed in the building **1008**. The remote units **318(1)-318(16)** may be located in building **1008** in the same configuration as in the communications services layout **1006** in **FIG. 10B**. In the communications services layout **1100,** the remote units **318(1)-318(16)** are located approximately 6 meters from each other. Areas **1102** in the building **1008** illustrated in **FIG. 11B** are areas where a wireless client device can receive a downlink communications signal from a remote unit **318(1)-318(16)** above a threshold signal strength (e.g., reference signal receive power (RSRP)) sufficient to engage in SISO communications (e.g., > 12 dB). Areas **1104** in the building **1008** illustrated in **FIG. 11B** are areas where a wireless client device cannot receive a downlink communications signal from a remote unit **318(1)-318(16)** above a threshold signal strength sufficient to engage in SISO communications (e.g., < 12 dB), and thus 2x2 interleaved MIMO communications are supported according to the interleaved MIMO communications configuration for the DCS **300** illustrated in **FIG. 11A**.

[0077] **FIG. 11C** is a schematic diagram illustrating another communications services layout **1110** of remote units **318(1)-318(8)** in the DCS **300** in **FIG. 11A** installed in the building **1008**. In the communications services layout **1110,** the remote units **318(1)-318(8)** are located approximately 12 meters from each other. Areas **1112** in the building **1008** illustrated in **FIG. 11C** are areas where a wireless client device can receive a downlink communications signal from a remote unit **318(1)-318(8)** above a threshold signal strength (e.g., reference signal receive power (RSRP)) sufficient to engage in SISO communications (e.g., > 12 dB). Areas **1114** in the building **1008** illustrated in **FIG. 11C** are areas where a wireless client device cannot receive a downlink communications signal from a remote unit **318(1)-318(8)** above a threshold signal strength sufficient to engage in SISO communications (e.g., < 12 dB), and thus 2x2 interleaved MIMO communications are supported according to the interleaved MIMO communications configuration for the DCS **300** illustrated in **FIG. 11A**. Note that the area **1114** in the building **1008** in **FIG. 11C** where 2x2 interleaved MIMO communications services are supported is smaller than the area **1104** in building **1008** in **FIG. 11B**, because the remote units **318(1)-318(8)** are spaced farther apart in the building **1008** in **FIG. 11C**. For example, area **1104** in **FIG. 11B** wherein the 2x2 interleaved MIMO communications services is supported may be approximately 97% of the total areas **1102, 1104** where communication services are supported by the DCS **300**, whereas area **1114** in **FIG. 11C** may be approximately 76% of the total areas **1112, 1114** where communication services are supported. Nevertheless, a 76% area supporting interleaved MIMO communications services is provided with approximately half of the number of remote units **318(1)-318(8)**, which may be an acceptable tradeoff.

[0078] With reference back to **FIG. 11A**, the routing circuit **1000** is configured to control the routing of the optical interface circuits **310(1)-310(W)** to the physical layers **1002(1)-1002(8)** according to the routing configuration **1004** to control which downlink SISO communications signals **308D-S(A)-308D-S(C)** are routed to the remote units **318(1)-318(8)**. In this example, the HEC **362** as shown in **FIG. 4B** may be configured to program the routing configuration **1004** of the routing circuit **1000**. The routing configuration **1004** may be stored in a memory or other circuit settings. In this example, the routing configuration **1004** is configured to cause the routing circuit **1000** to route the downlink MIMO communications signals **308D-M(A)** to remote units **318(1), 318(3), 318(5), 318(7),** and the downlink MIMO communications signals **308D-M(B)** to remote units **318(2), 318(4), 318(6), 318(8)**. In this regard, remote unit **318(1)** is interleaved MIMO cell bonded to adjacent remote units **318(2), 318(3)**, remote unit **318(2)** is interleaved MIMO cell bonded to adjacent remote units **318(1), 318(4)**, remote unit **318(3)** is interleaved MIMO cell bonded to adjacent remote units **318(1), 318(4)**, as so on, as shown in **FIG. 11A**. The remote units **318(1)-318(8)** are also configured to receive and distribute received respective uplink MIMO communications signals **308U-M(A)(1)-308U-M(A)(4), 308U-M(B)(1)-308U-M(B)(4)** from the respective remote units

318(1), **318(3)**, **318(5)**, **318(7)**, **318(2)**, **318(4)**, **318(6), 318(8)** over dedicated physical layers **1002(1)-1002(8)** to the central unit **306** to be distributed back to a network, such as BTS or BBU. The routing circuit **1000** routes the received uplink MIMO communications signals **308U-M(A)(1)-308U-M(A)(4), 308U-M(B)(1)-308U-M(B)(4)** from the dedicated physical layers **1002(1)-1002(8)** to particular radio interface circuits **304(1)-304(T)** according to the routing configuration **1004**.

[0079] Note that while **FIG. 11A** shows downlink MIMO communications signals **308D-M(A)** are routed to physical layers **1002(1), 1002(3), 1002(5), and 1002(7)** distributed to remote units **318(1), 318(3), 318(5)**, and **318(7)**, and downlink MIMO communications signals **308D-M(B)** are routed to physical layers **1002(2), 1002(4), 1002(6),** and **1002(8)** to be distributed to remote units **318(2), 318(4), 318(6), and 318(8)**, it is also possible to route the same downlink MIMO communications signal (e.g., downlink MIMO communications signal **308D-M(A)** and/or downlink MIMO communications signal **308D-M(B)**) to the same physical layer **1002(1)-1002(8)** to be routed to the same remote unit **318(1)-318(8)**. for example downlink MIMO communications signal **308D-M(A)** and downlink MIMO communications signal **308D-M(B)** could be routed to the same remote unit **318(1)-318(8)** is configured to provide co-located MIMO communications services. Different groupings of downlink MIMO communications signal (e.g., downlink MIMO communications signal **308D-M(A)** and/or downlink MIMO communications signal **308D-M(B)**) can be routed to groupings of the remote units **318(1)-318(8)**.

[0080] It may also be desired for DCS **300** in **FIG. 11A** to support enhanced MIMO communications services, such as 4x4 MIMO communications services. It may be desired to configure the DCS **300** in **FIG. 11A** to support MIMO communications without having to change the location of the remote units **318(1)-318(X)**. In this regard, by changing the routing configuration **1004** to provide for interleaved MIMO cell bonding between adjacent remote units **318(1)-318(8)** as previously discussed, it may be possible to re-configure the DCS **300** to support 4x4 MIMO communications without having to change the location of the remote units **318(1)-318(8)** or with minimal relocating or providing of additional remote units **318(1)-318(8)**. This provides an upgrade path for customers of the DCS **300** in **FIG. 11A** should, for example, only 2x2 MIMO communications services be initially desired to be supported, but then 4x4 MIMO communications services may be desired to be supported in the future.

[0081] In this regard, **FIG. 12** is a schematic diagram illustrating the DCS **300** in **FIGS.**

5A and **5B** configured to support distribution of 4x4 interleaved MIMO communications streams to remote units **318(1)-318(X), 318(8)** (where 'X' = 8 in this example) to support MIMO communications services. The remote units **318(1)-318(8)** are installed in the DCS **300** according to the desired locations and desired separation distances (e.g., between 12-15 meters) to provide the desired remote coverage areas. The central unit **306** is configured to receive downlink MIMO communications signals **308D-M(A)-308D-M(D)** for MIMO communications streams 'A', 'B', 'C', and 'D' such as from a BTS or BBU as examples. Each downlink MIMO communications signal **308D-M(A)-308D-M(D)** represents a particular MIMO communications stream 'A', 'B', 'C', and 'D' for a communications service. As shown in **FIG. 12**, the central unit **306** includes radio interface circuits **304A, 304B** that are configured to receive and process the respective received downlink MIMO communications signals **308D-M(A), 308D-M(B)** and **308D-M(C), 308D-M(D)**. As also illustrated in this example in **FIG. 12**, the central unit **306** includes the optical interface circuits **310A, 310B** to convert the respective received downlink MIMO communications signals **308D-M(A), 308D-M(B)**, and **308D-M(C), 308D-M(D)** into optical downlink MIMO communications signals **308D-M(A), 308D-M(B)** and **308D-M(C), 308D-M(D)**. The routing circuit **1000** is configured to route the downlink MIMO communications signals **308D-M(A), 308D-M(B)** and **308D-M(C), 308D-M(D)** to the desired remote units **318(1)-318(8), 318(X)** (where 'X' = 8 in this example) according to the routing configuration **1004** for the DCS **300**. In this regard, the DCS **300** includes the physical layers **1002(1)-1002(8)** dedicated to each of the remote units **318(1)-318(8)**. The physical layers **1002(1)-1002(8)** dedicated to each of the remote units **318(1)-318(8)** are maintained from the central unit **306** to the remote units **318(1)-318(8)**. In this example, the physical layers **1002(1)-1002(8)** are the dedicated communications links in the form of optical fiber communications links **314(1)-314(8)**. Each optical fiber communications link **314(1)-314(8)** can separate optical fiber communications links for carrying downlink and uplink communications signals separately as shown in **FIG. 3**, or a single optical fiber communications link for carrying uplink and downlink communications signals.

[0082] With continuing reference to **FIG. 12**, the routing circuit **1000** is configured to control the routing of the optical interface circuits **310A, 310B** to the physical layers **1002(1)-1002(8)** according to the routing configuration **1004** to control which downlink MIMO communications signals **308D-M(A)-308D-M(D)** routed to the remote units **318(1)-318(8)**. In this example, the HEC **362** as shown in **FIG. 4B** may be configured to program the routing configuration **1004** of the routing circuit **1000**. The routing configuration **1004** may be stored in a memory or other circuit settings. In this example, the routing configuration **1004** is configured to cause the routing circuit **1000** to route the downlink MIMO communications signals **308D-M(A)** to remote units **318(1)** and **318(5)**, downlink MIMO communications signals **308D-M(B)** to remote units **318(2)** and **318(6)**, downlink MIMO communications signals **308D-M(C)** to remote units **318(3)** and **318(7)**, and downlink MIMO communications signals **308D-M(D)** to remote units **318(4)** and **318(8)**. In this regard, remote unit **318(1)** is interleaved MIMO cell bonded to adjacent remote units **318(2)-318(4)**, remote unit **318(2)** is interleaved MIMO cell bonded to adjacent remote units **318(1), 318(3), 318(4)**, remote unit **318(3)** is interleaved MIMO cell bonded to adjacent remote units **318(1), 318(4), 318(5)**, and so on, as shown in **FIG. 12**. The remote units **318(1)-318(8)** are also configured to receive and distributed received respective uplink MIMO communications signals **308U-M(A)(1)-308U-M(A)(2), 308U-M(B)(1)-308U-M(B)(2), 308U-M(C)(1)-308U-M(C)(2),** and **308U-M(D)(1)-308U-M(D)(2)** from the respective remote units **318(1)**, **318(5)**, **318(2)**, **318(6)**, **318(3)**, **318(7)**, **318(4), 318(8)** over dedicated physical layers **1002(1)-1002(8)** to the central unit **306** to be distributed back to a network, such as BTS or BBU. The routing circuit **1000** routes the received uplink MIMO communications signals **308U-M(A)(1)-308U-M(A)(2), 308U-M(B)(1)-308U-M(B)(2), 308U-M(C)(1)-308U-M(C)(2),** and **308U-M(D)(1)-308U-M(D)(2)** from the dedicated physical layers **1002(1)-1002(8)** to particular radio interface circuits **304A, 304B** according to the routing configuration **1004.**

[0083] To support configuration or reconfiguration of interleaved MIMO communications services in the DCS **300**, the DCS **300** can also support simulating the interleaved MIMO performance of the DCS **300** to determine possible interleaved MIMO communication service configurations to be presented to a technician or customer. In this regard, the interleaved MIMO performance of an existing DCS **300** infrastructure is simulated. This simulation can involve the use of RF simulation software that may be resident in the DCS **300** or located outside the DCS **300**, such as in the cloud accessible to the DCS **300** to be executed by a processor circuit, such as the HEC **362**. Alternatively, the RF simulation software may be resident and executed in a standalone computer system outside of the DCS **300**. The simulated interleaved MIMO performance of an existing DCS **300** can be used to determine possible interleaved MIMO configurations in the DCS **300** along with the associated configurations and changes needed to realize such possible interleaved MIMO configurations. For example, the simulation may involve creating a "heat" map of both

SISO and interleaved MIMO remote coverage areas of the remote units **318(1)-318(X)** in the DCS **300** based on existing configurations for and locations of the remote units **318(1)-318(X)** and the assigned routing of MIMO communications streams over the physical layers **1002(1)-1002(X)** to the remote units **318(1)-318(X)**. These possible interleaved MIMO communications service configurations can then be presented to a technician or customer to determine if any of the possible interleaved MIMO communications service configurations should be deployed in the DCS **300**. For example, one possible interleaved MIMO communication service configuration may be to change the supported MIMO communications services from 2x2 interleaved MIMO communications services to 4x4 interleaved MIMO communications services. If the possible interleaved MIMO communications service configurations should be deployed in the DCS **300**, the DCS **300** can be reconfigured to support the selected interleaved MIMO communications service configurations. If the infrastructure of the DCS **300** is indicated as not being able to be changed, the possible interleaved MIMO communications service configurations presented will involve using the existing infrastructure of remote units **318(1)-318(X)** and their locations, but with possible different physical layer **1002(1)-1002(X)** assignments for distribution of MIMO communications streams to the remote units **318(1)-318(X)**. If the infrastructure of the DCS **300** is indicated as being able to be changed, the possible interleaved MIMO communications service configurations presented can also involve changing (e.g., adding to) the number and/or location remote units **318(1)-318(X)** along with possible different physical layer **1002(1)-1002(X)** assignments for distribution of MIMO communications streams to the remote units **318(1)-318(X)**.

[0084] In this regard, **FIG. 13** is a flowchart illustrating an exemplary process **1300** of configuring and/or re-configuring the DCS **300** in in **FIGS. 5A** and **5B** to support interleaved MIMO communications services based on the existing remote units **318(1)-318(X)** deployed in the DCS **300** and their installed locations to achieve a desired interleaved MIMO communications services performance in the DCS **300**. The process **1300** may be represented by software instructions resident in the DCS **300** and executed by the HEC **362** as an example. The process **1300** is referenced below as being executed by the HEC **362**, but such could be executed by another circuit or other computer outside of the DCS **300**. The process starts (block **1302**), such as by initiation by a technician or customer sending an interleaved MIMO communications service configuration request to the HEC **362**. It is determined by the HEC **362** if interleaved MIMO communications are already deployed for the DCS **300** (block **1304**). The HEC **362** can check the routing configuration **1004** (**FIG. 10A**) or other setting in the DCS **300** for example to determine if interleaved MIMO communications are already deployed for the DCS **300**. If interleaved MIMO communications are already deployed for the DCS **300**, the customer or technician can be notified, such as through a display or by communicating such information over the external interface **360** (**FIG. 4B**) to another system (block **1306**). The process then ends (block **1308**).

[0085] With continuing reference to **FIG. 13**, if in block **1304**, interleaved MIMO communications are not already deployed for the DCS **300**, the HEC **362** determines if configuring the DCS **300** to support interleaved MIMO communications should be for the infrastructure of existing remote units **318(1)-318(X)** as they exist and are deployed in the DCS **300**, or if redesigns to the number and/or location of the remote units **318(1)-318(X)** in the DCS **300** are possible (block **1310**). For example, a customer or technician may indicate this information via the external interface **360**, such as from a keyboard input or touchscreen input on a display as examples. If the configuring of the DCS **300** to support interleaved MIMO communications should be for the infrastructure of existing remote units **318(1)-318(X)** as they exist, the HEC **362** then performs an interleaved MIMO upgrade estimation to determine how the physical layers **1002(1)-1002(X)** can be assigned to the remote units **318(1)-318(X)** to support interleaved MIMO communications (block **1312**). A simulation software, which may be resident in the DCS **300**, and is executed by the HEC **362** analyzes the existing performance of the DCS **300** and provides one or more possible interleaved MIMO communications service configurations based on the analyzed performance with no additional remote unit **318(1)-318(X)** and no changes to the existing locations of the remote units **318(1)-318(X)** (block **1314**). The process then obtains the requirements of one or more different interleaved MIMO communication services based on the analyzed performance of the DCS **300** (block **1316**). The different interleaved MIMO communications services could include 2x2 interleaved MIMO communications service, 4x4 interleaved MIMO communications service, NxN interleaved MIMO communications services. The requirements, such as coverage areas, capacity, bill of materials (BOM) space requirements, benchmark information along with other options such as CAPEX and OPEX savings, can be determined to achieve each of the different interleaved MIMO communications services (block **1318**). For example, a 2x2 MIMO RF performance simulation using a given building model can estimate or predict the percentage MIMO coverage possible in a building. As an example, a BOM generation software tool can be employed to provide details of the radio interface circuits **304** required, RDCs **354, 356** or physical layers required and/or how to group communications services and on to what physical layers **1002(1)-1002(X)**. The HEC **362** for example may execute software instructions facilitates a step-by-step process for performing such simulation, such as on a graphical user interface (GUI). For example, a BOM software tool can be configured to interface with a database that has associated costs per the BOM generated by the BOM generator software tool. The performance, BOM, space, and cost requirements can be generated for each option including the original design. The options can be compared with the original design to understand the cost savings, performance gains, and/or space requirements for each option.

[0086] The different interleaved MIMO communications services along with their determined requirements could then be presented to the technician or customer, along with the associated costs and savings information to determine if the technician or customer would like to enable a routing configuration **1004** to provide a desired interleaved MIMO communications services (block **1320**). If the customer or technician does not choose to deploy a presented interleaved MIMO communications service, the process ends (block **1308**). If however, the customer or technician does choose to deploy a presented interleaved MIMO communications service, the HEC **362** determines the validity of the choice and guides the technician or customer through the deployment steps, to activate the appropriate settings and files in the DCS **300** to update the routing configuration **1004**, and then notifies the customer or technician (block **1322**).

[0087] With continuing reference to **FIG. 13**, if in block **1310**, it is decided that the configuring of the DCS **300** to support interleaved MIMO communications can allow redesign and/or re-configuration of the existing remote units **318(1)-318(X)** as they exist, the HEC **362** then performs an interleaved MIMO upgrade estimation to determine how the physical layers **1002(1)-1002(X)** can be assigned to the remote units **318(1)-318(X)** to support interleaved MIMO communications (block **1324**). If the configuring of the DCS **300** to support interleaved MIMO communications can allow for a redesign of infrastructure of the remote units **318(1)-318(X)**, the HEC **362** then performs an interleaved MIMO upgrade estimation to determine how the physical layers **1002(1)-1002(X)** can be assigned to the remote units **318(1)-318(X)** to support interleaved MIMO communications based on changes to locations of the remote units **318(1)-318(X)** to achieve the optimum antenna to antenna distance in the remote units **318(1)-318(X)** (block **1326**). A simulation software, which may be resident in the DCS **300**, and is executed by the HEC **362** analyzes the existing performance of the DCS **300** and provides one or more possible interleaved MIMO communications service configurations based on the analyzed performance with no additional remote unit **318(1)-318(X)** and no changes to the existing locations of the remote units **318(1)-318(X)** (block **1326**). The process then obtains the requirements one or more different interleaved MIMO communications services based on the analyzed performance of the DCS **300** (block **1328**). The different interleaved MIMO communications services could include 2x2 interleaved MIMO communications service, 4x4 interleaved MIMO communications service, NxN interleaved MIMO communications services. The requirements, such as coverage areas, capacity, BOM space requirements, benchmark information along with other options such as CAPEX and OPEX savings, can be determined to achieve each of the different interleaved MIMO communications services (block **1328**). The different interleaved MIMO communications services along with their determined requirements could then be presented to the technician or customer, along with the associated costs and savings information to determine if the technician or customer would like to enable a routing configuration **1004** to provide a desired interleaved MIMO communications service (block **1330**). If the customer or technician does not choose to deploy a presented interleaved MIMO communication service, the process ends (block **1308**). If however, the customer or technician does choose to deploy a presented interleaved MIMO communication service, the HEC **362** determines the validity of the choice and guides the technician or customer through the deployment steps, to activate the appropriate profile settings and files in the DCS **300** to update the routing configuration **1004**, and then notifies the customer or technician (block **1322**).

[0088] **FIG. 14** is a flowchart illustrating an exemplary process **1400** of configuring and/or re-configuring the DCS in in **FIGS. 5A** and **5B** to support interleaved MIMO communications services based on the existing remote units **318(1)-318(X)** deployed in the DCS **300** and with repositioning installed locations of remote units **318(1)-318(X)** and/or adding MIMO communications streams to achieve a desired interleaved MIMO communications services performance in the DCS **300**. The process **1400** in **FIG. 14** can be employed as the processes involved in blocks **1312-1318** and **1324-1330** in **FIG. 13**. The process starts (block **1402**), and the existing remote unit **318(1)-318(X)** design for providing SISO communications services is loaded into the DCS **300** to build a model of the DCS **300** using a RF simulation software program (block **1404**). For example, the RF simulation software program could generate reports on existing interleaved MIMO communications service, such as a "heat map" on required additional BOM, costs, and performance improvements needed to achieve along with comparisons between the different interleaved MIMO communications services and SISO communications services and co-located or traditional MIMO communications services (block **1406**). The user could also generate estimates on the required additional BOM, budget, performance and improvement metrics of MIMO cell bonding configuration options and compare such with alternative co-located MIMO communications services implementations using the RF simulation software program or other means. The user can then use the RF simulation software program or other program to obtain characteristics of different interleaved MIMO communications services that could include obtaining one or more performance characteristics to provide 2x2 interleaved MIMO communications service, 4x4 interleaved MIMO communications service, NxN interleaved MIMO communications services by the RF simulation software program (block **1408**). These requirements, such as coverage areas, capacity, BOM space requirements, benchmark information along with other options such as CAPEX and OPEX savings, can be determined to achieve each of the different interleaved MIMO communications services (block **1408**). The different interleaved MIMO communications services and their performance along with their determined requirements could then be presented to the technician or customer, along with the associated costs and savings information to determine if the technician or customer would like to enable a routing configuration **1004** to provide a desired interleaved MIMO communication service (block **1410**). The validity of the selected MIMO communications service along with the ability of the DCS **300** and remote units **318(1)-318(X)** to achieve is then determined along with the necessary profiles, settings, and routing configuration **1004** to enable the selected interleaved MIMO communications service for a future deployment, if desired (block **1412**). Optionally, on the user request, the user can interface with the RF simulation software program to navigate through equipment installation steps, to enable the requested MIMO cell bonding profile, validate the performance of selected interleaved MIMO communications against the estimated results and present the results, such as through a GUI or other display. The HEC **362** then enables the selected interleaved MIMO communications service, and validates the performance against the estimated performance to present the result to the technician or user (block **1414**), and the process ends (block **1416**).

[0089] **FIGS. 15A** and **15B** are diagrams of exemplary graphical user interfaces (GUI) **1500, 1530** that facilitate configuring and/or reconfiguring distribution of MIMO communications streams in a DCS, such as the DCS **300** in **FIGS. 5A** and **5B** and according to any of the exemplary interleaved MIMO communications services discussed herein. The HEC **362** for example may execute software instructions that generate the GUIs **1500, 1530** to be displayed on a display in a computer system to a customer or technician in response to a processor executing of software instructions. In this regard, as shown in **FIG. 15A**, the GUI **1500** includes a main menu **1502** of options to manage the configuration and settings of the DCS **300** to provide the desired communications services. For example, a user can select the CONFIG tab **1504** to review and edit the configuration settings for the DCS **300**. The DCS **300** selected is shown in the DCS identification section **1505**. A workstation mix area **1506** is presented to the user that includes a floor plan layout of a building in which the DCS **300** is installed. Details of the existing rooms and planned rooms for the building in which the DCS **300** is installed as shown in building and planning areas **1508, 1510**. The administration history of the DCS **300** is displayed in an administration history area **1512**. The module information on the modules in the DCS **300** is shown in a modulation information area **1513** in response to selection of the module information tab **1514**. The RF presentation of the DCS **300** to show a heat map of the DCS **300** can be initiated by selecting the RF presentation tab **1516**. The module configuration in the DCS **300** can be modified by selecting the modify button **1518** and viewed by selecting the view button **1520**.

[0090] **FIG. 15B** illustrates another GUI **1530** that is based on selected the profiles tab **1532** in the main menu **1502**. As discussed above, profiles store configuration information for configuring the DCS **300** to provide the desired communications services. The central unit **306** configuration of the DCS **300** is shown in area **1536**. The optical ports of the DCS **300** for the selected optical interface circuit **310** are shown in area **1538**, where optical port 1 **1540(1)** is shown as being configured. Optical ports 2 and 3 can be added or removed by selecting the add remove buttons **1541(2), 1541(3)**. A profile list **1546** of the DCS **300** is shown with the names of profiles **1542** that can be configured for the DCS **300** to achieve different communications services. For a selected profile **1542** in the profiles list **1546**, profile options **1544** are provided for creating, importing profiles, including from third party software such as IBWave for example. These profiles **1542** can be imported to configure the DCS **300**. A selected profile **1542** can also be modified by selecting a button **1550** in a profile options window **1548**. These modifications can include editing, deleting, returning, saving, exporting, and activation of a selected profile **1542**.

[0091] The software executed to perform the processes in **FIGS. 13** and **14**, and generate the GUIs **1500, 1530** in **FIGS. 15A** and **15B** could be provided by the RF simulation software program discussed in U.S. Patent Application Serial No. 15/332,603, entitled "Implementing A Live Wireless Distribution System (WDS) Configuration From A Virtual WDS Design Using An Original Equipment Manufacturer (OEM) Specific Software System In A WDS," which is incorporated by reference herein in its entirety.

[0092] **FIG. 16** is a schematic diagram representation of additional detail illustrating a computer system **1600** that could be employed in any component in the DCS **300**, including but not limited to the routing circuit **1000** (**FIGS. 10A, 11A** and **12**), and the HEC **362** (**FIG. 4B**) to support configuring and/or reconfiguring distribution of MIMO communications streams to support interleaved MIMO communications services. The computer system **1600** can be configured to support programming a routing configuration **1004**, and/or to support providing GUI to a display, as shown in **FIGS. 15A** and **15B** for example. In this regard, the computer system **1600** is adapted to execute instructions from an exemplary computer-readable medium to perform these and/or any of the functions or processing described herein. The computer system **1600** may be connected (e.g., networked) to other machines in a LAN, an intranet, an extranet, or the Internet. While only a single device is illustrated, the term "device" shall also be taken to include any collection of devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein. The computer system **1600** may be a circuit or circuits included in an electronic board card, such as, a printed circuit board (PCB), a server, a personal computer, a desktop computer, a laptop computer, a personal digital assistant (PDA), a computing pad, a mobile device, or any other device, and may represent, for example, a server or a user's computer.

[0093] The exemplary computer system **1600** in this embodiment includes a processing device or processor **1602**, a main memory **1604** (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM), such as synchronous DRAM (SDRAM), etc.), and a static memory **1606** (e.g., flash memory, static random access memory (SRAM), etc.), which may communicate with each other via a data bus **1608**. Alternatively, the processor **1602** may be connected to the main memory **1604** and/or static memory **1606** directly or via some other connectivity means. The processor **1602** may be a controller, and the main memory **1604** or static memory **1606** may be any type of memory. For example, the routing configuration **1004** may be stored in the main memory **1604** and loaded into static memory **1606** when being programmed, changed, or otherwise accessed, and then reloaded into main memory **1604**.

[0094] The processor **1602** represents one or more general-purpose processing devices, such as a microprocessor, central processing unit, or the like. More particularly, the processor **1602** may be a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or other processors implementing a combination of instruction sets. The processor **1602** is configured to execute processing logic in instructions for performing the operations and steps discussed herein.

[0095] The computer system **1600** may further include a network interface device **1610**. The computer system **1600** also may or may not include an input **1612**, configured to receive input and selections to be communicated to the computer system **1600** when executing instructions. The computer system **1600** also may or may not include an output **1614**, including but not limited to a display, a video display unit (e.g., a liquid crystal display (LCD) or a cathode ray tube (CRT)), an alphanumeric input device (e.g., a keyboard), and/or a cursor control device (e.g., a mouse).

[0096] The computer system **1600** may or may not include a data storage device that includes instructions **1616** stored in a computer-readable medium **1618**. The instructions **1616** may also reside, completely or at least partially, within the main memory **1604** and/or within the processor **1602** during execution thereof by the computer system **1600**, the main memory **1604** and the processor **1602** also constituting computer-readable medium. The instructions **1616** may further be transmitted or received over a network **1620** via the network interface device **1610**.

[0097] While the computer-readable medium **1618** is shown in an exemplary embodiment to be a single medium, the term "computer-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "computer-readable medium" shall also be taken to include any medium that is capable of storing, encoding, or carrying a set of instructions for execution by the processing device and that cause the processing device to perform any one or more of the methodologies of the embodiments disclosed herein. The term "computer-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, optical medium, and magnetic medium.

[0098] The embodiments disclosed herein include various steps. The steps of the embodiments disclosed herein may be formed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software.

[0099] The embodiments disclosed herein may be provided as a computer program product, or software, that may include a machine-readable medium (or computer-readable medium) having stored thereon instructions, which may be used to program a computer system (or other electronic devices) to perform a process according to the embodiments disclosed herein. A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes: a machine-readable storage medium (e.g., ROM, random access memory ("RAM"), a magnetic disk storage medium, an optical storage medium, flash memory devices, etc.); and the like.

[00100] Unless specifically stated otherwise and as apparent from the previous discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing," "computing," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data and memories represented as physical (electronic) quantities within the computer system's registers into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

[00101] The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatuses to perform the required method steps. The required structure for a variety of these systems will appear from the description above. In addition, the embodiments described herein are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the embodiments as described herein.

[00102] Those of skill in the art will further appreciate that the various illustrative logical blocks, modules, circuits, and algorithms described in connection with the embodiments disclosed herein may be implemented as electronic hardware, instructions stored in memory or in another computer-readable medium and executed by a processor or other processing device, or combinations of both. The components of the distributed antenna systems described herein may be employed in any circuit, hardware component, integrated circuit (IC), or IC chip, as examples. Memory disclosed herein may be any type and size of memory and may be configured to store any type of information desired. To clearly illustrate this interchangeability, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. How such functionality is implemented depends on the particular application, design choices, and/or design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present embodiments.

[00103] The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or other programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. Furthermore, a controller may be a processor. A processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

[00104] The embodiments disclosed herein may be embodied in hardware and in instructions that are stored in hardware, and may reside, for example, in RAM, flash memory, ROM, Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a remote station. In the alternative, the processor and the storage medium may reside as discrete components in a remote station, base station, or server.

[00105] It is also noted that the operational steps described in any of the exemplary embodiments herein are described to provide examples and discussion. The operations described may be performed in numerous different sequences other than the illustrated sequences. Furthermore, operations described in a single operational step may actually be performed in a number of different steps. Additionally, one or more operational steps discussed in the exemplary embodiments may be combined. Those of skill in the art will also understand that information and signals may be represented using any of a variety of technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips, that may be references throughout the above description, may be represented by voltages, currents, electromagnetic waves, magnetic fields, or particles, optical fields or particles, or any combination thereof.

[00106] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps, or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is in no way intended that any particular order be inferred.

[00107] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit or scope of the invention. Since modifications, combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and their equivalents.

What is claimed is:

1. A distributed communications system (DCS), comprising:

a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units;

the central unit configured to:

distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration; and

distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units; and

the plurality of remote units each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers, each remote unit among the plurality of remote units comprising at least one antenna and configured to:

distribute received uplink communications signals received over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit; and

distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna;

the central unit further configured to:

configure the routing configuration to:

assign a first multiple-input, multiple-output (MIMO) communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area; and

assign a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

2. The DCS of claim 1, wherein the central unit is further configured to configure the routing configuration to:

assign a third MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area overlapping with the first remote coverage area and the second remote coverage area to interleave MIMO cell bond the third remote unit to the first remote unit and the second remote unit; and

assign a fourth MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the first remote coverage area, the second remote coverage area, and the third remote coverage area to interleave MIMO cell bond the fourth remote unit to the first remote unit, the second remote unit, and the third remote unit.

3. The DCS of claim 1, wherein the central unit is further configured to configure the routing configuration to:

assign a third MIMO communications signal among the received one or more downlink communications signals for a second MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area; and

assign a fourth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the third remote coverage area to interleave MIMO cell bond the third remote unit and the fourth remote unit.

4. The DCS of claim 3, wherein the central unit is further configured to configure the routing configuration to:

assign a fifth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a fifth remote unit among the plurality of remote units having a fifth remote coverage area; and

assign a sixth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a sixth remote unit among the plurality of remote units having a sixth remote coverage area overlapping with the fifth remote coverage area to interleave MIMO cell bond the fifth remote unit and the sixth remote unit.

5. The DCS of claim 1, wherein the central unit comprises at least one MIMO splitter circuit configured to:

split the first MIMO communications signal into at least two first split MIMO communications signals;

split the first MIMO communications signal into at least two second split MIMO communications signals;

the central unit configured to configure the routing configuration to:

assign a first split MIMO communications signal of the at least two first split MIMO communications signals for the first MIMO communications service to the first remote unit among the plurality of remote units having the first remote coverage area; and

assign a second split MIMO communications signal of the at least two first split MIMO communications signals for the first MIMO communications service to the second remote unit among the plurality of remote units having the second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit;

assign a first split MIMO communications signal of the at least two second split MIMO communications signals for the first MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area; and

assign a second split MIMO communications signal of the at least two second split MIMO communications signals for the first MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the third remote coverage area to interleave MIMO cell bond the third remote unit and the fourth remote unit.

6. The DCS of claim 1, wherein the central unit comprises at least one MIMO splitter circuit configured to:

split the first MIMO communications signal into at least two first split MIMO communications signals.

7. The DCS of claim 1, wherein the plurality of downlink physical layers and the plurality of uplink physical layers are the same respective physical layers.

8. The DCS of claim 1, wherein the first remote unit is located within at least 20 meters of the second remote unit.

9. The DCS of claim 1, wherein the first remote unit is located within at least 12 meters of the second remote unit.

10. The DCS according to any of claims 1 through 9, wherein the first remote coverage area is substantially non-overlapping with the second remote coverage area.

11. The DCS of claim according to any of claims 1 through 10, wherein the central unit further comprises an external interface and a controller configured to:

receive routing assignments for the routing configuration from the external interface; and

store the routing assignments in the routing configuration.

12. The DCS of claim 1, further comprising a controller configured to:

receive an interleaved MIMO communications service configuration request from the external interface indicating if interleaved MIMO communications services are to be configured for the DCS;

determine from the received interleaved MIMO communications service configuration request if the plurality of remote units in the DCS are to remain existing or be redesigned; and

in response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to remain existing:

determine existing performance of the plurality of remote units to provide interleaved MIMO communications services;

determine an interleaved MIMO routing configuration to support interleaved MIMO communications services in the DCS with the existing plurality of remote units;

send the determined interleaved MIMO routing configuration to the external interface; and

store the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration.

13. The DCS of claim 12, wherein the controller is configured to determine the existing performance of the plurality of remote units to provide interleaved MIMO communications services by being configured to:

simulate at least one interleaved MIMO communications service for the DCS based on the existing plurality of remote units; and

determine at least one performance characteristic of the simulated at least one interleaved MIMO communications service for the DCS based on the existing plurality of remote units.

14. The DCS of claim 12, further comprising a controller configured to:

in response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned:

determine the existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units;

determine an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units;

send the determined interleaved MIMO routing configuration to the external interface; and

store the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration.

15. The DCS of claim 14, wherein the controller is configured to determine the existing performance of the plurality of remote units to provide interleaved MIMO communications services by being configured to:

simulate at least one interleaved MIMO communications service for the DCS based on at least one redesigned infrastructure of a plurality of remote units; and

determine at least one performance characteristic of the simulated at least one interleaved MIMO communications service for the DCS based on at least one redesigned infrastructure of the plurality of remote units.

16. A method of configuring a distributed communications system (DCS) for providing interleaved multiple-input, multiple-output (MIMO) communications services, comprising:

receiving an interleaved MIMO communications service configuration request from an external interface indicating if interleaved MIMO communications services are to be configured for a DCS, the DCS comprising:

a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units;

the central unit configured to:

distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration; and

distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units; and

the plurality of remote units each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers, each remote unit among the plurality of remote units comprising at least one antenna and configured to:

distribute received uplink communications signals received over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit; and

distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna;

determining from the received interleaved MIMO communications service configuration request if the plurality of remote units in the DCS are to remain existing or be redesigned; and

in response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned:

determining an existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units;

determining an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units;

sending the determined interleaved MIMO routing configuration to the external interface; and

storing the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration;

assign a first MIMO communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area; and

assigning a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

17. The method of claim 16, wherein determining the existing performance of the plurality of remote units to provide interleaved MIMO communications services comprises:

simulating at least one interleaved MIMO communications service for the DCS based on the existing plurality of remote units; and

determining at least one performance characteristic of the simulated at least one interleaved MIMO communications service for the DCS based on the existing plurality of remote units.

18. The method of claim 16, further comprising:

in response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned:

determining the existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units;

determining an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units;

sending the determined interleaved MIMO routing configuration to the external interface; and

storing the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration.

19. The method of claim 18, comprising determining the existing performance of the plurality of remote units to provide interleaved MIMO communications services by being configured to:

simulate at least one interleaved MIMO communications service for the DCS based on at least one redesigned infrastructure of a plurality of remote units; and

determine at least one performance characteristic of the simulated at least one interleaved MIMO communications service for the DCS based on at least one redesigned infrastructure of the plurality of remote units.

20. The method of claim 16, wherein configuring the routing configuration further comprises:

assigning a third MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area overlapping with the first remote coverage area and the second remote coverage area to interleave MIMO cell bond the third remote unit to the first remote unit and the second remote unit; and

assigning a fourth MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the first remote coverage area, the second remote coverage area, and the third remote coverage area to interleave MIMO cell bond the fourth remote unit to the first remote unit, the second remote unit, and the third remote unit.

21. The method of claim 16, wherein configuring the routing configuration further comprises:

assigning a third MIMO communications signal among the received one or more downlink communications signals for a second MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area; and

assigning a fourth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the third remote coverage area to interleave MIMO cell bond the third remote unit and the fourth remote unit.

22. The method of claim 21, wherein configuring the routing configuration further comprises:

assigning a fifth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a fifth remote unit among the plurality of remote units having a fifth remote coverage area; and

assigning a sixth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a sixth remote unit among the plurality of remote units having a sixth remote coverage area overlapping with the fifth remote coverage area to interleave MIMO cell bond the fifth remote unit and the sixth remote unit.

23. The method of claim 16, further comprising:

splitting the first MIMO communications signal into at least two first split MIMO communications signals;

splitting the first MIMO communications signal into at least two second split MIMO communications signals;

wherein configuring the routing configuration comprises:

assigning a first split MIMO communications signal of the at least two first split MIMO communications signals for the first MIMO communications service to the first remote unit among the plurality of remote units having the first remote coverage area; and

assigning a second split MIMO communications signal of the at least two first split MIMO communications signals for the first MIMO communications service to the second remote unit among the plurality of remote units having the second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit;

assigning a first split MIMO communications signal of the at least two second split MIMO communications signals for the first MIMO communications service to a third remote unit among the plurality of remote units having a third remote coverage area; and

assigning a second split MIMO communications signal of the at least two second split MIMO communications signals for the first MIMO communications service to a fourth remote unit among the plurality of remote units having a fourth remote coverage area overlapping with the third remote coverage area to interleave MIMO cell bond the third remote unit and the fourth remote unit.

24. A non-transitory computer-readable medium having stored thereon computer executable instructions which, when executed by a processor, cause the processor to:

receive an interleaved multiple-input, multiple-output (MIMO) communications service configuration request from an external interface indicating if interleaved MIMO communications services are to be configured for a distributed communications system (DCS), the DCS comprising:

a central unit comprising a routing configuration assigning received one or more downlink communications signals to one or more downlink physical layers among a plurality of downlink physical layers each coupled to a dedicated remote unit among a plurality of remote units;

the central unit configured to:

distribute the received one or more downlink communications signals to the plurality of downlink physical layers each dedicated to a remote unit among the plurality of remote units according to the routing configuration; and

distribute received one or more uplink communications signals from the plurality of remote units over a plurality of uplink physical layers each dedicated to a remote unit among the plurality of remote units; and

the plurality of remote units each coupled to a downlink physical layer among the plurality of downlink physical layers and an uplink physical layer among the plurality of uplink physical layers, each remote unit among the plurality of remote units comprising at least one antenna and configured to:

distribute received uplink communications signals over the at least one antenna over a coupled uplink physical layer among the plurality of uplink physical layers to the central unit; and

distribute received downlink communications signals from a coupled downlink physical layer among the plurality of downlink physical layers through the at least one antenna;

determine from the received interleaved MIMO communications service configuration request if the plurality of remote units in the DCS are to remain existing or be redesigned; and

in response to the received interleaved MIMO communications service configuration request indicating the plurality of remote units in the DCS are to be redesigned:

determine the existing performance of the plurality of remote units to provide interleaved MIMO communications services according to a redesign of the plurality of remote units;

determine an interleaved MIMO routing configuration to support the interleaved MIMO communications services in the DCS with the plurality of remote units;

send the determined interleaved MIMO routing configuration to the external interface; and

store the determined interleaved MIMO routing configuration as the routing configuration in response to receiving an indication over the external interface to enable the interleaved MIMO routing configuration;

assign a first MIMO communications signal among the received one or more downlink communications signals for a first MIMO communications service to a first remote unit among the plurality of remote units having a first remote coverage area; and

assign a second MIMO communications signal among the received one or more downlink communications signals for the first MIMO communications service to a second remote unit among the plurality of remote units having a second remote coverage area overlapping with the first remote coverage area to interleave MIMO cell bond the first remote unit and the second remote unit.

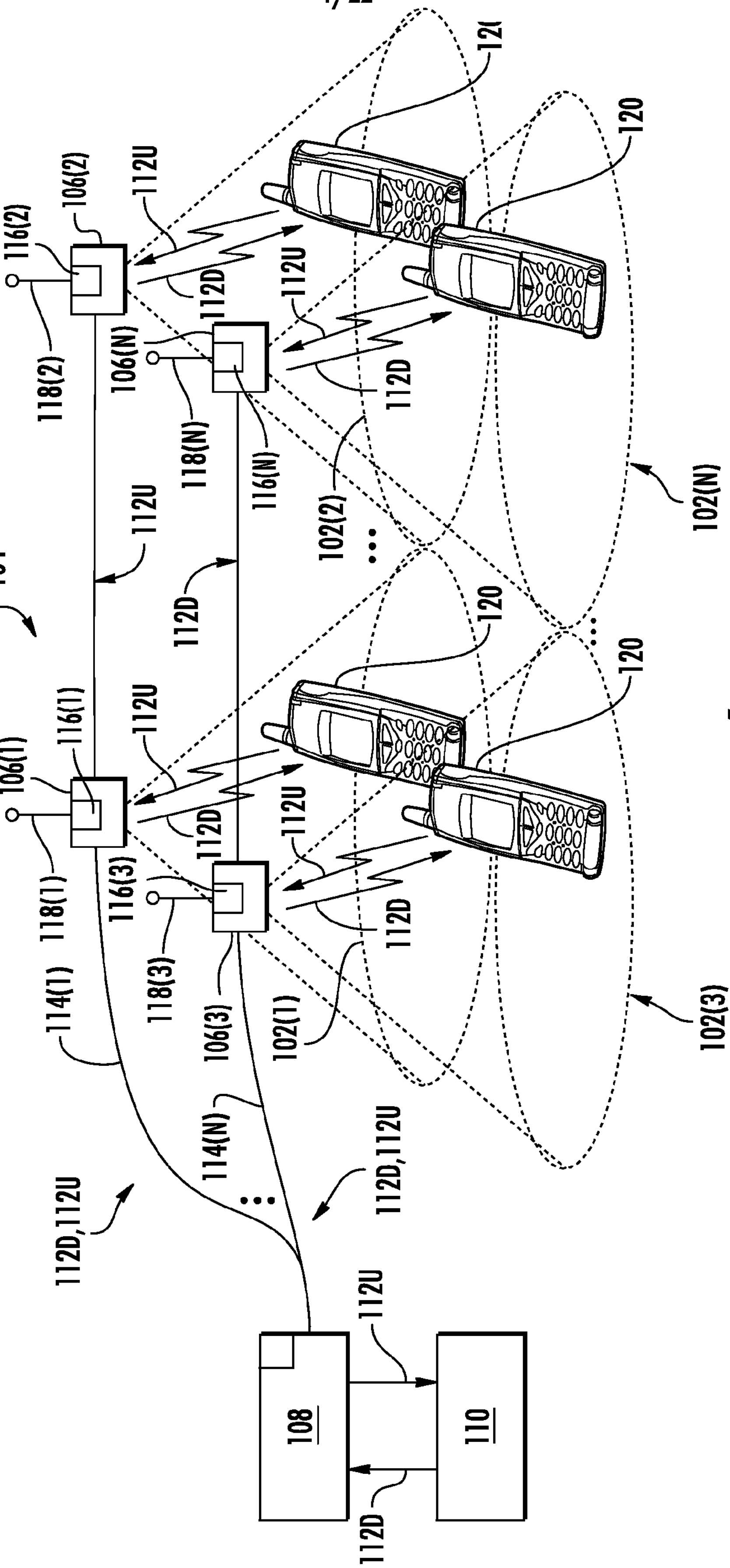

100
104
106(1)
106(2)
106(3)
106(N)
108
110
112U
112D
112D,112U
114(1)
114(N)
116(1)
116(2)
116(3)
116(N)
118(1)
118(2)
118(3)
118(N)
120
102(1)
102(2)
102(3)
102(N)

FIG. 1

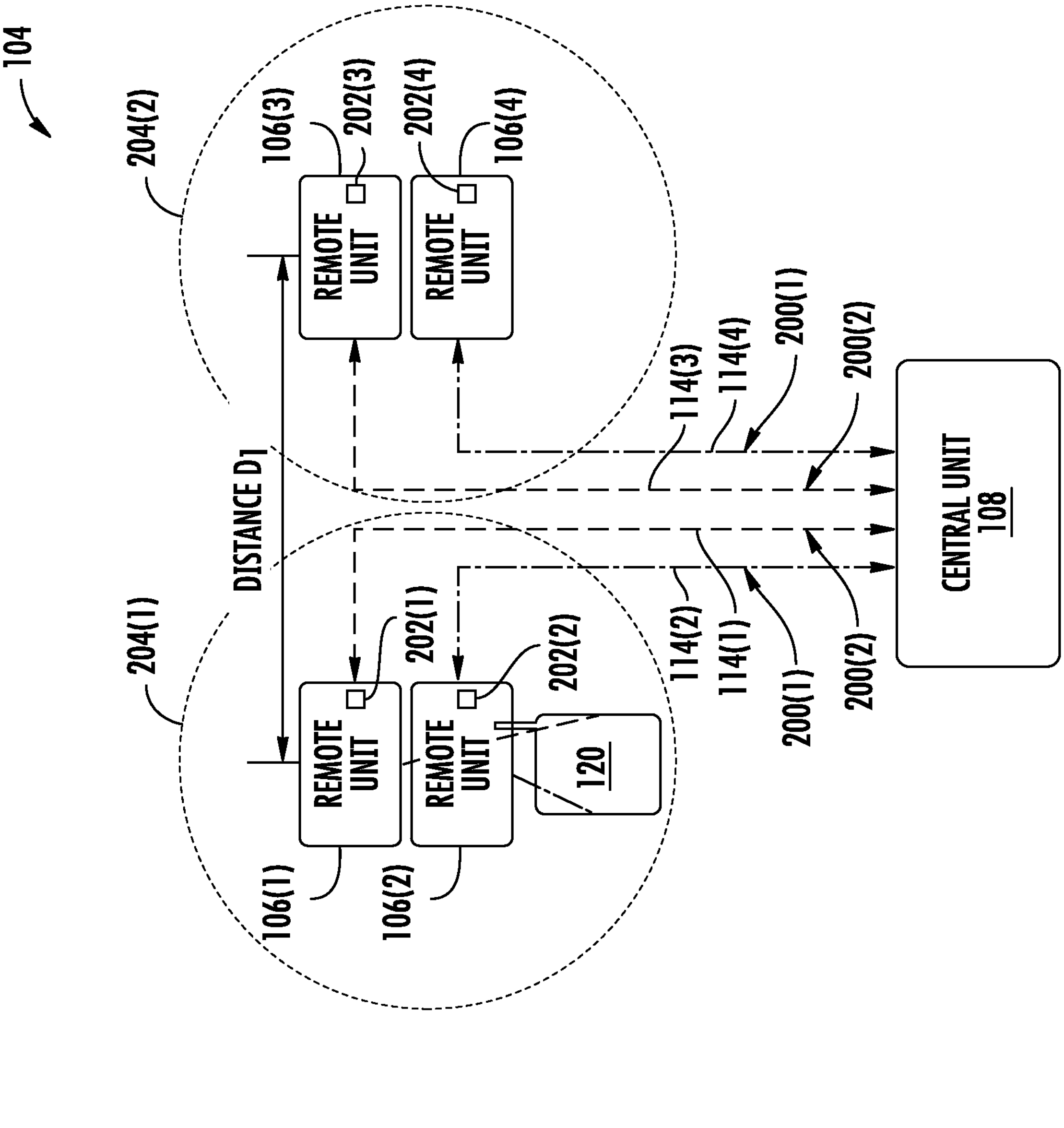

104
204(2)
106(3)
202(3)
202(4)
106(4)
REMOTE UNIT
REMOTE UNIT
DISTANCE D1
114(3)
114(4)
200(1)
200(2)
CENTRAL UNIT 108
204(1)
202(1)
202(2)
REMOTE UNIT
REMOTE UNIT
120
106(1)
106(2)
114(2)
114(1)
200(1)
200(2)

FIG. 2

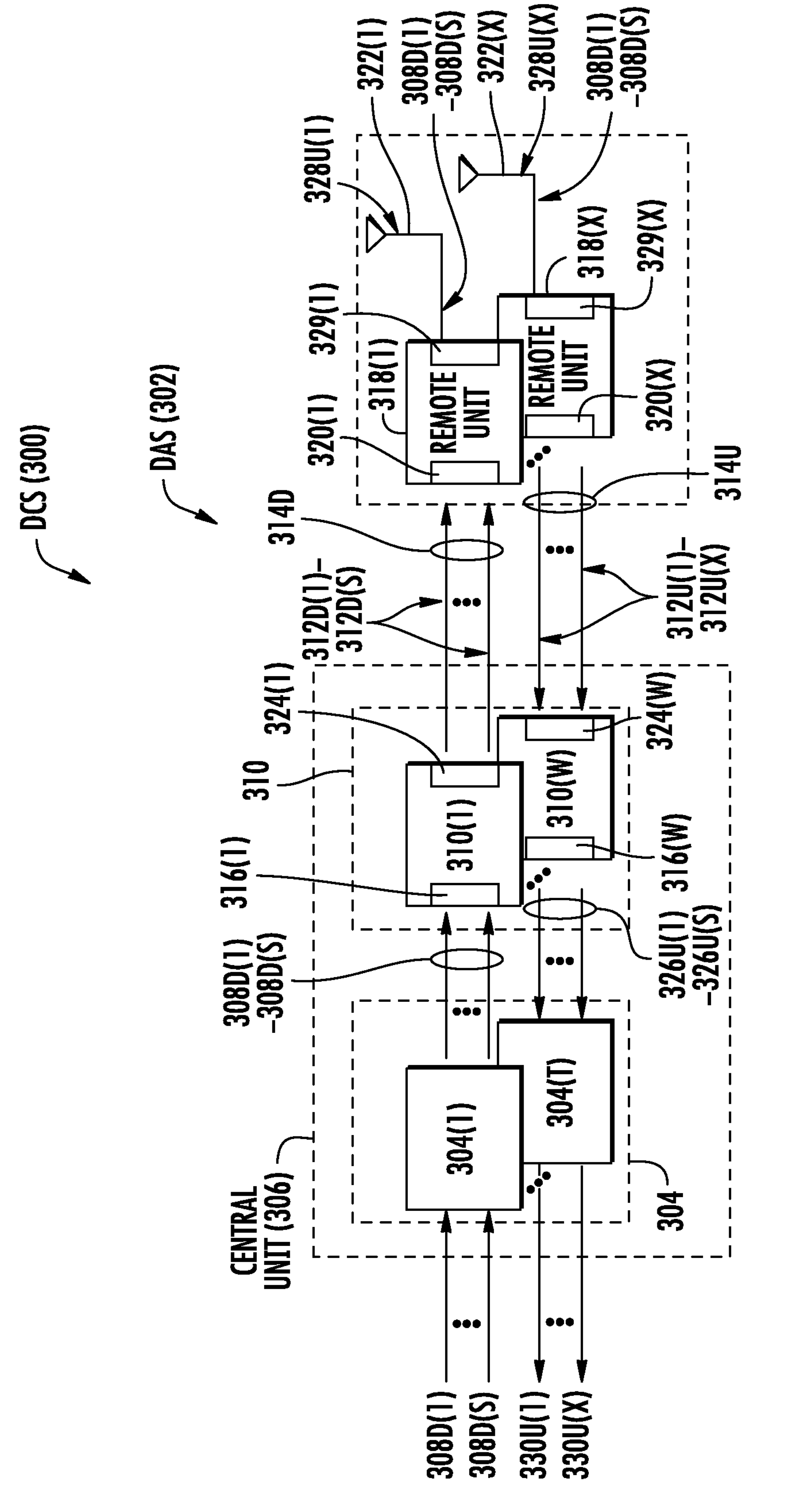

DCS (300)
DAS (302)
CENTRAL UNIT (306)
304
304(1)
304(T)
308D(1)
308D(S)
330U(1)
330U(X)
308D(1) –308D(S)
310
310(1)
310(W)
316(1)
316(W)
324(1)
324(W)
326U(1) –326U(S)
312D(1)– 312D(S)
312U(1)– 312U(X)
314D
314U
REMOTE UNIT
REMOTE UNIT
318(1)
318(X)
320(1)
320(X)
329(1)
329(X)
328U(1)
328U(X)
322(1)
322(X)
308D(1) –308D(S)
308D(1) –308D(S)

FIG. 3

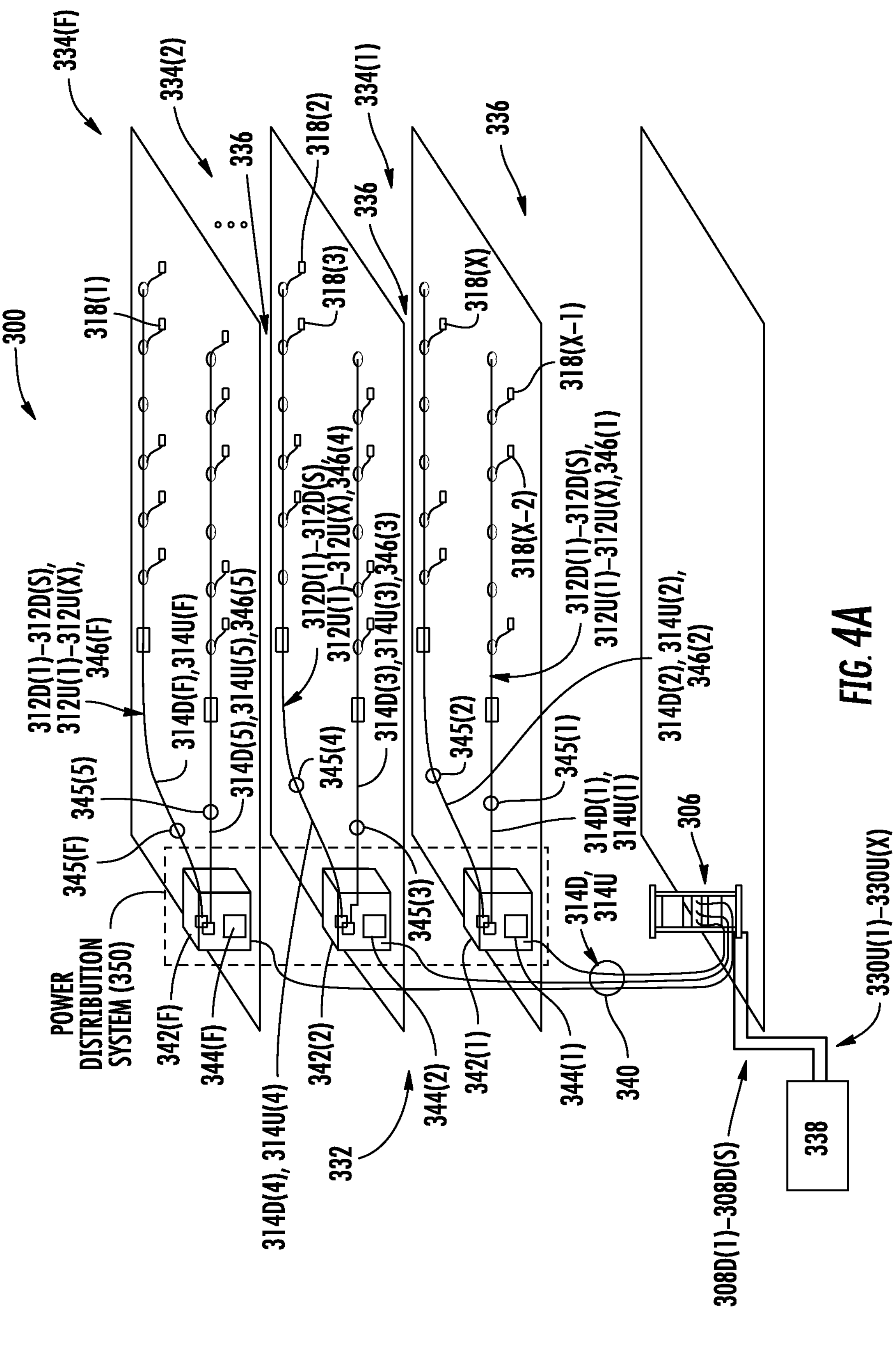
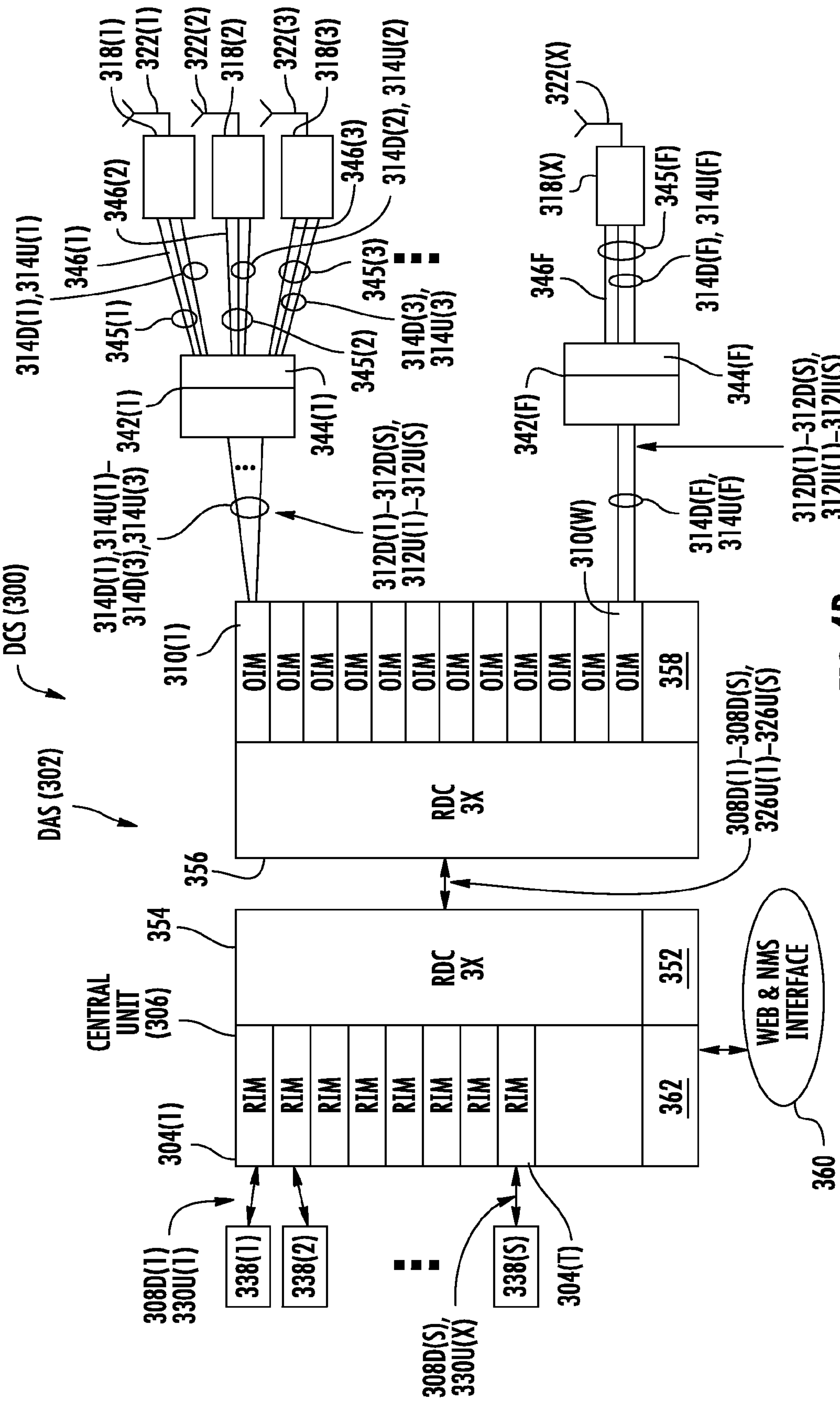

300
334(F)
334(2)
334(1)
336
318(1)
318(2)
318(3)
318(X)
318(X−1)
318(X−2)
312D(1)−312D(S), 312U(1)−312U(X), 346(F)
312D(1)−312D(S), 312U(1)−312U(X), 346(4)
312D(1)−312D(S), 312U(1)−312U(X), 346(1)
314D(F), 314U(F)
314D(5), 314U(5), 346(5)
314D(3), 314U(3), 346(3)
314D(2), 314U(2), 346(2)
314D(1), 314U(1)
314D(4), 314U(4)
314D, 314U
345(F)
345(5)
345(4)
345(3)
345(2)
345(1)
POWER DISTRIBUTION SYSTEM (350)
342(F)
344(F)
342(2)
344(2)
342(1)
344(1)
340
332
306
330U(1)−330U(X)
308D(1)−308D(S)
338

FIG. 4A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DAS (302)
CENTRAL UNIT (306)
RIM
RDC 3X
352
362
354
356
358
OIM
310(1)
310(W)
304(1)
304(T)
338(1)
338(2)
338(S)
308D(1) 330U(1)
308D(S), 330U(X)
308D(1)–308D(S), 326U(1)–326U(S)
WEB & NMS INTERFACE
360
314D(1),314U(1)–314D(3),314U(3)
312D(1)–312D(S), 312U(1)–312U(S)
342(1)
344(1)
345(1)
345(2)
345(3)
346(1)
346(2)
346(3)
314D(1),314U(1)
314D(2), 314U(2)
314D(3), 314U(3)
318(1)
318(2)
318(3)
322(1)
322(2)
322(3)
342(F)
344(F)
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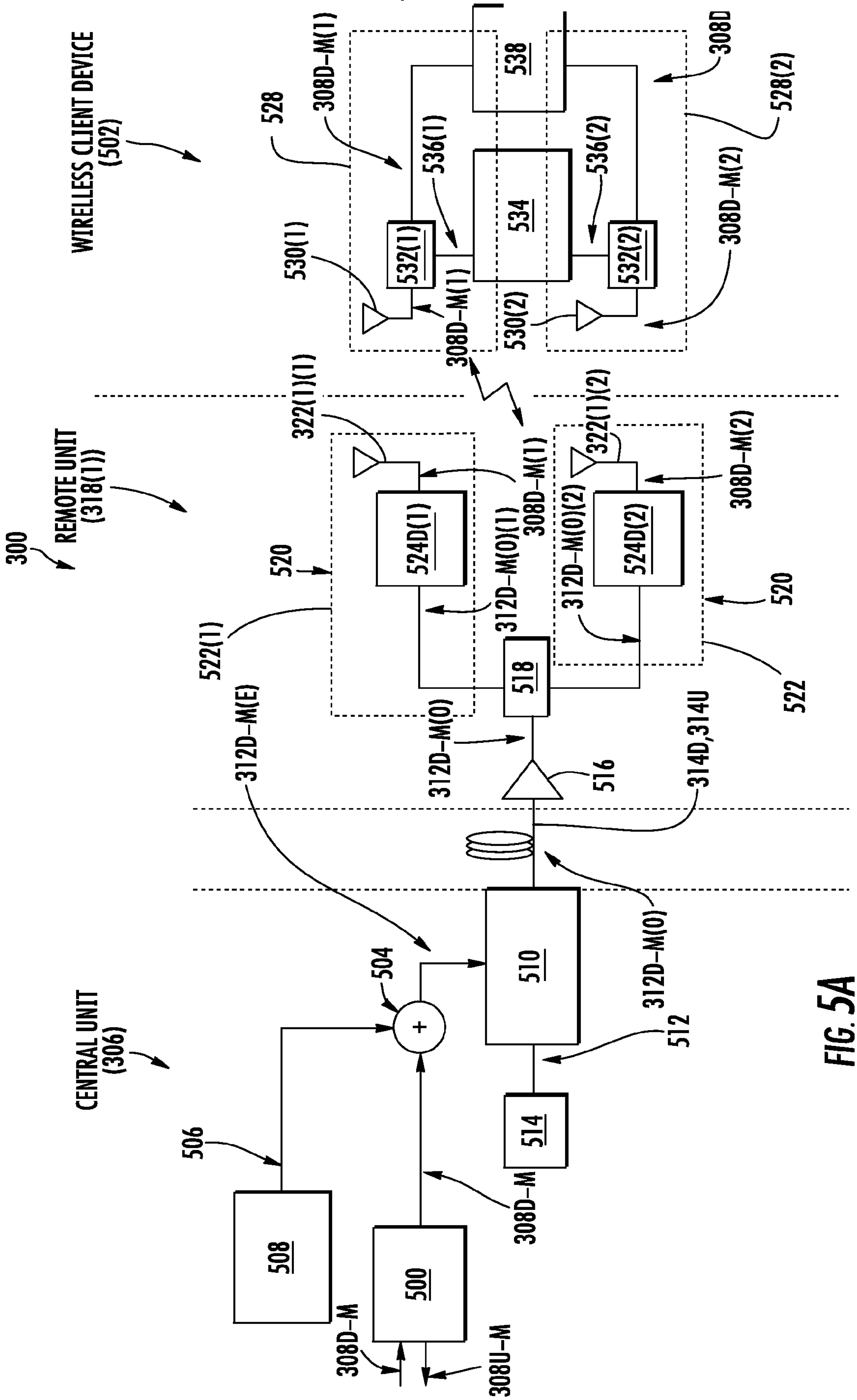
346F
314D(F), 314U(F)
318(X)
322(X)

FIG. 4B



WIRELESS CLIENT DEVICE
(502)
REMOTE UNIT
(318(1))
CENTRAL UNIT
(306)
300
528
308D-M(1)
538
308D
528(2)
536(1)
536(2)
534
530(1)
532(1)
532(2)
308D-M(2)
308D-M(1)
530(2)
322(1)(1)
322(1)(2)
308D-M(1)
308D-M(2)
524D(1)
524D(2)
308D-M(0)(1)
308D-M(0)(2)
520
520
312D-M(0)(1)
312D-M(0)(2)
522(1)
522
518
312D-M(E)
312D-M(0)
516
314D,314U
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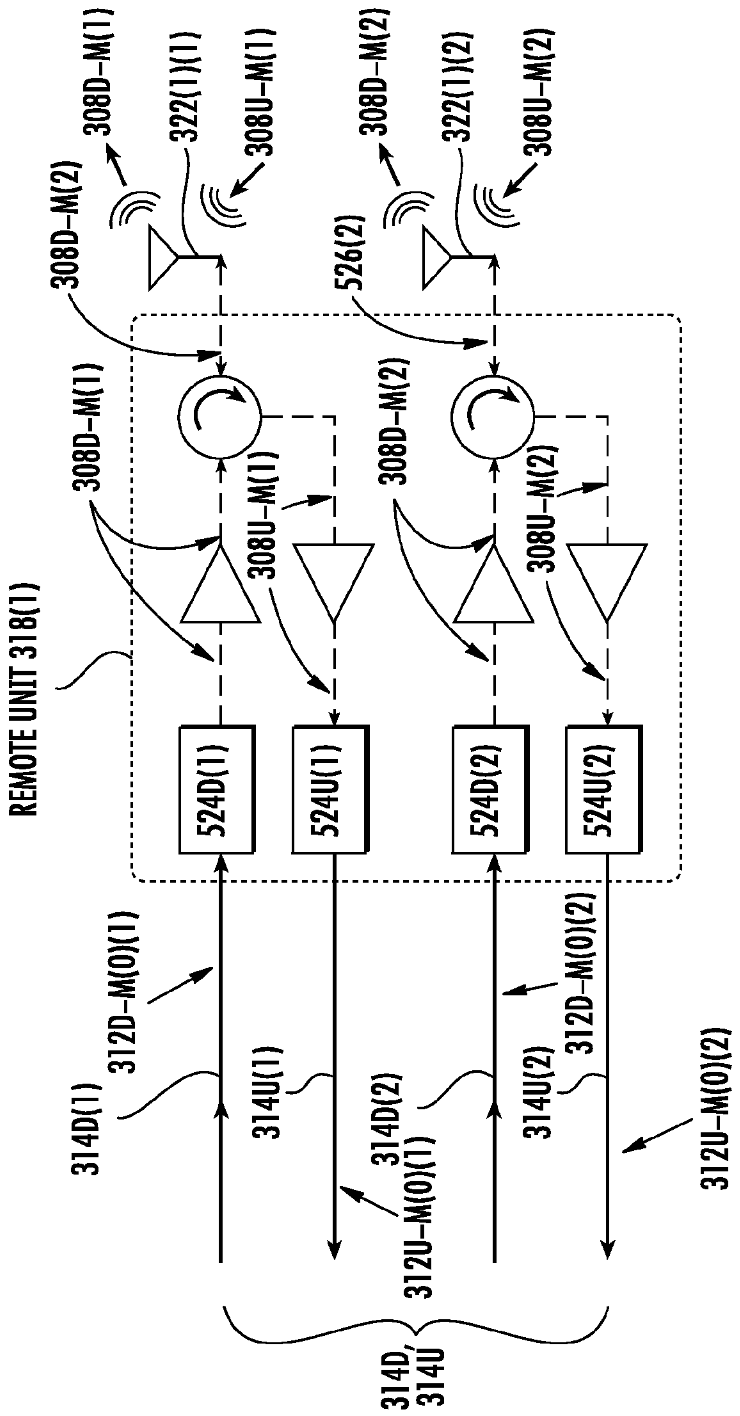
312D-M(0)
512
506
508
514
308D-M
500
308D-M
308U-M

FIG. 5A



REMOTE UNIT 318(1)
308D–M(1)
322(1)(1)
308U–M(1)
308D–M(2)
322(1)(2)
308U–M(2)
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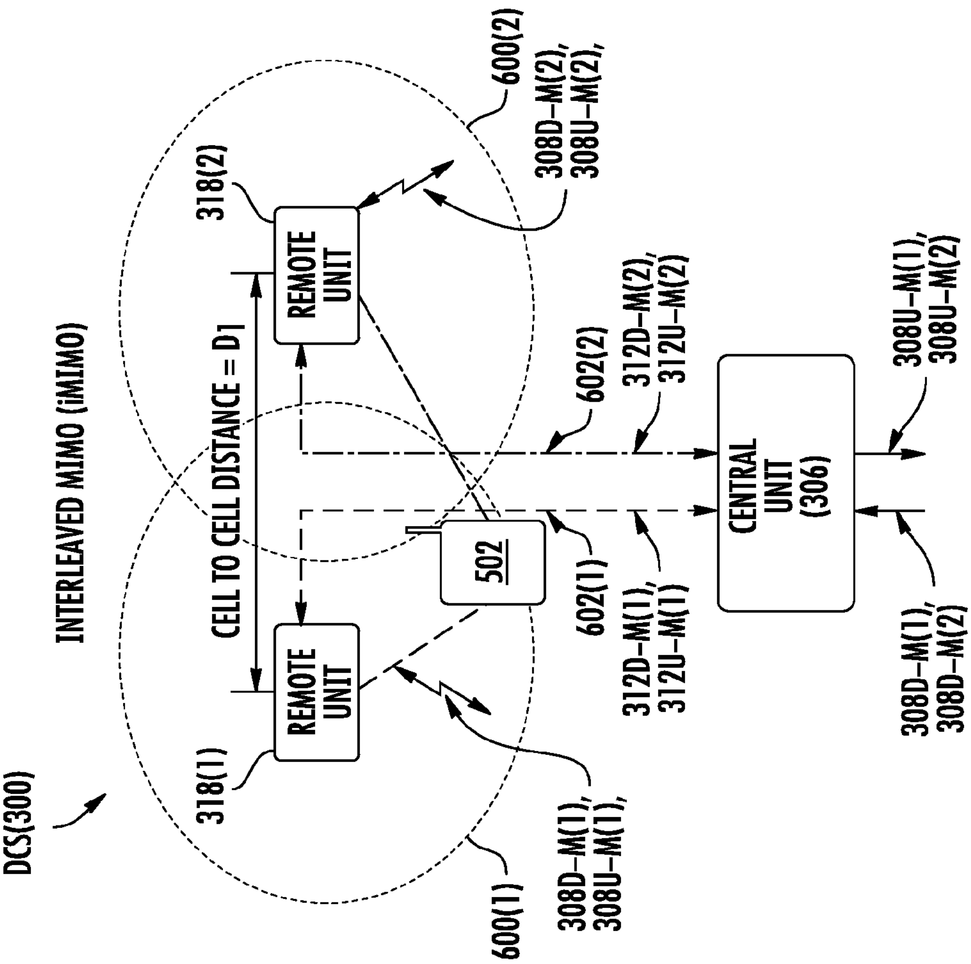
526(2)
308D–M(1)
308U–M(1)
308D–M(2)
308U–M(2)
524D(1)
524U(1)
524D(2)
524U(2)
312D–M(0)(1)
314D(1)
314U(1)
314D(2)
312U–M(0)(1)
314U(2)
312D–M(0)(2)
312U–M(0)(2)
314D,
314U

FIG. 5B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INTERLEAVED MIMO (iMIMO)
CELL TO CELL DISTANCE = D1
318(1)
REMOTE UNIT
318(2)
REMOTE UNIT
502
CENTRAL UNIT (306)
600(1)
600(2)
602(1)
602(2)
308D-M(1), 308U-M(1),
308D-M(2), 308U-M(2),
312D-M(1), 312U-M(1)
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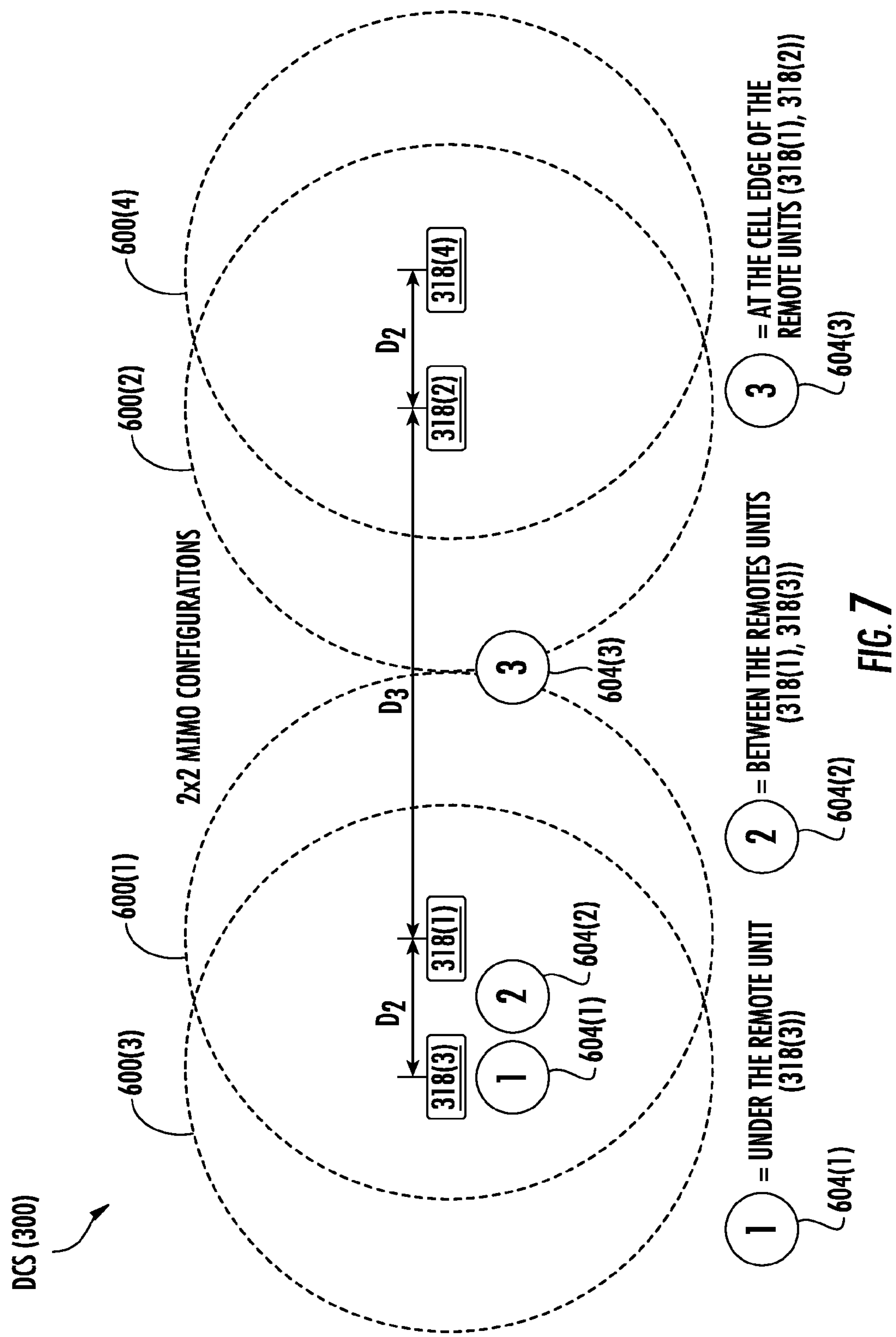
308D-M(1), 308D-M(2)

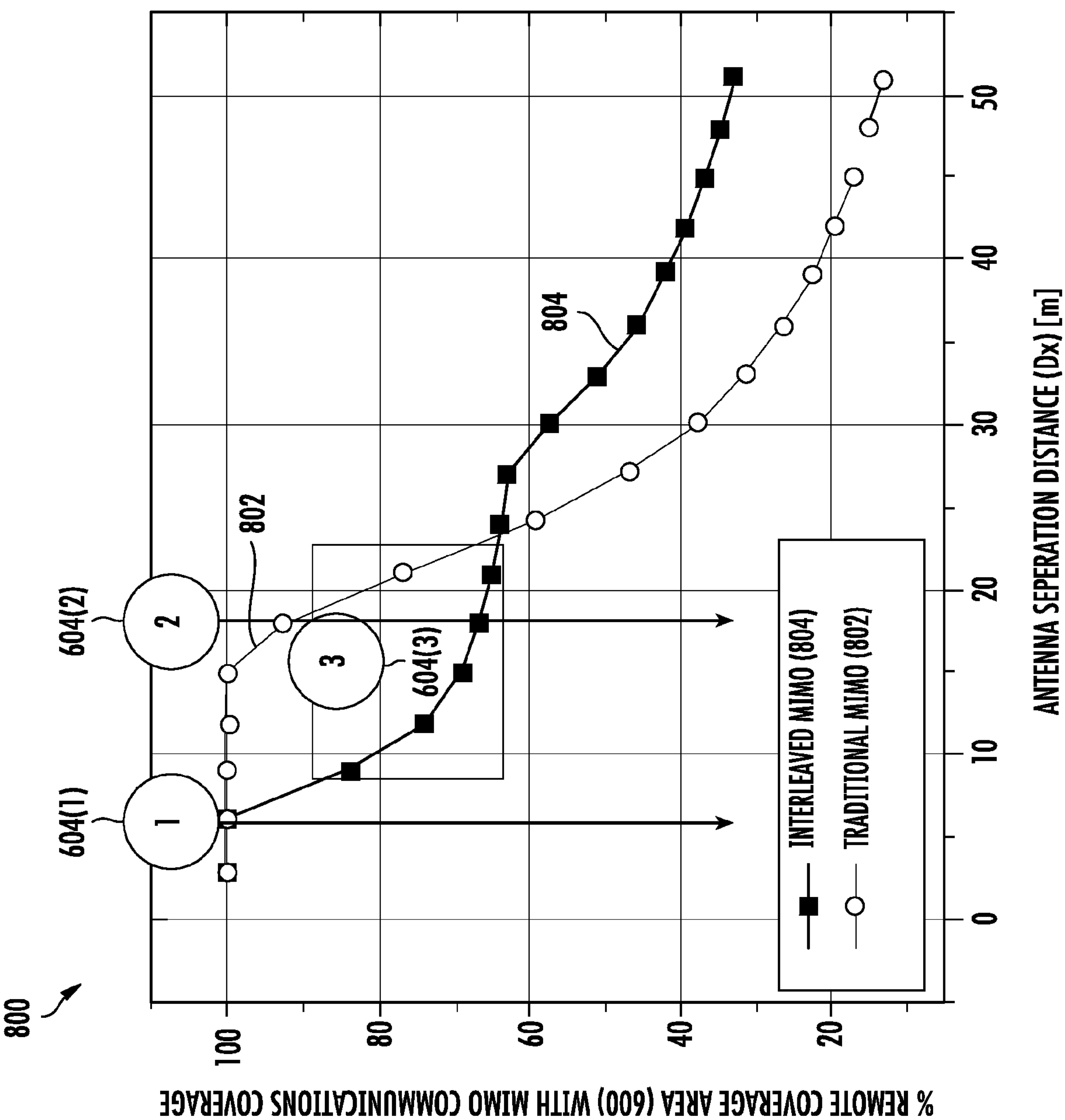
FIG. 6



DCS (300)
2x2 MIMO CONFIGURATIONS
600(1)
600(2)
600(3)
600(4)
318(1)
318(2)
318(3)
318(4)
D_2
D_2
D_3
604(1)
604(2)
604(3)
1 = UNDER THE REMOTE UNIT (318(3))
2 = BETWEEN THE REMOTES UNITS (318(1), 318(3))
3 = AT THE CELL EDGE OF THE REMOTE UNITS (318(1), 318(2))

FIG. 7

FIG. 8


800
% REMOTE COVERAGE AREA (600) WITH MIMO COMMUNICATIONS COVERAGE
ANTENNA SEPERATION DISTANCE (Dx) [m]
100
80
60
40
20
0
10
20
30
40
50
604(1)
604(2)
604(3)
1
2
3
802
804
INTERLEAVED MIMO (804)
TRADITIONAL MIMO (802)

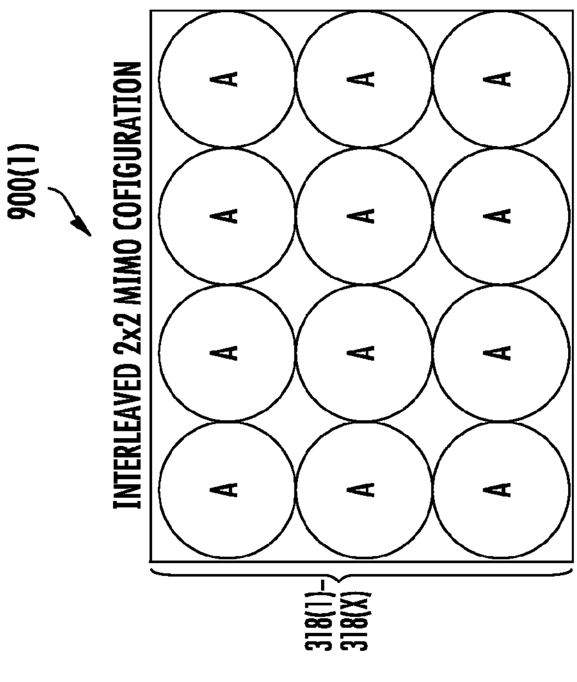


FIG. 9A

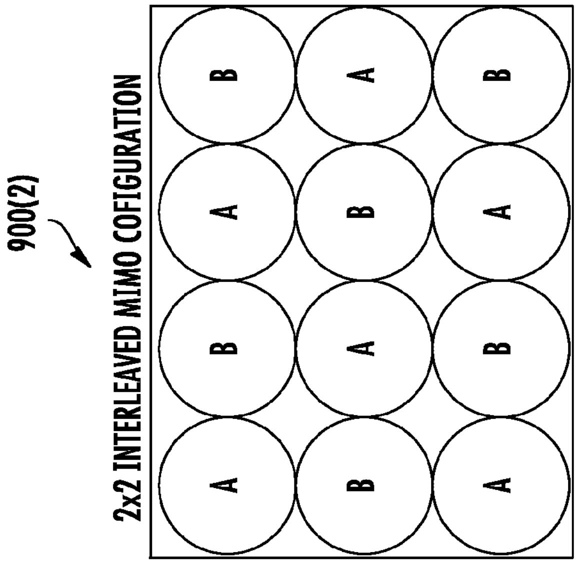


FIG. 9B

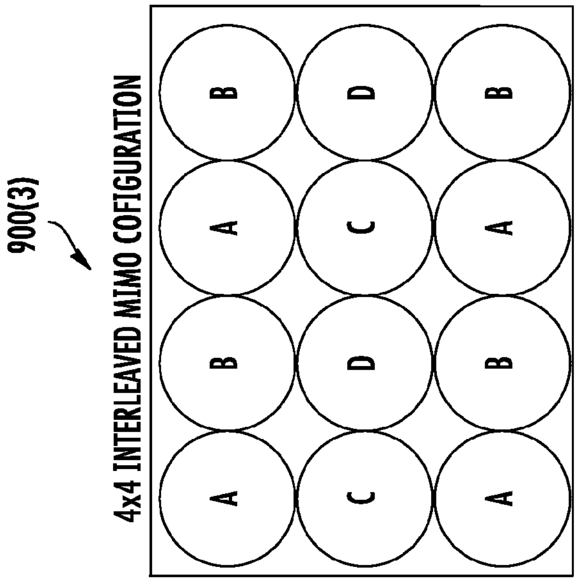


FIG. 9C

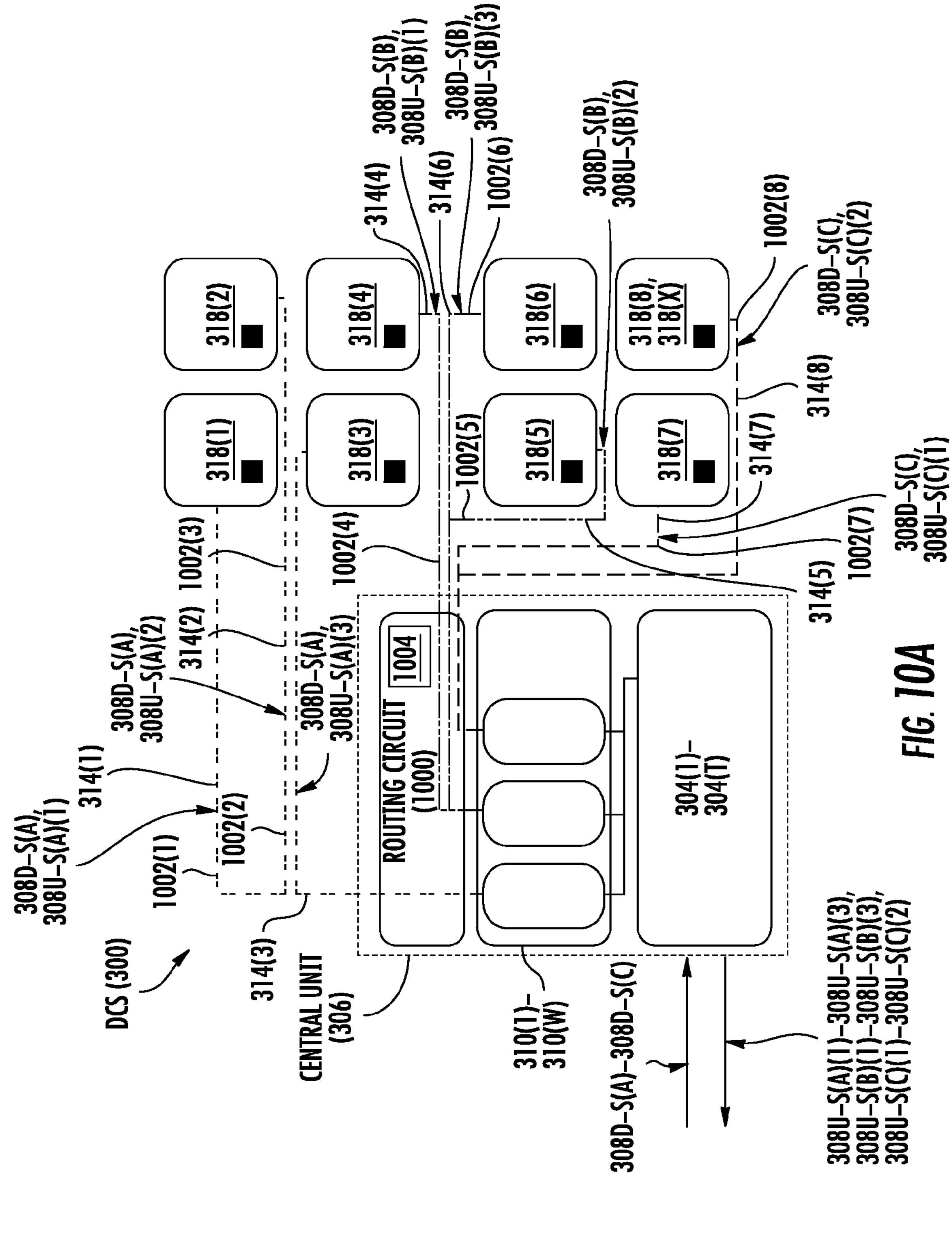

DCS (300)
308D–S(A), 308U–S(A)(1)
1002(1)
314(1)
1002(2)
308D–S(A), 308U–S(A)(2)
314(2)
1002(3)
308D–S(A), 308U–S(A)(3)
314(3)
CENTRAL UNIT (306)
ROUTING CIRCUIT (1000)
1004
1002(4)
314(4)
308D–S(B), 308U–S(B)(1)
314(6)
308D–S(B), 308U–S(B)(3)
1002(6)
1002(5)
308D–S(B), 308U–S(B)(2)
1002(8)
308D–S(C), 308U–S(C)(2)
314(8)
314(7)
308D–S(C), 308U–S(C)(1)
1002(7)
314(5)
318(1)
318(2)
318(3)
318(4)
318(5)
318(6)
318(7)
318(8), 318(X)
310(1)–310(W)
304(1)–304(T)
308D–S(A)–308D–S(C)
308U–S(A)(1)–308U–S(A)(3), 308U–S(B)(1)–308U–S(B)(3), 308U–S(C)(1)–308U–S(C)(2)

FIG. 10A

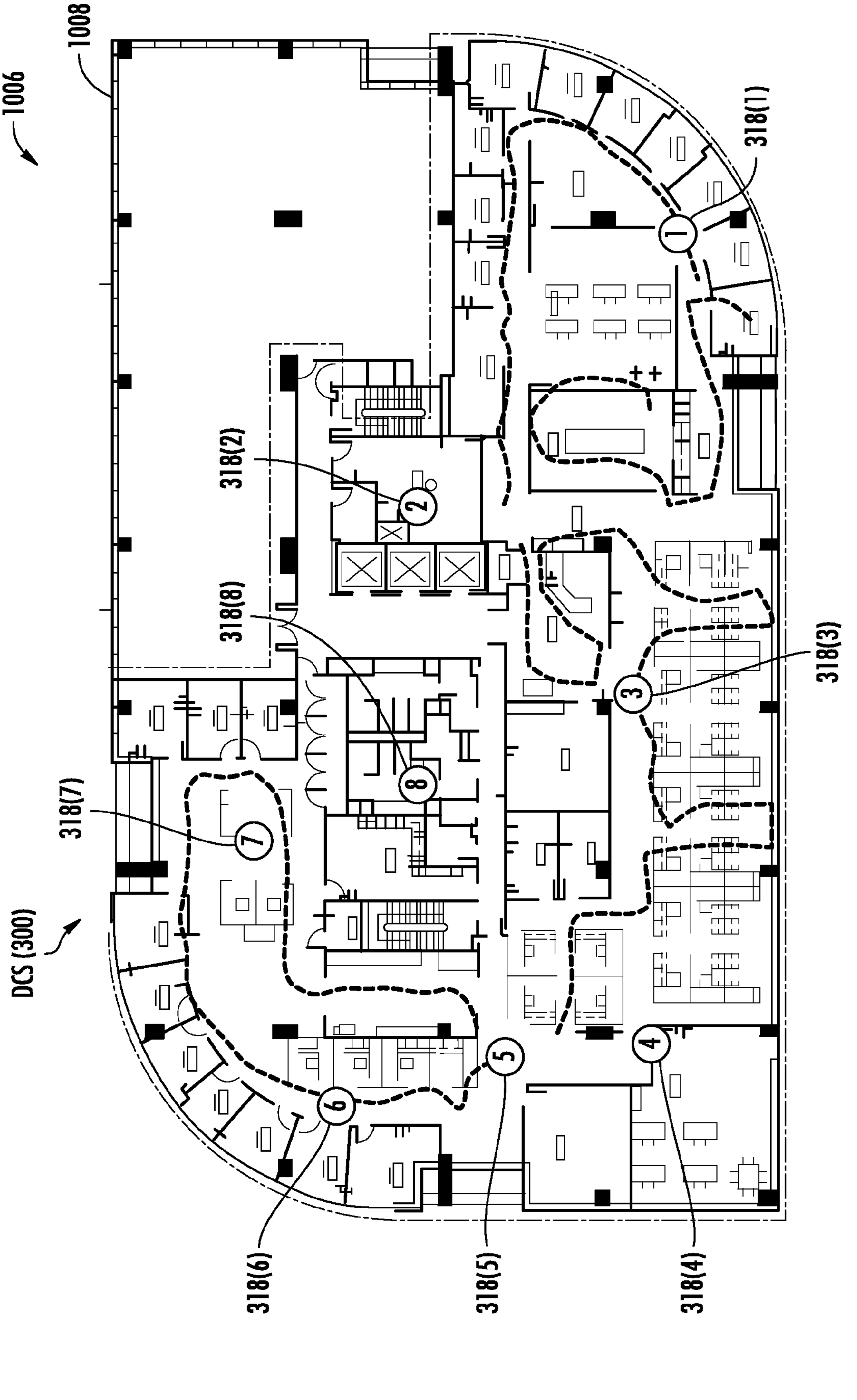
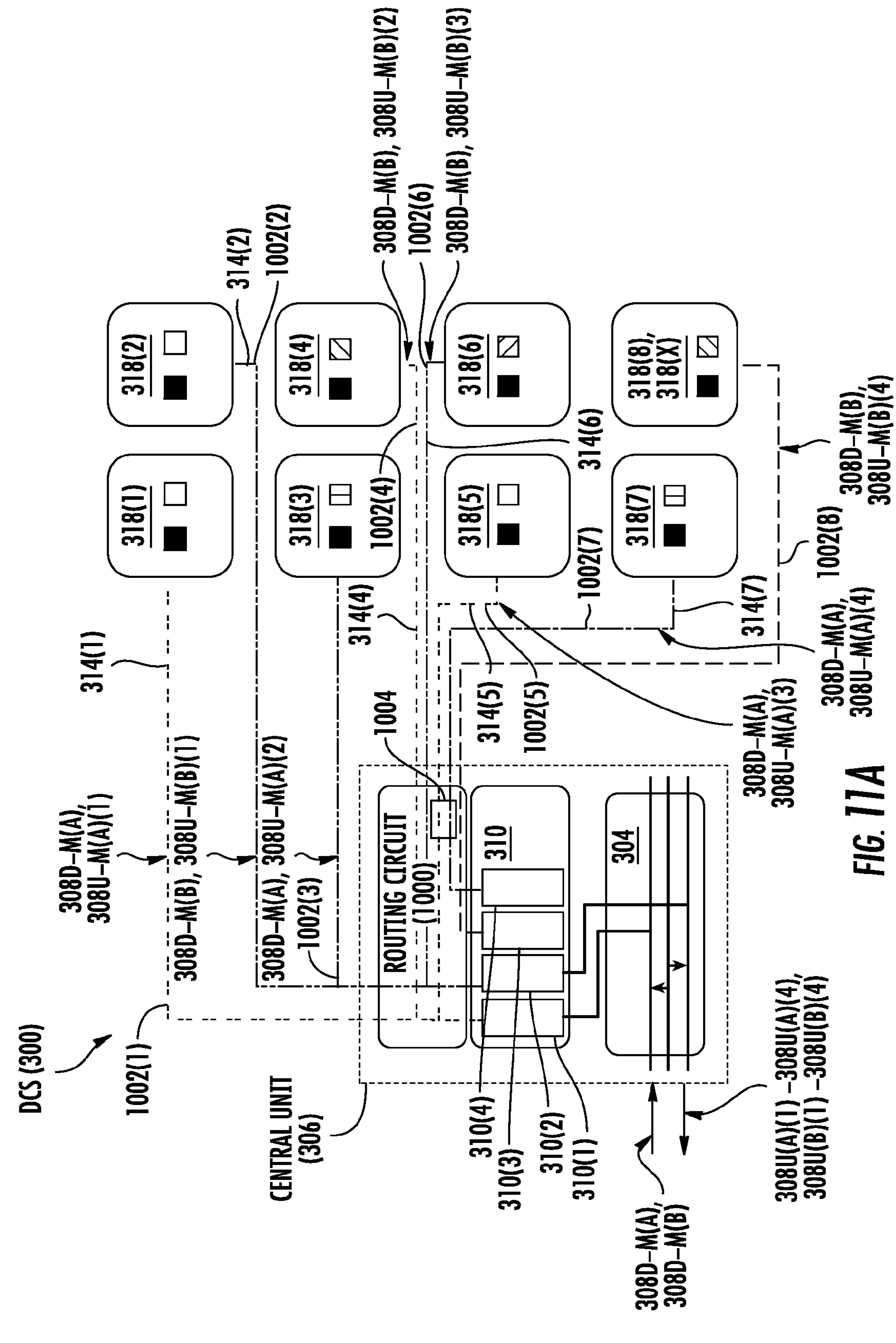

1006
1008
318(1)
318(2)
318(8)
318(3)
318(7)
DCS (300)
318(6)
318(5)
318(4)
1
2
3
4
5
6
7
8

FIG. 10B



DCS (300)
1002(1)
CENTRAL UNIT (306)
308D–M(A), 308U–M(A)(1)
308D–M(B), 308U–M(B)(1)
308D–M(A), 308U–M(A)(2)
1002(3)
314(1)
ROUTING CIRCUIT (1000)
1004
310
304
310(4)
310(3)
310(2)
310(1)
308D–M(A), 308D–M(B)
308U(A)(1) –308U(A)(4), 308U(B)(1) –308U(B)(4)
318(1)
318(2)
318(3)
318(4)
318(5)
318(6)
318(7)
318(8), 318(X)
314(2)
1002(2)
308D–M(B), 308U–M(B)(2)
1002(6)
308D–M(B), 308U–M(B)(3)
1002(4)
314(6)
314(4)
1002(7)
314(5)
1002(5)
308D–M(A), 308U–M(A)(3)
314(7)
308D–M(A), 308U–M(A)(4)
1002(8)
308D–M(B), 308U–M(B)(4)

FIG. 11A

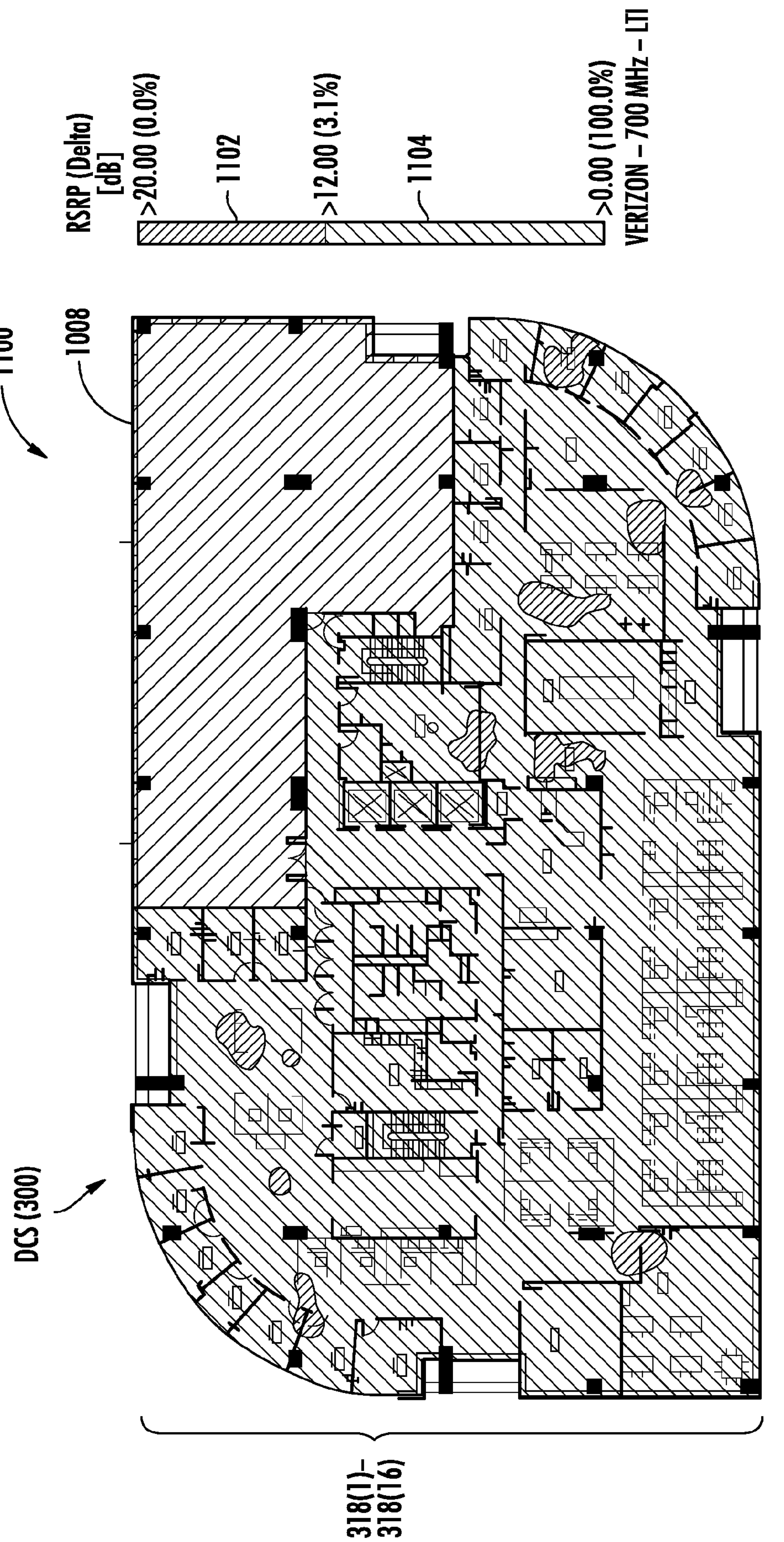

RSRP (Delta)
[dB]
>20.00 (0.0%)
1102
>12.00 (3.1%)
1104
>0.00 (100.0%)
VERIZON – 700 MHz – LTI
1100
1008
DCS (300)
318(1)-
318(16)

FIG. 11B

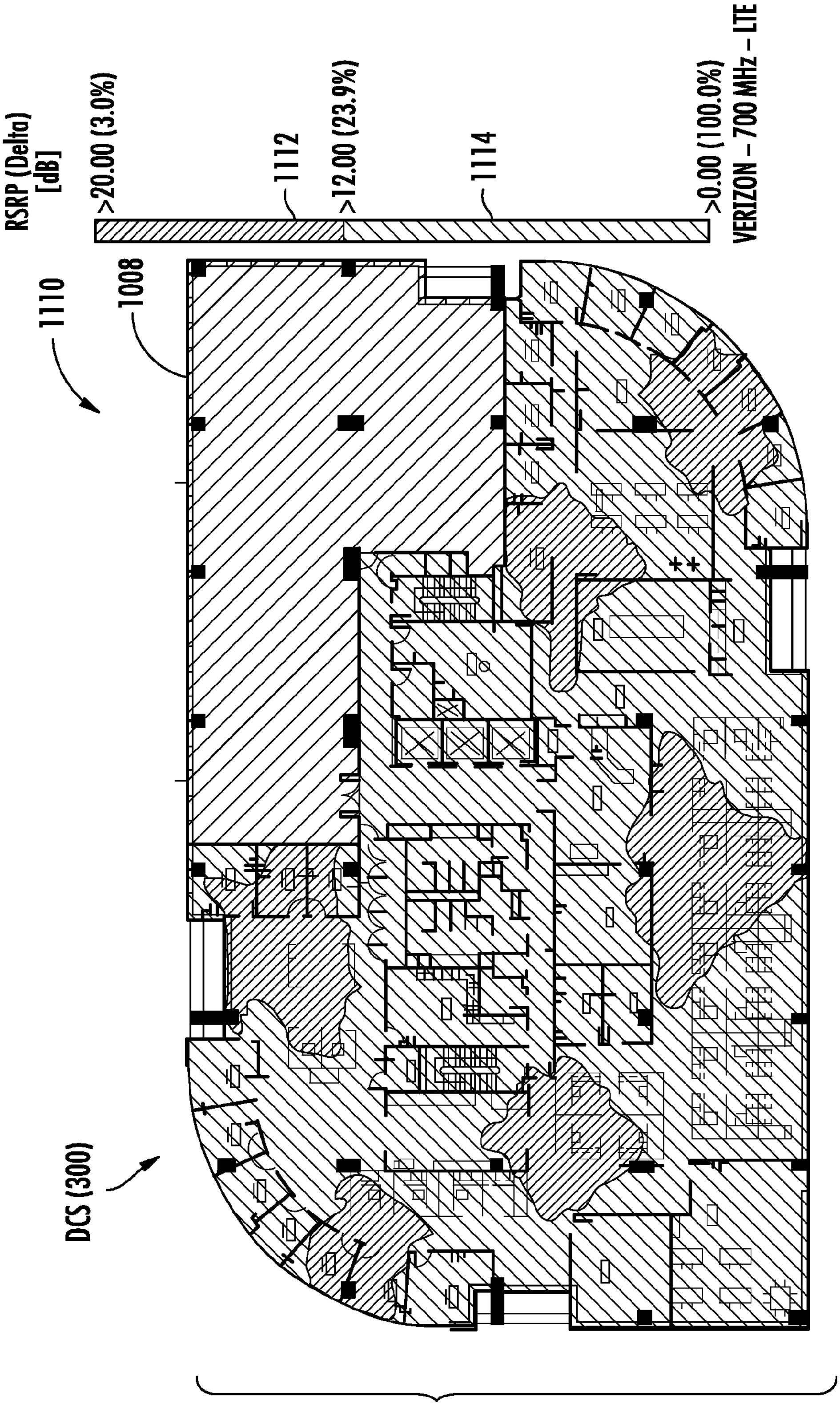

RSRP (Delta)
[dB]
>20.00 (3.0%)
1112
>12.00 (23.9%)
1114
>0.00 (100.0%)
VERIZON – 700 MHz – LTE
1110
1008
DCS (300)
318(1)–
318(8)

FIG. 11C

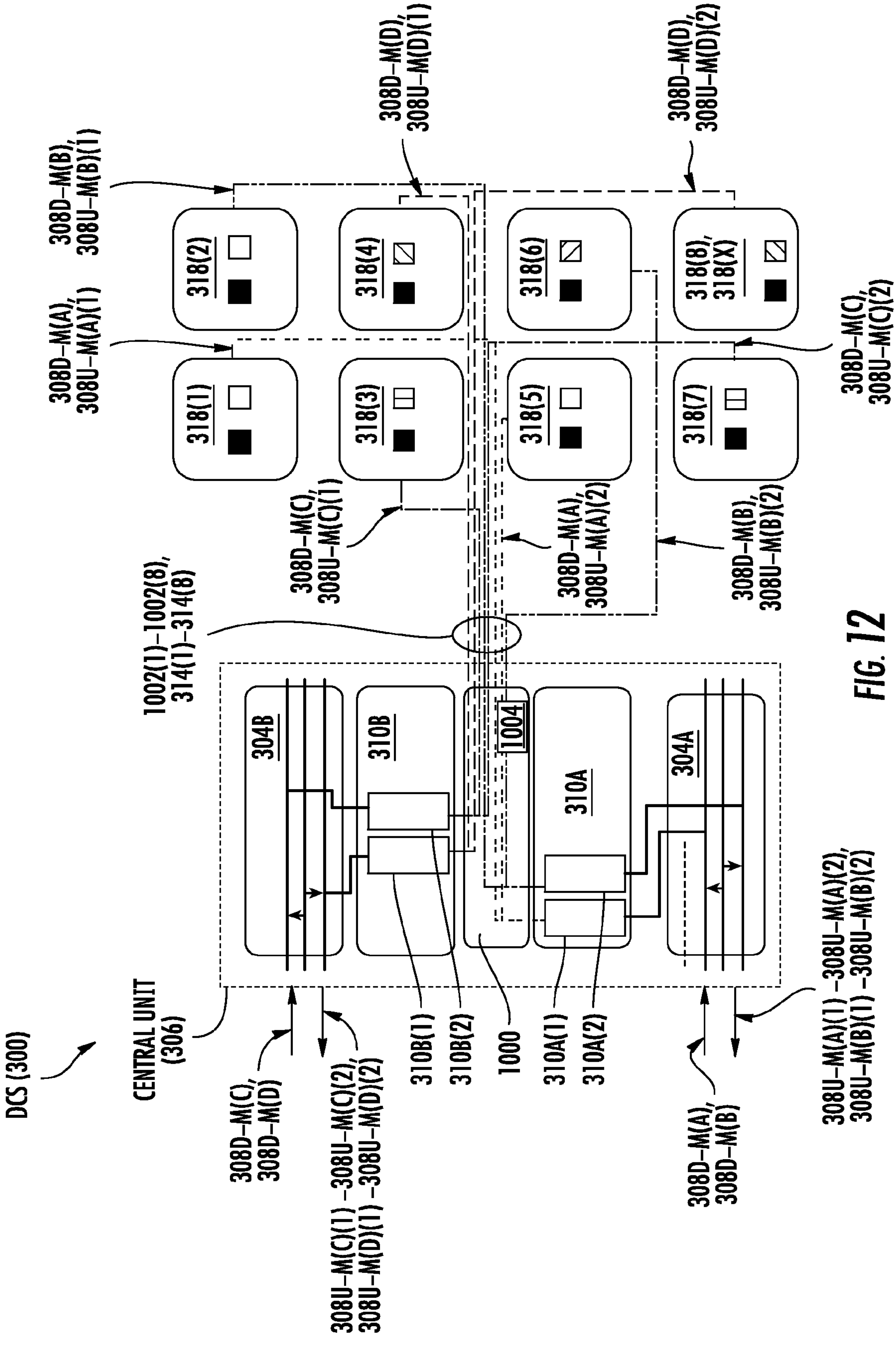

DCS (300)
CENTRAL UNIT (306)
304B
310B
1004
310A
304A
310B(1)
310B(2)
1000
310A(1)
310A(2)
308D–M(C), 308D–M(D)
308U–M(C)(1) –308U–M(C)(2), 308U–M(D)(1) –308U–M(D)(2)
308D–M(A), 308D–M(B)
308U–M(A)(1) –308U–M(A)(2), 308U–M(B)(1) –308U–M(B)(2)
1002(1)–1002(8), 314(1)–314(8)
318(1)
318(2)
318(3)
318(4)
318(5)
318(6)
318(7)
318(8), 318(X)
308D–M(A), 308U–M(A)(1)
308D–M(B), 308U–M(B)(1)
308D–M(D), 308U–M(D)(1)
308D–M(D), 308U–M(D)(2)
308D–M(C), 308U–M(C)(1)
308D–M(A), 308U–M(A)(2)
308D–M(B), 308U–M(B)(2)
308D–M(C), 308U–M(C)(2)

FIG. 12

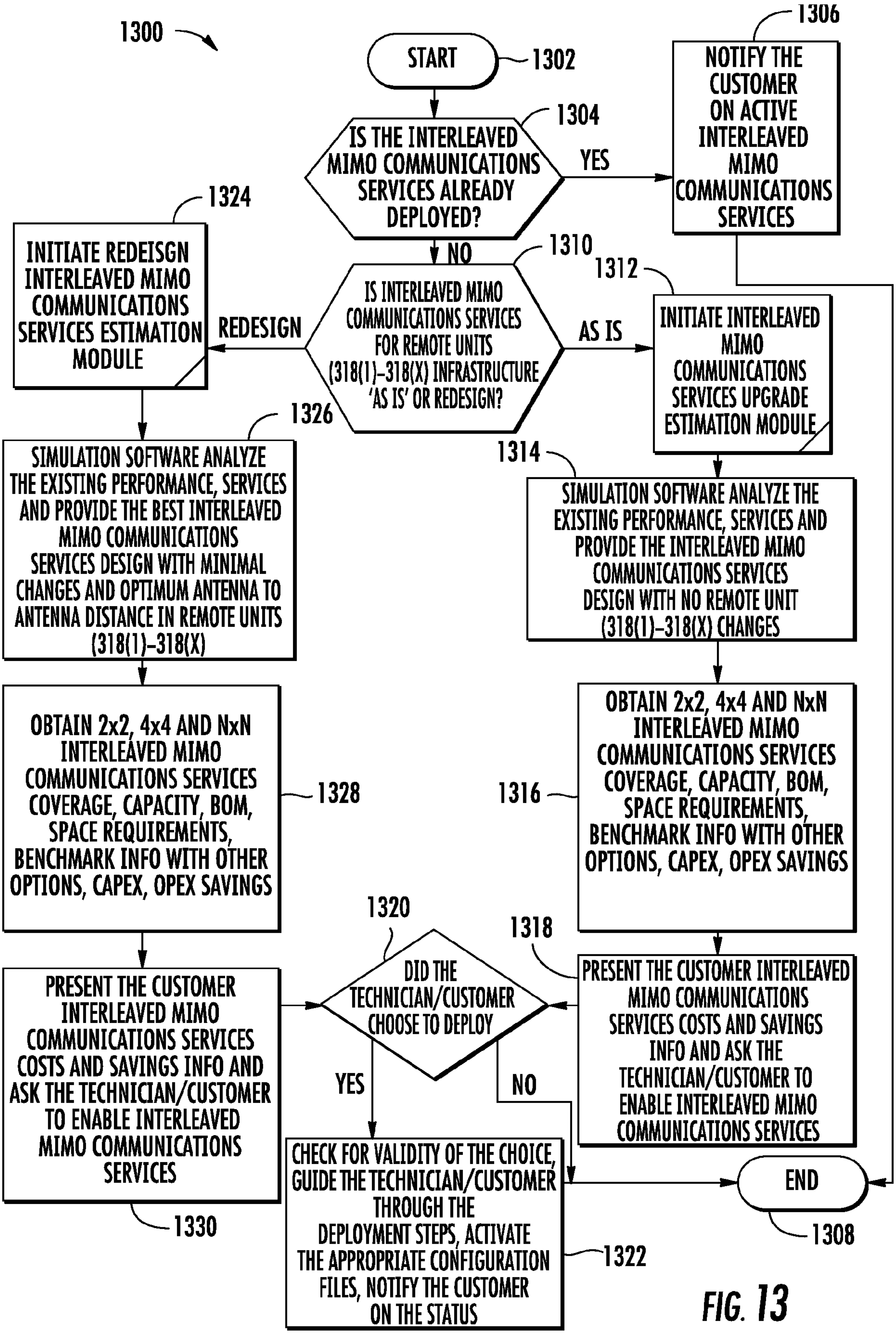

1300
START
1302
IS THE INTERLEAVED MIMO COMMUNICATIONS SERVICES ALREADY DEPLOYED?
1304
YES
NOTIFY THE CUSTOMER ON ACTIVE INTERLEAVED MIMO COMMUNICATIONS SERVICES
1306
NO
IS INTERLEAVED MIMO COMMUNICATIONS SERVICES FOR REMOTE UNITS (318(1)-318(X) INFRASTRUCTURE 'AS IS' OR REDESIGN?
1310
REDESIGN
INITIATE REDEISGN INTERLEAVED MIMO COMMUNICATIONS SERVICES ESTIMATION MODULE
1324
AS IS
INITIATE INTERLEAVED MIMO COMMUNICATIONS SERVICES UPGRADE ESTIMATION MODULE
1312
SIMULATION SOFTWARE ANALYZE THE EXISTING PERFORMANCE, SERVICES AND PROVIDE THE BEST INTERLEAVED MIMO COMMUNICATIONS SERVICES DESIGN WITH MINIMAL CHANGES AND OPTIMUM ANTENNA TO ANTENNA DISTANCE IN REMOTE UNITS (318(1)-318(X))
1326
SIMULATION SOFTWARE ANALYZE THE EXISTING PERFORMANCE, SERVICES AND PROVIDE THE INTERLEAVED MIMO COMMUNICATIONS SERVICES DESIGN WITH NO REMOTE UNIT (318(1)-318(X) CHANGES
1314
OBTAIN 2x2, 4x4 AND NxN INTERLEAVED MIMO COMMUNICATIONS SERVICES COVERAGE, CAPACITY, BOM, SPACE REQUIREMENTS, BENCHMARK INFO WITH OTHER OPTIONS, CAPEX, OPEX SAVINGS
1328
OBTAIN 2x2, 4x4 AND NxN INTERLEAVED MIMO COMMUNICATIONS SERVICES COVERAGE, CAPACITY, BOM, SPACE REQUIREMENTS, BENCHMARK INFO WITH OTHER OPTIONS, CAPEX, OPEX SAVINGS
1316
PRESENT THE CUSTOMER INTERLEAVED MIMO COMMUNICATIONS SERVICES COSTS AND SAVINGS INFO AND ASK THE TECHNICIAN/CUSTOMER TO ENABLE INTERLEAVED MIMO COMMUNICATIONS SERVICES
1330
DID THE TECHNICIAN/CUSTOMER CHOOSE TO DEPLOY
1320
PRESENT THE CUSTOMER INTERLEAVED MIMO COMMUNICATIONS SERVICES COSTS AND SAVINGS INFO AND ASK THE TECHNICIAN/CUSTOMER TO ENABLE INTERLEAVED MIMO COMMUNICATIONS SERVICES
1318
YES
NO
CHECK FOR VALIDITY OF THE CHOICE, GUIDE THE TECHNICIAN/CUSTOMER THROUGH THE DEPLOYMENT STEPS, ACTIVATE THE APPROPRIATE CONFIGURATION FILES, NOTIFY THE CUSTOMER ON THE STATUS
1322
END
1308

FIG. 13

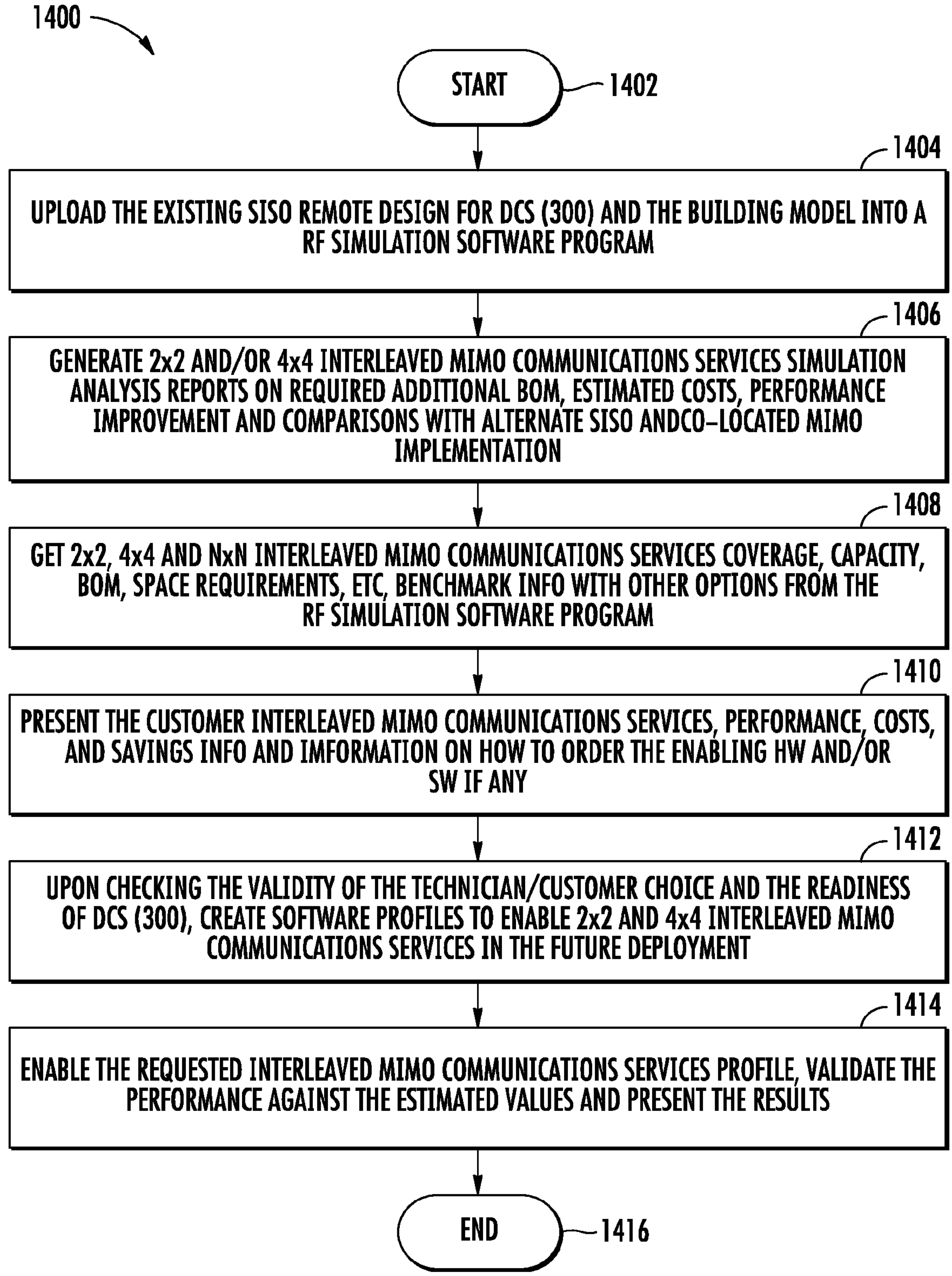

1400
START
1402
1404
UPLOAD THE EXISTING SISO REMOTE DESIGN FOR DCS (300) AND THE BUILDING MODEL INTO A RF SIMULATION SOFTWARE PROGRAM
1406
GENERATE 2x2 AND/OR 4x4 INTERLEAVED MIMO COMMUNICATIONS SERVICES SIMULATION ANALYSIS REPORTS ON REQUIRED ADDITIONAL BOM, ESTIMATED COSTS, PERFORMANCE IMPROVEMENT AND COMPARISONS WITH ALTERNATE SISO ANDCO-LOCATED MIMO IMPLEMENTATION
1408
GET 2x2, 4x4 AND NxN INTERLEAVED MIMO COMMUNICATIONS SERVICES COVERAGE, CAPACITY, BOM, SPACE REQUIREMENTS, ETC, BENCHMARK INFO WITH OTHER OPTIONS FROM THE RF SIMULATION SOFTWARE PROGRAM
1410
PRESENT THE CUSTOMER INTERLEAVED MIMO COMMUNICATIONS SERVICES, PERFORMANCE, COSTS, AND SAVINGS INFO AND IMFORMATION ON HOW TO ORDER THE ENABLING HW AND/OR SW IF ANY
1412
UPON CHECKING THE VALIDITY OF THE TECHNICIAN/CUSTOMER CHOICE AND THE READINESS OF DCS (300), CREATE SOFTWARE PROFILES TO ENABLE 2x2 AND 4x4 INTERLEAVED MIMO COMMUNICATIONS SERVICES IN THE FUTURE DEPLOYMENT
1414
ENABLE THE REQUESTED INTERLEAVED MIMO COMMUNICATIONS SERVICES PROFILE, VALIDATE THE PERFORMANCE AGAINST THE ESTIMATED VALUES AND PRESENT THE RESULTS
END
1416

FIG. 14

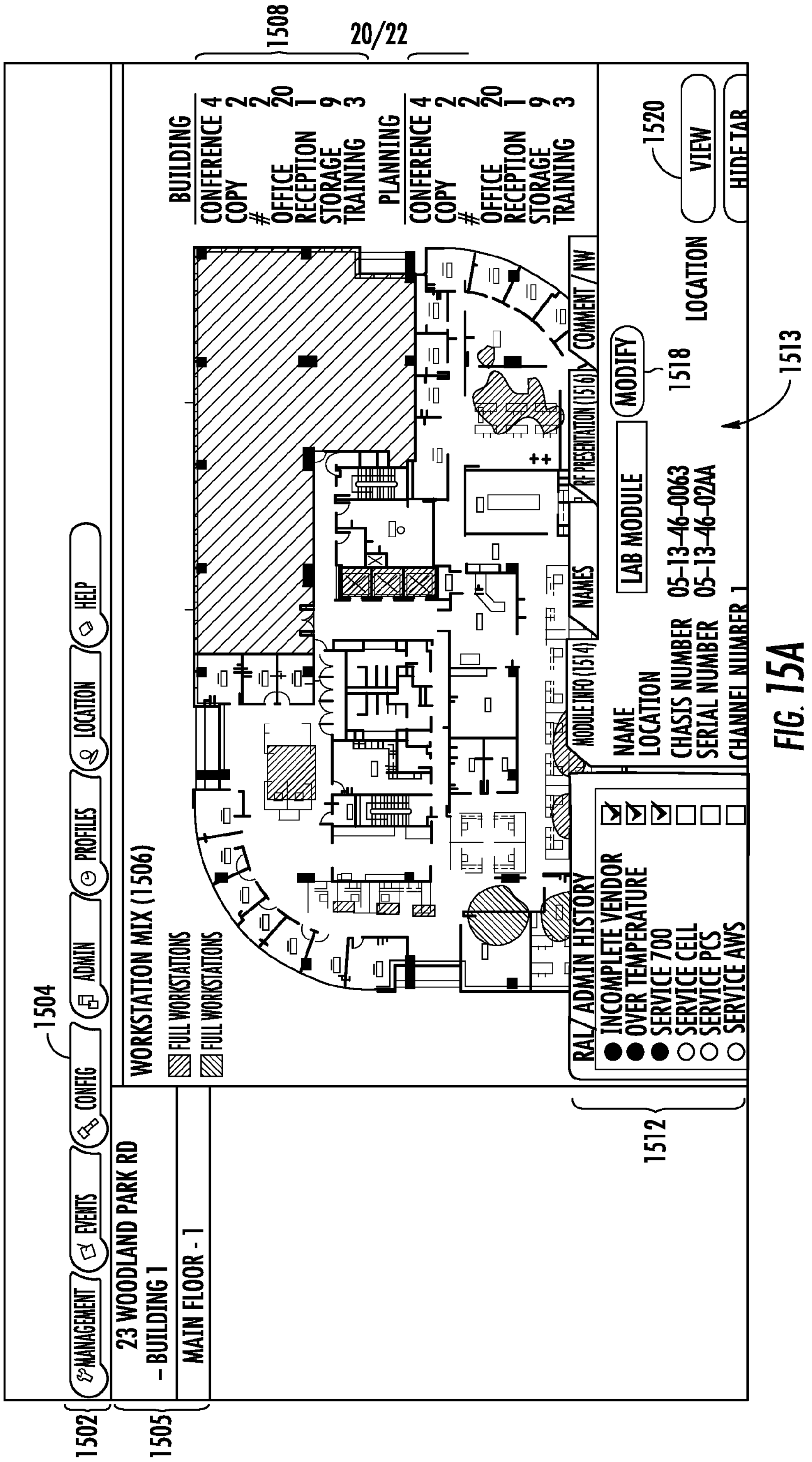

1500
1508
20/22
MANAGEMENT
EVENTS
CONFIG
ADMIN
PROFILES
LOCATION
HELP
1504
23 WOODLAND PARK RD
- BUILDING 1
MAIN FLOOR - 1
1502
1505
WORKSTATION MIX (1506)
FULL WORKSTATIONS
FULL WORKSTATIONS
BUILDING
CONFERENCE 4
COPY 2
2
OFFICE 20
RECEPTION 1
STORAGE 9
TRAINING 3
PLANNING
CONFERENCE 4
COPY 2
2
OFFICE 20
RECEPTION 1
STORAGE 9
TRAINING 3
1520
VIEW
HIDE TAB
LOCATION
COMMENT / NW
RF PRESENTATION (1516)
NAMES
MODULE INFO (1514)
MODIFY
1518
1513
LAB MODULE
NAME
LOCATION
CHASIS NUMBER 05-13-46-0063
SERIAL NUMBER 05-13-46-02AA
CHANNEL NUMBER 1
RAL/ ADMIN HISTORY
INCOMPLETE VENDOR
OVER TEMPERATURE
SERVICE 700
SERVICE CELL
SERVICE PCS
SERVICE AWS
1512

FIG. 15A

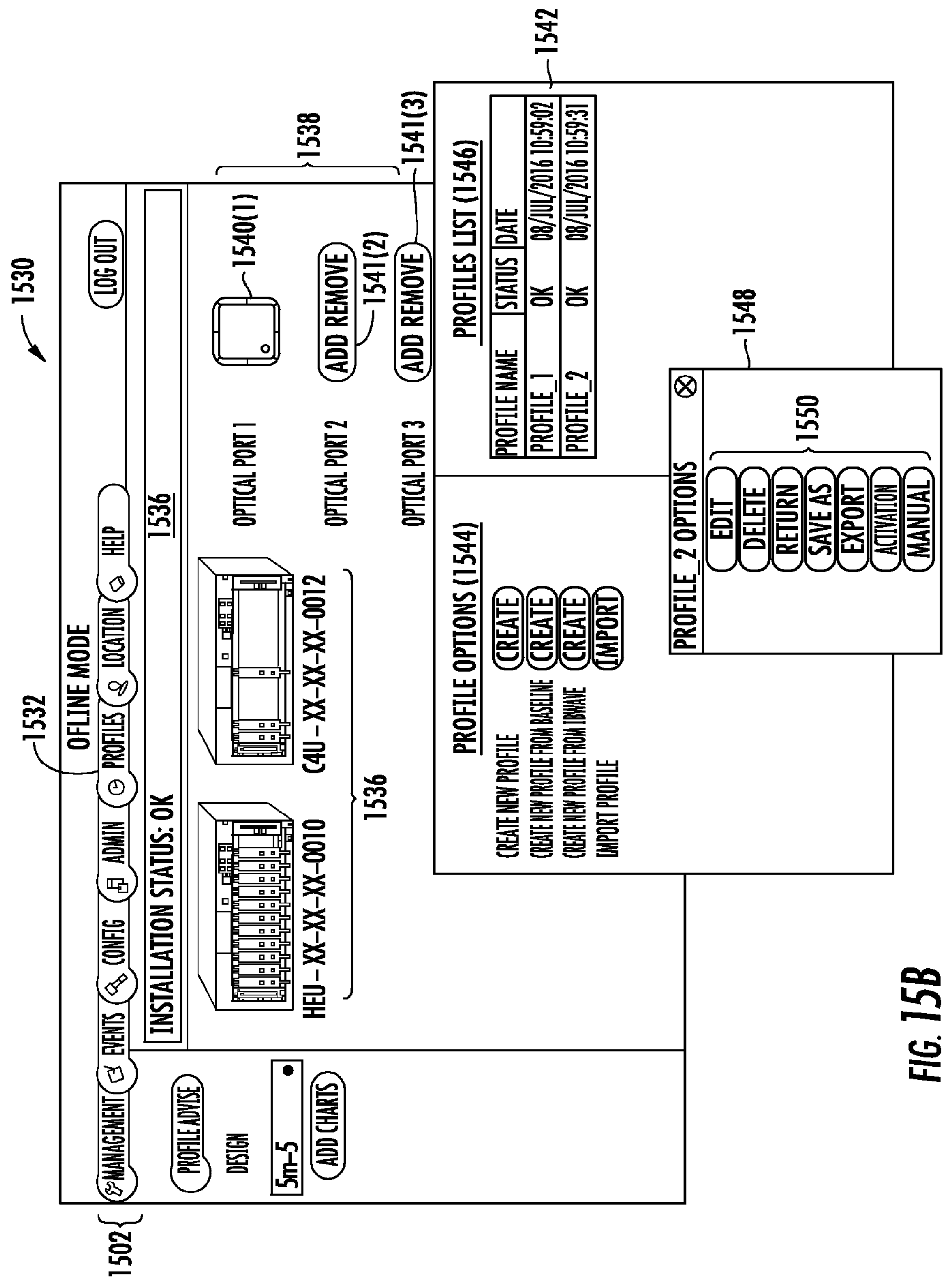

1530
1532
OFLINE MODE
MANAGEMENT
EVENTS
CONFIG
ADMIN
PROFILES
LOCATION
HELP
LOG OUT
1502
PROFILE ADVISE
DESIGN
5m-5
ADD CHARTS
INSTALLATION STATUS: OK
1536
HEU-XX-XX-XX-0010
C4U-XX-XX-XX-0012
1536
OPTICAL PORT 1
OPTICAL PORT 2
OPTICAL PORT 3
1540(1)
ADD REMOVE
1541(2)
ADD REMOVE
1541(3)
1538
1542
PROFILES LIST (1546)
PROFILE NAME
STATUS
DATE
PROFILE_1
OK
08/JUL/2016 10:59:02
PROFILE_2
OK
08/JUL/2016 10:59:31
PROFILE OPTIONS (1544)
CREATE NEW PROFILE
CREATE NEW PROFILE FROM BASELINE
CREATE NEW PROFILE FROM IBWAVE
IMPORT PROFILE
CREATE
CREATE
CREATE
IMPORT
1548
PROFILE_2 OPTIONS
1550
EDIT
DELETE
RETURN
SAVE AS
EXPORT
ACTIVATION
MANUAL

FIG. 15B

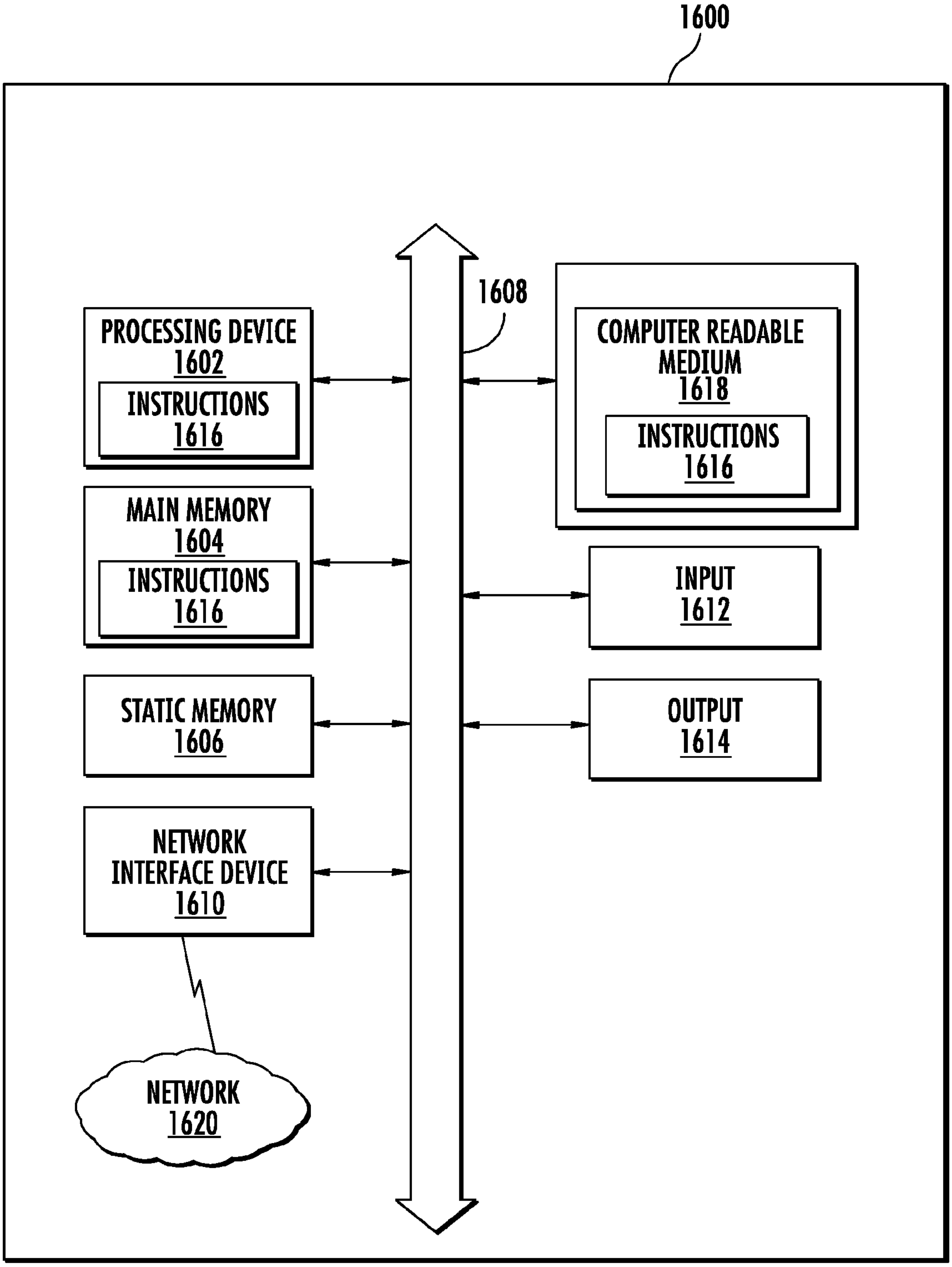

1600
1608
PROCESSING DEVICE
1602
INSTRUCTIONS
1616
MAIN MEMORY
1604
INSTRUCTIONS
1616
STATIC MEMORY
1606
NETWORK INTERFACE DEVICE
1610
NETWORK
1620
COMPUTER READABLE MEDIUM
1618
INSTRUCTIONS
1616
INPUT
1612
OUTPUT
1614

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/035334

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-10

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/035334

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/024 H04W72/04
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H04W

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/017835 A1 (CMAXWIRELESS CO LTD [KR]) 4 February 2016 (2016-02-04) the whole document & EP 3 176 961 A1 (CMAXWIRELESS CO LTD [KR]) 7 June 2017 (2017-06-07) paragraphs [0029], [0037], [0044], [0045], [0048], [0092] - [0095], [0100] figures 1, 2, 3, 6 -----	1-10

☐ 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
8 August 2018	12/10/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Franz, Stefan

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/035334

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016017835 A1	04-02-2016	EP 3176961 A1	07-06-2017
		KR 101571055 B1	23-11-2015
		US 2017250736 A1	31-08-2017
		WO 2016017835 A1	04-02-2016

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-10

A distributed communication system wherein the central unit is further configured to configure the routing configuration to: assign a fifth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a fifth remote unit among the plurality of remote units having a fifth remote coverage area; and assign a sixth MIMO communications signal among the received one or more downlink communications signals for the second MIMO communications service to a sixth remote unit among the plurality of remote units having a sixth remote coverage area overlapping with the fifth remote coverage area to interleave MIMO cell bond the fifth remote unit and the sixth remote unit.

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2. claims: 11-24

The distributed communication system, wherein the central unit further comprises an external interface and a controller configured to:receive routing assignments for the routing configuration from the external interface; andstore the routing assignments in the routing configuration.
