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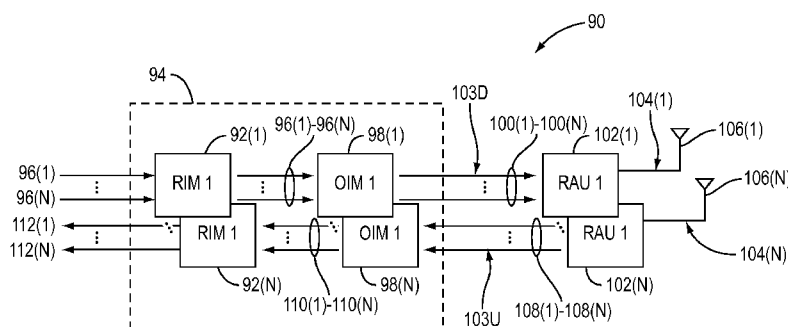


FIG. 4

(57) Abstract: Optical fiber-based distributed communications systems are disclosed herein. The optical fiber-based distributed communications systems support a variety of features. These features include, but are not limited to, the ability to distribute both radio frequency (RF) communication services and digital data services in the optical fiber-based distributed communications systems. Flexibility is provided in the components of the optical fiber-based distributed communications systems to provide upgradability and other enhanced features. The optical fiber-based distributed communications systems disclosed herein can provide features that support scalability, upgradability, reliability, management, capacity, and enhanced coverage areas. They comprise a plurality of radio interface modules, each adapted to support a given radio frequency band and to distribute received downlink RF communication signals, and a plurality of optical interfaces adapted to convert the downlink RF signals from the radio interface modules into a plurality of downlink optical RF communication signals.

OPTICAL FIBER-BASED DISTRIBUTED COMMUNICATIONS SYSTEMS, AND RELATED COMPONENTS AND METHODS

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/330,383, filed on May 2, 2010 and entitled, “OPTICAL FIBER-BASED DISTRIBUTED COMMUNICATIONS SYSTEMS, AND RELATED COMPONENTS AND METHODS,” which is incorporated herein by reference in its entirety.

BACKGROUND

Field of the Disclosure

[0002] The technology of the disclosure relates to optical fiber-based distributed communications systems for distributing radio frequency (RF) signals over optical fiber.

Technical Background

[0003] Wireless communication is rapidly growing, with ever-increasing demands for high-speed mobile data communication. As an example, so-called “wireless fidelity” or “WiFi” systems and wireless local area networks (WLANs) are being deployed in many different types of areas (e.g., coffee shops, airports, libraries, etc.). Distributed communications systems communicate with wireless devices called “clients,” which must reside within the wireless range or “cell coverage area” in order to communicate with an access point device.

[0004] One approach to deploying a distributed communications system involves the use of radio frequency (RF) antenna coverage areas, also referred to as “antenna coverage areas.” Antenna coverage areas can have a radius in the range from a few meters up to twenty meters as an example. Combining a number of access point devices creates an array of antenna coverage areas. Because the antenna coverage areas each cover small areas, there are typically only a few users (clients) per antenna coverage area. This allows for minimizing the amount of RF bandwidth shared among the wireless system users. It may be desirable to provide antenna coverage areas in a building or other facility to provide distributed communications system access to clients within the building or facility. However, it may be desirable to employ optical fiber to distribute communication signals. One of the benefits of optical fiber is increased bandwidth.

[0005] One type of distributed communications system for creating antenna coverage areas, called “Radio-over-Fiber” or “RoF,” utilizes RF signals sent over optical fibers. Such systems can include a head-end station optically coupled to a plurality of remote antenna units that each provide an antenna coverage area. Each remote antenna unit can include an RF transceiver coupled to an antenna to transmit RF signals wirelessly, and each the remote antenna unit is are coupled to the head-end station via an optical fiber link. The RF transceivers in the remote antenna units are transparent to the RF signals. The remote antenna units convert incoming optical RF signals from an optical fiber downlink to electrical RF signals via optical-to-electrical (O/E) converters, which are then passed to the RF transceiver. The RF transceiver converts the electrical RF signals to electromagnetic signals via antennas coupled to the RF transceiver provided in the remote antenna units. The antennas also receive electromagnetic signals, i.e., wireless electromagnetic radiation, from clients in the antenna coverage area and convert them to electrical RF signals (i.e., electrical RF signals in wire). The remote antenna units then convert the electrical RF signals to optical RF signals via electrical-to-optical (E/O) converters. The optical RF signals are then sent over an optical fiber uplink to the head-end station.

SUMMARY OF THE DETAILED DESCRIPTION

[0006] Embodiments disclosed in the detailed description include optical fiber-based distributed communications systems that support a variety of features. These features include, but are not limited to, the ability to distribute both RF communication services and digital data services in the optical fiber-based distributed communications systems. Flexibility is provided in the components of the optical fiber-based distributed communications systems to provide upgradability and other enhanced features. The optical fiber-based distributed communications systems disclosed herein can provide features that support scalability, upgradability, reliability, management, capacity, and enhanced coverage areas.

[0007] Additional features are set out in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments as described herein, including the detailed description that follows, the claims, as well as the appended drawings.

[0008] It is to be understood that both the foregoing general description and the following detailed description present embodiments, and are intended to provide an

overview or framework for understanding the nature and character of the disclosure. The accompanying drawings are included to provide a further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments, and together with the description serve to explain the principles and operation of the concepts disclosed.

BRIEF DESCRIPTION OF THE FIGURES

[0009] **FIG. 1** is a schematic diagram of an exemplary optical fiber-based distributed communications system;

[0010] **FIG. 2** is a more detailed schematic diagram of an exemplary head-end unit (HEU) and a remote antenna unit (RAU) that can be deployed in the optical fiber-based distributed communications system of **FIG. 1**;

[0011] **FIG. 3** is a partially schematic cut-away diagram of an exemplary building infrastructure in which the optical fiber-based distributed communications system in **FIG. 1** can be employed;

[0012] **FIG. 4** is a schematic diagram of another exemplary optical fiber-based distributed communications system;

[0013] **FIG. 5** is a more detailed schematic diagram of the exemplary optical fiber-based distributed communications system of **FIG. 4**;

[0014] **FIG. 6** is a schematic diagram of an exemplary HEU that can be employed in the optical fiber-based distributed communications systems of **FIG. 4** and **5**;

[0015] **FIG. 7** is a schematic diagram of an exemplary RAU that can be employed in the optical fiber-based distributed communications systems of **FIG. 4** and **5**;

[0016] **FIG. 8** is a schematic diagram of an exemplary building infrastructure in which digital data services and RF communication services are provided in an optical fiber-based distributed communications system;

[0017] **FIG. 9** is a schematic diagram of an exemplary Multiple Input/Multiple Output (MIMO) communication scheme that can be employed in the optical fiber-based distributed communications systems of **FIGS. 4** and **5**;

[0018] **FIG. 10** is a schematic diagram an alternate exemplary MIMO communication scheme that can be employed in the optical fiber-based distributed communications systems of **FIGS. 4** and **5**;

[0019] FIG. 11 is a schematic diagram of exemplary multiple HEUs provided to support multiple optical fiber-based distributed communications systems at different locations or facilities under common control and/or management;

[0020] FIG. 12 is a schematic diagram of exemplary multiple remote HEUs provided to support multiple optical fiber-based distributed communications systems at different locations or facilities under management of an exemplary main end HEU;

[0021] FIG. 13 is a schematic diagram of providing multiple optical fiber-based distributed communications systems, each providing different communication services, in a single facility or infrastructure;

[0022] FIG. 14 is a schematic diagram of multiple optical fiber-based distributed communications systems, each providing different communication services, in a single facility or infrastructure over a shared fiber optic cable;

[0023] FIG. 15 is a schematic diagram of exemplary optical fiber-based distributed communications systems providing multiple communication services in common RAUs employing separate amplifiers for each communication service; and

[0024] FIG. 16 is a schematic diagram of exemplary optical fiber-based distributed communications systems providing multiple communication services via shared amplifiers provided in common RAUs.

DETAILED DESCRIPTION

[0025] Reference will now be made in detail to the embodiments, examples of which are illustrated in the accompanying drawings, in which some, but not all embodiments are shown. Indeed, the concepts may be embodied in many different forms and should not be construed as limiting herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Whenever possible, like reference numbers will be used to refer to like components or parts.

[0026] Embodiments disclosed in the detailed description include optical fiber-based distributed communications systems that support a variety of features. These features include, but are not limited to, the ability to distribute both RF communication services and digital data services in the optical fiber-based distributed communications systems. Flexibility is provided in the components of the optical fiber-based distributed communications systems to provide upgradability and other enhanced features. The optical fiber-based distributed communications systems disclosed herein can provide features that support scalability, upgradability, reliability, management, capacity, and enhanced coverage areas.

[0027] In this regard, **FIG. 1** is a schematic diagram of an embodiment of an optical fiber-based distributed communications system. In this embodiment, the system is an optical fiber-based distributed communications system **10** that is configured to create one or more antenna coverage areas for establishing communications with wireless client devices located in the radio frequency (RF) range of the antenna coverage areas. The optical-fiber based distributed communications system **10** provides RF communications service (e.g., cellular services). In this embodiment, the optical fiber-based distributed communications system **10** includes a head-end unit (HEU) **12**, one or more remote antenna units (RAUs) **14**, and an optical fiber **16** that optically couples the HEU **12** to the RAU **14**. The HEU **12** is configured to receive communications over downlink electrical RF signals **18D** from a source or sources, such as a network or carrier as examples, and provide such communications to the RAU **14**. The HEU **12** is also configured to return communications received from the RAU **14**, via uplink electrical RF signals **18U**, back to the source or sources. In this regard and in this embodiment, the optical fiber **16** includes at least one downlink optical fiber **16D** to carry signals communicated from the HEU **12** to the RAU **14** and at least one uplink optical fiber **16U** to carry signals communicated from the RAU **14** back to the HEU **12**.

[0028] The optical fiber-based distributed communications system **10** has an antenna coverage area **20** that can be substantially centered about the RAU **14**. The antenna coverage area **20** of the RAU **14** forms an RF coverage area **21**. The HEU **12** is adapted to perform or to facilitate any one of a number of Radio-over-Fiber (RoF) applications, such as radio frequency (RF) identification (RFID), wireless local-area network (WLAN) communication, or cellular phone service. Shown within the antenna coverage area **20** is a client device **24** in the form of a mobile device as an example, which may be a cellular telephone as an example. The client device **24** can be any device that is capable of receiving RF communication signals. The client device **24** includes an antenna **26** (e.g., a wireless card) adapted to receive and/or send electromagnetic RF signals.

[0029] With continuing reference to **FIG. 1**, to communicate the electrical RF signals over the downlink optical fiber **16D** to the RAU **14**, to in turn be communicated to the client device **24** in the antenna coverage area **20** formed by the RAU **14**, the HEU **12** includes an electrical-to-optical (E/O) converter **28**. The E-O converter **28** converts the downlink electrical RF signals **18D** to downlink optical RF signals **22D** to be communicated over the downlink optical fiber **16D**. The RAU **14** includes an optical-to-electrical (O/E) converter **30** to convert received downlink optical RF signals **22D** back to

electrical RF signals to be communicated wirelessly through an antenna **32** of the RAU **14** to client devices **24** located in the antenna coverage area **20**.

[0030] Similarly, the antenna **32** is also configured to receive wireless RF communications from client devices **24** in the antenna coverage area **20**. In this regard, the antenna **32** receives wireless RF communications from client devices **24** and communicates electrical RF signals representing the wireless RF communications to an E/O converter **34** in the RAU **14**. The E-O converter **34** converts the electrical RF signals into uplink optical RF signals **22U** to be communicated over the uplink optical fiber **16U**. An O/E converter **36** provided in the HEU **12** converts the uplink optical RF signals **22U** into uplink electrical RF signals, which can then be communicated as uplink electrical RF signals **18U** back to a network or other source. The HEU **12** in this embodiment is not able to distinguish the location of the client devices **24** in this embodiment. The client device **24** could be in the range of any antenna coverage area **20** formed by an RAU **14**.

[0031] **FIG. 2** is a more detailed schematic diagram of the exemplary optical fiber-based distributed communications system of **FIG. 1** that provides electrical RF service signals for a particular RF service or application. In an exemplary embodiment, the HEU **12** includes a service unit **37** that provides electrical RF service signals by passing (or conditioning and then passing) such signals from one or more outside networks **38** via a network link **39**. In a particular example embodiment, this includes providing WLAN signal distribution as specified in the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard, i.e., in the frequency range from 2.4 to 2.5 GigaHertz (GHz) and from 5.0 to 6.0 GHz. Any other electrical RF signal frequencies are possible for other embodiments. In another exemplary embodiment, the service unit **37** provides electrical RF service signals by generating the signals directly. In another exemplary embodiment, the service unit **37** coordinates the delivery of the electrical RF service signals between client devices **24** within the antenna coverage area **20**.

[0032] With continuing reference to **FIG. 2**, the service unit **37** is electrically coupled to the E-O converter **28** that receives the downlink electrical RF signals **18D** from the service unit **37** and converts them to corresponding downlink optical RF signals **22D**. In an exemplary embodiment, the E-O converter **28** includes a laser suitable for delivering sufficient dynamic range for the RoF applications described herein, and optionally includes a laser driver/amplifier electrically coupled to the laser. Examples of suitable lasers for the E-O converter **28** include, but are not limited to, laser diodes, distributed

feedback (DFB) lasers, Fabry-Perot (FP) lasers, and vertical cavity surface emitting lasers (VCSELs).

[0033] With continuing reference to **FIG. 2**, the HEU **12** also includes the O-E converter **36**, which is electrically coupled to the service unit **37**. The O-E converter **36** receives the uplink optical RF signals **22U** and converts them to corresponding uplink electrical RF signals **18U**. In an example embodiment, the O-E converter **36** is a photodetector, or a photodetector electrically coupled to a linear amplifier. The E-O converter **28** and the O-E converter **36** constitute a "converter pair" **35**, as illustrated in **FIG. 2**.

[0034] In accordance with an exemplary embodiment, the service unit **37** in the HEU **12** can include an RF signal modulator/demodulator unit **40** for modulating/demodulating the downlink electrical RF signals **18D** and the uplink electrical RF signals **18U**, respectively. The service unit **37** can include a digital signal processing unit ("digital signal processor") **42** for providing to the RF signal modulator/demodulator unit **40** an electrical signal that is modulated onto an RF carrier to generate a desired downlink electrical RF signal **18D**. The digital signal processor **42** is also configured to process a demodulation signal provided by the demodulation of the uplink electrical RF signal **18U** by the RF signal modulator/demodulator unit **40**. The HEU **12** can also include an optional central processing unit (CPU) **44** for processing data and otherwise performing logic and computing operations, and a memory unit **46** for storing data, such as data to be transmitted over a WLAN or other network for example.

[0035] With continuing reference to **FIG. 2**, the RAU **14** also includes a converter pair **48** comprising the O-E converter **30** and the E-O converter **34**. The O-E converter **30** converts the received downlink optical RF signals **22D** from the HEU **12** back into downlink electrical RF signals **50D**. The E-O converter **34** converts uplink electrical RF signals **50U** received from the client device **24** into the uplink optical RF signals **22U** to be communicated to the HEU **12**. The O-E converter **30** and the E-O converter **34** are electrically coupled to the antenna **32** via an RF signal-directing element **52**, such as a circulator for example. The RF signal-directing element **52** serves to direct the downlink electrical RF signals **50D** and the uplink electrical RF signals **50U**, as discussed below. In accordance with an exemplary embodiment, the antenna **32** can include one or more patch antennas, such as disclosed in U.S. Patent Application Serial. No. 11/504,999, filed August 16, 2006 entitled "Radio-over-Fiber Transponder With A Dual-Band Patch Antenna System," and U.S. Patent Application Serial No. 11/451,553, filed June 12, 2006

entitled “Centralized Optical Fiber-based Wireless Picocellular Systems and Methods,” both of which are incorporated herein by reference in their entireties.

[0036] With continuing reference to **FIG. 2**, the optical fiber-based distributed communications system **10** also includes a power supply **54** that generates an electrical power signal **56**. The power supply **54** is electrically coupled to the HEU **12** for powering the power-consuming elements therein. In an exemplary embodiment, an electrical power line **58** runs through the HEU **12** and over to the RAU **14** to power the O-E converter **30** and the E-O converter **34** in the converter pair **48**, the optional RF signal-directing element **52** (unless the RF signal-directing element **52** is a passive device such as a circulator for example), and any other power-consuming elements provided. In an exemplary embodiment, the electrical power line **58** includes two wires **60** and **62** that carry a single voltage and that are electrically coupled to a DC power converter **64** at the RAU **14**. The DC power converter **64** is electrically coupled to the O-E converter **30** and the E-O converter **34** in the converter pair **48**, and changes the voltage or levels of the electrical power signal **56** to the power level(s) required by the power-consuming components in the RAU **14**. In an exemplary embodiment, the DC power converter **64** is either a DC/DC power converter or an AC/DC power converter, depending on the type of electrical power signal **56** carried by the electrical power line **58**. In another example embodiment, the electrical power line **58** (dashed line) runs directly from the power supply **54** to the RAU **14** rather than from or through the HEU **12**. In another example embodiment, the electrical power line **58** includes more than two wires and carries multiple voltages.

[0037] To provide further exemplary illustration of how an optical fiber-based distributed communications system can be deployed indoors, **FIG. 3** is provided. **FIG. 3** is a partially schematic cut-away diagram of a building infrastructure **70** employing an optical fiber-based distributed communications system. The system may be the optical fiber-based distributed communications system **10** of **FIGS. 1** and **2**. The building infrastructure **70** generally represents any type of building in which the optical fiber-based distributed communications system **10** can be deployed. As previously discussed with regard to **FIGS. 1** and **2**, the optical fiber-based distributed communications system **10** incorporates the HEU **12** to provide various types of communication services to coverage areas within the building infrastructure **70**, as an example. For example, as discussed in more detail below, the optical fiber-based distributed communications system **10** in this embodiment is configured to receive wireless RF signals and convert the

RF signals into RoF signals to be communicated over the optical fiber **16** to multiple RAUs **14**. The optical fiber-based distributed communications system **10** in this embodiment can be, for example, an indoor distributed antenna system (IDAS) to provide wireless service inside the building infrastructure **70**. These wireless signals can include cellular service, wireless services such as RFID tracking, Wireless Fidelity (WiFi), local area network (LAN), WLAN, and combinations thereof, as examples.

[0038] With continuing reference to **FIG. 3**, the building infrastructure **70** in this embodiment includes a first (ground) floor **72**, a second floor **74**, and a third floor **76**. The floors **72**, **74**, **76** are serviced by the HEU **12** through a main distribution frame **78** to provide antenna coverage areas **80** in the building infrastructure **70**. Only the ceilings of the floors **72**, **74**, **76** are shown in **FIG. 3** for simplicity of illustration. In the example embodiment, a main cable **82** has a number of different sections that facilitate the placement of a large number of RAUs **14** in the building infrastructure **70**. Each RAU **14** in turn services its own coverage area in the antenna coverage areas **80**. The main cable **82** can include, for example, a riser cable **84** that carries all of the downlink and uplink optical fibers **16D**, **16U** to and from the HEU **12**. The riser cable **84** may be routed through an interconnect unit (ICU) **85**. The ICU **85** may be provided as part of or separate from the power supply **54** in **FIG. 2**. The ICU **85** may also be configured to provide power to the RAUs **14** via the electrical power line **58**, as illustrated in **FIG. 2** and discussed above, provided inside an array cable **87** and distributed with the downlink and uplink optical fibers **16D**, **16U** to the RAUs **14**. The main cable **82** can include one or more multi-cable (MC) connectors adapted to connect select downlink and uplink optical fibers **16D**, **16U**, along with an electrical power line, to a number of optical fiber cables **86**.

[0039] The main cable **82** enables multiple optical fiber cables **86** to be distributed throughout the building infrastructure **70** (e.g., fixed to the ceilings or other support surfaces of each floor **72**, **74**, **76**) to provide the antenna coverage areas **80** for the first, second and third floors **72**, **74** and **76**. In an example embodiment, the HEU **12** is located within the building infrastructure **70** (e.g., in a closet or control room), while in another example embodiment the HEU **12** may be located outside of the building infrastructure **70** at a remote location. A base transceiver station (BTS) **88**, which may be provided by a second party such as a cellular service provider, is connected to the HEU **12**, and can be co-located or located remotely from the HEU **12**. A BTS is any station or source that provides an input signal to the HEU **12** and can receive a return signal from the HEU **12**.

In a typical cellular system, for example, a plurality of BTSs are deployed at a plurality of remote locations to provide wireless telephone coverage. Each BTS serves a corresponding cell and when a mobile station enters the cell, the BTS communicates with the mobile station. Each BTS can include at least one radio transceiver for enabling communication with one or more subscriber units operating within the associated cell.

[0040] The optical fiber-based distributed communications system **10** in **FIGS. 1-3** and described above provides point-to-point communications between the HEU **12** and the RAU **14**. Each RAU **14** communicates with the HEU **12** over a distinct downlink and uplink optical fiber pair to provide the point-to-point communications. Whenever an RAU **14** is installed in the optical fiber-based distributed communications system **10**, the RAU **14** is connected to a distinct downlink and uplink optical fiber pair connected to the HEU **12**. The downlink and uplink optical fibers may be provided in the optical fiber **16**. Multiple downlink and uplink optical fiber pairs can be provided in a fiber optic cable to service multiple RAUs **14** from a common fiber optic cable. For example, with reference to **FIG. 3**, RAUs **14** installed on a given floor **72**, **74**, or **76** may be serviced from the same optical fiber **16**. In this regard, the optical fiber **16** may have multiple nodes where distinct downlink and uplink optical fiber pairs can be connected to a given RAU **14**.

[0041] It may be desirable to provide an optical fiber-based distributed communications system that can support a wide variety of radio sources. For example, it may be desired to provide an optical fiber-based distributed communications system that can support various radio types and sources, including but not limited to Long Term Evolution (LTE), US Cellular (CELL), Global System for Mobile Communications (GSM), Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), Advanced Wireless Services (AWS), iDEN (e.g., 800 MegaHertz (MHz), 900 MHz, and 1.5 GigaHertz (GHz)), etc. These radio sources can range from 400 MHz to 2700 MHz as an example. To support a radio source, the HEU must contain lasers that are capable of modulating the radio signal into optical RF signals at the frequency of the radio signal for transmission over optical fiber. Likewise, lasers must be provided to convert the optical RF signals back into electrical RF signals at the frequencies of the radio band supported. It is costly to provide different conversion lasers for all possible radio sources that may be desired to be supported by an optical fiber-based distributed communications system.

[0042] In this regard, in certain embodiments disclosed herein, optical fiber-based distributed communications systems are provided that support a wide range of radio

sources. The optical fiber-based distributed communications systems disclosed herein also provide a variety of features. These features include, but are not limited to, the ability to distribute both RF communication services and digital data services over the optical fiber-based distributed communications systems. Flexibility is provided in the components of the optical fiber-based distributed communications systems to provide upgradability and other enhanced features. The optical fiber-based distributed communications systems disclosed herein also provide features that support scalability, upgradability, reliability, management, capacity, and enhanced coverage areas.

[0043] In this regard, **FIG. 4** is a schematic diagram of another exemplary optical fiber-based distributed communications system **90**. In this embodiment, the optical fiber-based distributed communications system **90** is comprised of three basic components. One or more RF interface modules (RIMs) **92(1)-92(N)** are provided in a HEU **94** to receive and process downlink electrical RF signals **96(1)-96(N)** prior to optical conversion into downlink optical RF signals. The processing of the downlink electrical RF signals **96(1)-96(N)** can include any of the processing previously described above in the HEU **12** in **FIG. 2**. The “1-N” notation indicates that any number of the referenced component, 1-N, may be provided. As will be described in more detail below, the HEU **94** is configured to accept a plurality of RIMs **92** as modular components that can be easily installed and removed or replaced in the HEU **94**. In one embodiment, the HEU **94** is configured to support up to four (4) RIMs **92** as an example. Each RIM **92** 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 HEU **94** and optical fiber-based distributed communications system **90** to support the desired radio sources.

[0044] For example, one RIM **92** may be configured to support the Personal Communication Services (PCS) radio band. Another RIM **92** may be configured to support the Long Term Evolution (LTE) 700 radio band. In this example, by inclusion of these RIMs **92**, the HEU **94** would be configured to support downlink electrical RF signals **96** and electrical uplink RF signals **112** on both PCS and LTE 700 radio bands. RIMs **92** may be provided in the HEU **94** that support any other radio bands desired, including but not limited to PCS, LTE, CELL, GSM, CDMA, CDMA2000, TDMA, AWS, iDEN (e.g., 800 MHz, 900 MHz, and 1.5 GHz), Enhanced Data GSM Environment, (EDGE), Evolution-Data Optimized (EV-DO), 1xRTT (i.e., CDMA2000 1X (IS-2000)), High Speed Packet Access (HSPA), 3GPP1, 3GPP2, and Cellular Digital Packet Data (CDPD). More specific examples include, but are not limited to, radio bands

between 400-2700 MHz including but not limited to 700 (LTE), 698-716 MHz, 728-757 MHz, 776-787 MHz, 806-824 MHz, 824-849 (US Cellular), 851-869 MHz, 869-894 (US Cellular), 880-915 (EU R), 925-960 (TTE), 1930-1990 (US PCS), 2110-2155 (US AWS), 925-960 (GSM 900), 1710-1755 MHz, 1850-1915 MHz, 1805-1880 (GSM 1800), 1920-1995 MHz, and 2110-2170 (GSM 2100). The optical fiber-based distributed communications system **90** is capable of operating in the preceding bands on uplink as well.

[0045] The downlink electrical RF signals **96(1)-96(N)** are provided to a plurality of optical interface modules (OIMs) **98(1)-98(N)** to convert the downlink electrical RF signals **96(1)-96(N)** into downlink optical signals **100(1)-100(N)**. The OIMs **98** may be configured to provide one or more optical interface cards (OICs) that contain O-E and E-O converters, as will be described in more detail below. The OIMs **98** support the radio bands that can be provided by the RIMs **92**, including those previously described above. Thus, in this embodiment, the OIMs **98** may support a radio band range from 400 MHz to 2700 MHz, as an example, to avoid providing different types or models of OIM **98** support for narrower radio bands to support possibilities for different radio band supported RIMs **92** provided in the HEU **94**. Further, as an example, the OIMs **98** may be optimized for sub bands within the 400 MHz to 2700 MHz frequency range, such as 400 - 700 MHz, 700 MHz - 1 GHz, 1 GHz - 1.6 GHz, and 1.6 GHz - 2.7 GHz, as examples.

[0046] The OIMs **98(1)-98(N)** include E-O converters to convert the downlink electrical RF signals **96(1)-96(N)** to downlink optical signals **100(1)-100(N)**. The downlink optical signals **100(1)-100(N)** are communicated over downlink optical fiber(s) **103D** to a plurality of RAUs **102(1)-102(N)**. O-E converters in the RAUs **102(1)-102(N)** convert the downlink optical signals **100(1)-100(N)** back into downlink electrical RF signals **104(1)-104(N)** that are transmitted over antennas **106(1)-106(N)** to client devices in the transmission range of the antennas **106(1)-106(N)**. As will be described in more detail below, both RF communication signals and digital data signals or services may be provided as downlink optical signals **100(1)-100(N)**.

[0047] E-O converters are also provided in the RAUs **102(1)-102(N)** to convert uplink electrical RF signals received from client devices through the antennas **106(1)-106(N)** into uplink optical signals **108(1)-108(N)** to be communicated over uplink optical fibers **103U** to the OIMs **98(1)-98(N)**. The OIMs **98(1)-98(N)** include O-E converters that convert the uplink optical signals **108(1)-108(N)** into uplink electrical RF signals

110(1)-110(N) that are processed by the RIMs **92(1)-92(N)** and provided as uplink electrical RF signals **112(1)-112(N)**. As will be described in more detail below, both RF communication signals and digital data signals or services may be provided as uplink optical signals **108(1)-108(N)**.

[0048] The HEU **94** may also include client device localization support, such as Emergency 911 (E911) support. For example, localization services can be provided as described in U.S. Provisional Patent Application Serial No. 61/319,659 filed on March 31, 2010 entitled “Localization Services In Optical Fiber-Based Distributed Communications Components And Systems, and Related Methods,” incorporated herein by reference in its entirety.

[0049] **FIG. 5** is a more detailed schematic diagram of the exemplary optical fiber-based distributed communications system **90** of **FIG. 4**. As illustrated therein, the HEU **94** can be provided in a HEU housing **113**. A power supply **114** is provided in the HEU housing **113** configured to supply power to the power consuming components of the HEU **94**. A plurality of RIMs **92(1)-92(N)** are provided in the HEU **94** to receive the downlink electrical RF signals **96(1)-96(N)** and provide the uplink electrical RF signals **112(1)-112(N)**. The RIMs **92(1)-92(N)** are configured to support particular radio sources or range of radio frequencies. The HEU housing **113** supports modularity of the RIMs **92(1)-92(N)**. In this regard, RIMs **92(1)-92(N)** can be installed and removed as desired to allow the HEU **94** and optical fiber-based distributed communications system **90** to support the desired radio sources or ranges. A fan module **116** can also be included in the HEU **94** to provide cooling of the components in the HEU **94**.

[0050] A head-end controller (HEC) **118** may also be included in the HEU **94**. The HEC **118** may include a micro-controller(s) or microprocessor(s) to perform features, such as monitoring of the data communications, monitoring of various power levels and other data to determine if alarm conditions exists, to support remote access via a user interface, such as a graphical user interface (GUI). Examples of these features are described in International Application No. PCT/US10/22847 filed on February 2, 2010 entitled “Optical Fiber-Based Distributed Antenna Systems, Components, and Related Methods For Monitoring and Configuring Thereof,” incorporated herein by reference in its entirety.

[0051] As illustrated in **FIG. 6**, The RIMs **92(1)-92(N)** are coupled to an RF routing module (RRM) **150** in this embodiment. The RRM **150** routes the downlink electrical RF signals **96(1)-96(N)** after being processed by the RIMs **92(1)-92(N)** to an appropriate OIC

120 provided in an OIM **98**. The OIM **98** in this embodiment is configured to support up to three (3) OICs **120(1)-120(3)**. Each OIC **120** is configured to provide optical RF signals converted from downlink electrical RF signals **96** to a RAU **102**. Each OIC **120** in this embodiment includes an E-O converter and an O-E converter to convert downlink electrical RF signals **96** into downlink optical signals **100** to be provided to an RAU **102**, and convert received uplink optical signals **108** into uplink electrical RF signals **112**.

[0052] Digital data services may also be provided by the HEU **94**. In this regard, the HEU **94** in FIG. 5 can include an integrated digital data services (DDS) switch module **122** that is configured to receive and convert electrical digital data signals into optical digital data signals over the downlink optical fiber **103D** to be provided to the RAUs **102** to provide access to digital data services at the RAUs **102**. In this regard, an access point (AP) **123** to provide access to the digital data services can be provided at an RAU **102**. The integrated DDS switch module **122** is also configured to receive electrical digital signals from the AP **123** to be communicated over a network providing the digital data services to the integrated DDS switch module **122**. Examples of digital data services include, but are not limited to, WLAN, WiMax, WiFi, Digital Subscriber Line (DSL), and LTE, etc. The digital data services may be provided over an Ethernet network as an example. For example, the integrated DDS switch module **122** may be an Ethernet service module (e.g., a 100 Megabit (MB) service). Other Ethernet standards that could be supported, include but are not limited to 100 Megabits per second (Mbps) (i.e., fast Ethernet) or Gigabit (Gb) Ethernet, or ten Gigabit (10G) Ethernet. Digital data service protocols, such as Simple Network Management Protocol (SNMP), may be supported.

[0053] More information about providing digital data services in an optical fiber-based distributed communications system is disclosed in U.S. Provisional Patent Application Serial No. ____/____, filed on May 2, 2010 and entitled, "Providing Digital Data Services in Optical Fiber-based Distributed Radio Frequency (RF) Communication Services, and Related Components and Methods," incorporated herein by reference in its entirety.

[0054] The downlink and uplink optical fibers **103D**, **103U** from the OIMs **98** may be connected to a patch panel **124** and routed through one or more riser cables **126(1)-126(N)** to one or more ICUs **128(1)-128(N)**. The ICUs **128(1)-128(N)** provide a common point in which the downlink and uplink optical fibers **103D**, **103U** can be bundled into one or more array cables **130(1)-130(N)** for providing RF communication services and/or digital data services to the RAUs **102**. Any combination of services or types of optical

fibers can be provided in the array cables **130(1)-130(N)**. For example, the array cables **130(1)-130(N)** may include single mode and/or multi-mode optical fibers for RF communication services and/or digital data services. Digital data switch modules can also be provided in the ICU **128** as opposed to the HEU **94**. For example, an external DDS switch module **132** may be included or provided at the ICU **128** to provide digital data services to RAUs **102** through optical fibers provided in the array cable **130**. For example, the external DDS switch module **132** may support Ethernet, including but not limited to 100 Megabit (Mb), Gigabit (Gb) and 10 Gb services, as an example. Providing digital data services outside of the OIMs **98** via the external DDS switch module **132** may allow greater bandwidth digital data services to be provided if lasers in E-O converters in the OIM **98** are not able to provide the bandwidth of such digital data services.

[0055] As illustrated in **FIG. 5**, some RAUs **102(1)** are configured to provide digital data services via AP **123(1)** from both DDS switch modules **122** and **132** as well as RF communication services. Other RAUs **102(2)** may be configured to only provide digital data services via AP **123(2)**. Other RAUs **102(6)**, **102(30)**, **102(N)** may be configured to only provide RF communication services.

[0056] **FIG. 6** is a schematic diagram of the HEU **94** in **FIG. 5** to provide more detail on exemplary components that can be provided in the HEU **94**. As illustrated in **FIG. 6**, the RIM **92** may include an RF connector **134** to connect an RF cable to receive the downlink electrical RF signals **96** and provide the uplink electrical RF signals **112**. The RF connector **134** may be a duplexed or unduplexed connector. The downlink electrical RF signals **96** are provided to an amplification/attenuation stage **136** in a downlink BTS module **138** to process and condition the downlink electrical RF signals **96** to the desired power level prior to conversion to optical RF signals in the OIM **98**. As examples, the downlink input power to the RIMs **92** may be between -15 dB and 33 dB with a 43 dB maximum with gain settings adjustable based on the input power level of the radio source. As another example, the uplink input to the RIMs **92** may be in the range of -15 dB to -15 dB as an example. The RIM **92** may be configured to receive different types of radio sources, including but not limited to BTS, BDA, Digital Radio Head (DRH), and Picocell or Femtocells as examples.

[0057] To detect the power level of the downlink electrical RF signals **96**, a power level detector **140** may also be provided in the downlink BTS module **138**. The detected power levels may be provided to automatically adjust or calibrate the power level of the downlink electrical RF signal **96** or to report the power level to allow manual adjustment.

Similarly, an uplink BTS module **142** is provided in the RIM **92** to process and condition the uplink electrical RF signals **112** from the OIMs **98**. To detect the power level of the uplink electrical RF signals **112**, a power level detector may **144** may also be provided in the uplink BTS module **142**. The detected power levels may be provided to automatically adjust or calibrate the power level of the downlink electrical RF signals **96** or to report the power level of the uplink electrical RF signals **112** to allow manual adjustment. More information on calibration in an optical fiber-based distributed communications system is described in International Application No. PCT/US10/22857, filed on February 2, 2010, entitled “Optical Fiber-Based Distributed Antenna Systems, Components, and Related Methods for Calibration Thereof,” incorporated herein by reference in its entirety.

[0058] Downlink and uplink connectors **146**, **148** are provided in the downlink BTS module **138** and uplink BTS module **142**, respectively, to provide interfacing to the RRM **150**. The RRM **150** in this embodiment includes a combiner **152** to combine downlink electrical signals **96** from multiple RIMs **92**. The RRM **150** also contains a splitter **154** in this embodiment to split the downlink electrical signals **96** combined by combiner **152** to the plurality of OIMs **98** to be distributed to the RAUs **102**. Similarly, the RRM **150** contains a combiner **156** to combine received uplink electrical signals from the individual OIMs **98** and then split via splitter **158** to the RIMs **92**. Downlink and uplink connectors **160**, **162** provide an interface between the OIMs **98** and the splitter **154** and the combiner **156**, respectively.

[0059] FIG. 6 illustrates exemplary internal components of the OIM **98(1)** in more detail. These components can be included in the other OIMs **98** in the HEU **94** as well. As illustrated in FIG. 6, the OIM **98(1)** is configured to support three (3) RAUs **102** in this example. In this regard, three (3) E-O converters **164** are provided to convert downlink electrical signals into downlink optical signals **166** to be provided to the RAUs **102**. Three (3) O-E converters **168** are provided to convert uplink optical signals **170** from the RAUs **102** into uplink electrical signals. In this embodiment, the OIM **98(1)** is also configured to provide digital data services (DDS) to the RAUs **102**. In this regard, the DDS switch module **122D** can be provided to provide downlink digital data services from a DDS module **127** receiving digital signals through a connector **125** to the RAUs **102**. The DDS switch module **122D** receives electrical digital data services from an outside source and provides the electrical digital data services to the E-O converters **164** to convert the electrical digital data signals into optical digital signals. Thus, the lasers in the E-O converters **164** to convert the downlink electrical RF signals **96** into downlink

optical RF signals can also be used to convert the electrical digital signals into optical digital data signals. The downlink optical signals **166** can represent downlink optical RF signals and/or downlink optical digital signals. The DDS switch module **122U** is also provided in the OIM **98(1)** and receives uplink electrical digital signals from the RAUs **102** from the O-E converters **168**.

[0060] **FIG. 7** is a schematic diagram of exemplary internal components of the RAU **102** in **FIG. 5**. The RAU **102** may be provided as an electronics card, such as a printed circuit board (PCB), as an example. A power converter **179** may be included in the RAU **102** that receives and provides power to power consuming components of the RAU **102**. The power provided to the power converter **179** may be sourced from the array cable **130** from the ICU **128**, as illustrated in **FIG. 5**. As further illustrated in **FIG. 7**, the RAU **102** includes a downlink connector **180** that receives the downlink optical signal **166** and an uplink connector **182** that provides the uplink optical signal **170** to the OIM **98**. Additional downlink and uplink ports **184**, **186** may also be provided in the RAU **102**. The downlink optical signal **166** is split via a splitter **188** into E-O converters **190(1)-190(N)** to provide downlink electrical signals **192(1)-192(N)**, which are then multiplexed via multiplexer **194** to be provided to the antenna **106**. The multiplexer **194** also allows the antenna **106** to receive uplink electrical signals **196** from client devices that are provided from the multiplexer **194** as uplink electrical signals **193(1)-193(N)** to O-E converters **198(1)-198(N)** into a combiner **200** and to the uplink connector **182** and uplink port **186**.

[0061] A digital data port **202** is provided to provide access to downlink digital signals communicated to the RAU **102** from the OIM **98** via a cable **203** to the AP **123**. As previously discussed, other digital data services can be provided to the RAU **102** that are not converted to optical digital signals in the OIM **98**. For example, a DDS switch module **132** may be provided at the ICU **128**. The RAU **102** may include a media converter **204** that converts downlink optical digital signals into downlink electrical digital signals to be accessed via downlink ports **206** to an AP **123** and handle received electrical data signals from the AP **123** via uplink port **208**, as illustrated in **FIG. 7**. A power port **210** may also be provided to provide power to digital data service clients connected to the AP **123**. For example, the power could comply with Power-over-Ethernet standards. The media converter **204** may be field installable into the RAU **102**. Optional RF ports **212**, **214** can also be provided for receiving additional filtering.

[0062] Further, the RAU **102** may include downlink linear output power per frequency band supported. The RAU **102** may support filtering (e.g., IMD2, downlink/uplink, and out of band). The RAU **102** may support uplink SFDR optimization as an example. The RAU **102** may include broadband expansion ports, as previously described, for additional external RF modules. The RAU **102** may include downlink signal compensation for optical loss. Automatic gain control (AGC) may be provided for the uplink as needed (e.g., 20-25 dB range within 1 to 2 dB step). The RAU **102** may include an uplink/downlink pass band gain ripple within +/- 1.5 dB per radio band as an example. Final downlink power adjustment may be provided at levels within +/- 1 dB as an example.

[0063] **FIG. 8** illustrates the building infrastructure **70** of **FIG. 3**, but with illustrative examples of digital data services and digital client devices that can be provided to client devices in addition to RF communication services in the optical fiber-based distributed communications system **90**. As illustrated in **FIG. 8**, exemplary digital data services include WLAN **207**, femtocells (e.g., 3G and 4G) **208**, gateways **210**, battery backup units (BBU) **212**, remote radio heads (RRH) **214**, and servers **216**. Medical telemetry and building automation applications may be supported in the building infrastructure **70** as examples. More information regarding providing digital data services in an optical fiber-based distributed communications system and the RAU **102** is described in previously referenced U.S. Provisional Patent Application Serial No. ____/____,____ filed on May 2, 2010 and entitled, "Providing Digital Data Services in Optical Fiber-based Distributed Radio Frequency (RF) Communication Services, and Related Components and Methods," which is incorporated herein by reference in its entirety.

[0064] The HEU **94** supports upgradability from Single Input/Single Output (SISO) to Multiple Input/Multiple Output (MIMO) communication schemes, if desired. In this regard, **FIG. 9** is a schematic diagram of an exemplary MIMO communication scheme that can be employed in the optical fiber-based distributed communications systems **90** of **FIGS. 4-8**. By providing modularity in providing RIMs **92** as previously discussed, MIMO configurations can easily be configured in the HEU **94**. As illustrated in **FIG. 9**, four (4) RIMs **92(1)-92(4)** are provided in this example in the HEU **94** to provide the ability to handle four (4) different radio bands. One RIM **92** labeled "MIMO 1" is provided to support received and process downlink electrical RF signals **96(1)**. For instance, the radio band for downlink electrical RF signal **96(1)** could be LTE 700 as an

example. The other radio bands supported by the RIMs **92(2)-92(4)** may be other radio bands.

[0065] The RIM **92** labeled “MIMO 2” is provided in the HEU **94** to receive and support downlink electrical RF signals **96(1)** at the same radio band as supported by the RIM **92** labeled “MIMO 1.” In this manner, the same downlink electrical RF signals **96(1)** are provided to two OIMs **98(1), 98(2)** in the HEU **94** to be provided to two different RAUs **102(1), 102(2)**. The RAU **102(1)** receives downlink optical signals **100(1)-100(4)** at four (4) radio bands. The RAU **102(2)** receives downlink optical signal **100(1)** at one (1) radio band that is the same radio band as downlink optical signal **100(1)** received by the RAU **102(1)**. The RAUs **102(1), 102(2)** may be co-located or closely located, such as eight (8) to fifteen (15) meters (m) apart as an example. In this manner, the RAUs **102(1), 102(2)** can both communicate to client devices at the radio band of the downlink electrical signal **96(1)** and receive uplink electrical signals from client devices that are converted into uplink optical signals **108(1)** to allow for MIMO processing of uplink electrical RF signals **112(1)** resulting from the RAUs **102(1), 102(2)**.

[0066] FIG. 10 provides an alternative MIMO communication configuration in the optical fiber-based distributed communications system **90** to the MIMO communication configuration provided in FIG. 9. As illustrated in FIG. 10, the two (2) RIMs **92** labeled “MIMO 1” and “MIMO 2” are provided just as provided in FIG. 9. However in FIG. 10, only one OIM **98(1)** is illustrated for the MIMO communication configuration in this embodiment. In this embodiment, the OIM **98(1)** receives the downlink electrical RF signals **96(1)-96(4)** as provided in FIG. 9. The OIM **98(1)** receives and converts the downlink electrical RF signals **96(1)-96(4)** into downlink optical signals **100(1)-100(4)** as also provided in FIG. 9. However, instead of providing the downlink optical signal **100(1)** to a second OIM **98** as provided in FIG. 9, the downlink optical signals **100(1)-100(4)** are provided to the RAU **102(1)**. The RAU **102(1)** provides the conversion of the downlink optical signal **100(1)** to downlink electrical signals **219D** provided to a communications module **220** that is not an RAU **102**, but rather a transceiver with an antenna **222** that can communicate the received downlink optical signal **100(1)** received from the RAU **102(1)** to client devices. The communications module **220** is also configured to provide uplink electrical signals **219U** from client devices via reception by antenna **222** to the RAU **102(1)**. Additional ports on the RAU **94** may be used in this regard. Uplink electrical signals from a client device in response to the downlink optical signal **100(1)** can be returned by the RAU **102(1)** to the HEU **94** for MIMO processing.

The patch panel **124** can route the uplink electrical RF signals **112(1)** to the RIMs **92** labeled “MIMO 1” and “MIMO 2” for MIMO processing.

[0067] The optical fiber-based distributed communications system **90** can also be deployed among multiple locations or buildings using multiple HEUs **94(1)-94(N)**. In this regard, **FIG. 11** is a schematic diagram of exemplary multiple HEUs **94(1)-94(N)** provided in multiple buildings **230(1)-230(N)**. The buildings **230(1)-230(N)** each include an optical fiber-based distributed communications system **90(1)-90(N)**. To provide centralized control of the HEUs **94(1)-94(N)**, a main radio interface unit (RIU) **232** can be provided that is configured to provide uplink and downlink electrical signals **234(1)-234(N)**, **236(1)-236(N)** to a combining module **238**. The combining module **238** is configured to combine the downlink electrical signals **234(1)-234(N)** and provide the combined downlink electrical signals **234(1)-234(N)** to converters **240(1)-240(N)** connected to downlink optical fibers **242D(1)-242D(N)** and uplink optical fibers **242U(1)-242U(2)** that are routed to the HEUs **94(1)-94(N)**. Converters **244(1)-244(N)** are provided to convert the downlink optical signals from the downlink optical fibers **242D(1)-242D(N)** into downlink electrical signals **246(1)-246(N)** to be input into the HEUs **94(1)-94(N)**. Thus, the transport of the downlink optical signals over the downlink optical fiber **242D** is transparent to the HEUs **94(1)-94(N)**. The HEUs **94(1)-94(N)** are also configured to provide uplink electrical signals **248(1)-248(N)** to the converters **244(1)-244(N)** to be communicated to the converters **240(1)-240(N)** to be communicated to the main RIU **232**. **FIG. 12** is another schematic diagram of the RIU **232** provided to interface to multiple HEUs **94(1)-94(N)** to provide a plurality of optical fiber-based distributed communications systems **90(1)-90(N)**.

[0068] Various configurations of providing multiple optical fiber-based distributed communications systems are possible with the optical fiber-based distributed communications systems **90** described above. For example, in one embodiment as illustrated in **FIG. 13**, multiple optical fiber-based distributed communications systems **90(1)-90(N)** can be provided in the same facility **248**, such as a building for example. A first operator **250(1)** can provide downlink electrical RF signals **252(1)** and receive uplink electrical RF signals **254(1)** at a desired radio band(s) to an HEU **94(1)** that is located in the same facility **248** as other HEUs **94(N)** to provide radio services at such radio band(s). Other operators **250(N)** can provide downlink electrical RF signals **252(N)** and receive uplink electrical RF signals **254(N)** at a desired radio band(s) to other HEUs **94(N)** in the same facility to provide radio services at other radio band(s).

[0069] FIG. 14 is a schematic diagram of the optical fiber-based distributed communications system 90 wherein multiple operators 250(1)-250(N) interfacing with multiple HEUs 94(1)-94(N) can share common cabling in the common facility 248. As illustrated in FIG. 14, the HEUs 94(1)-94(N) share a common riser cable 126 and common array cable 130. The RAUs 102(1) configured to receive RF signals from the first operator 250(1) are connected to optical fibers in the common array cable 130 connected to the first HEU 94(1). The RAUs 102(N) configured to receive RF signals from the other operators 250(N) are connected to optical fibers in the common array cable 130 connected to the other HEUs 94(N).

[0070] FIG. 15 is a schematic diagram of the optical fiber-based distributed communications system 90, wherein multiple operators 250(1)-250(N) interfacing with multiple HEUs 94(1)-94(N) can share common cabling and RAUs 102 in the common facility 248. As illustrated in FIG. 15, the HEUs 94(1)-94(N) share a common riser cable 126 and common array cable 130. The RAUs 102 are configured to receive RF signals from the operator 250(1)-250(N). The RAUs 102 contain multiple separate amplifiers 256(1)-256(N), each amplifier 256(1)-256(N) configured to be compatible with the radio bands of each operator 250(1)-250(N). FIG. 16 illustrates the optical fiber-based distributed communications system 90 of FIG. 15, but each RAU 102 contains a shared amplifier 258 for the multiple operators 250(1)-250(N) to support RF communications at the radio bands provided by the multiple operators 250(1)-250(N).

[0071] Other features are also possible with the optical fiber-based distributed communications systems and their components described herein. For example, the optical fiber-based wireless communications systems described herein can also support one-touch upgrade, if desired. One-touch upgrade enables service providers to add additional service bands by making all changes at a single point. The feature is enabled by the RAUs at the time of their installation. For example, assuming one or two frequencies are in use after the initial installation, adding a third (or fourth) radio band can be accomplished with a single visit. This can be accomplished by connecting the new RF source to the HEU and accessing an embedded graphical user interface (GUI) therein. The RAU(s) corresponding to the area where the new radio band is desired is selected, and the new radio band is enabled by selecting it from the list of choices on the screen. The new radio band can now be delivered without requiring access to telecom closets or ceiling access, for example.

[0072] Further, as used herein, it is intended that terms “fiber optic cables” and/or “optical fibers” include all types of single mode and multi-mode light waveguides, including one or more optical fibers that may be upcoated, colored, buffered, ribbonized and/or have other organizing or protective structure in a cable such as one or more tubes, strength members, jackets or the like. The optical fibers disclosed herein can be single mode or multi-mode optical fibers. Likewise, other types of suitable optical fibers include bend-insensitive optical fibers, or any other expedient of a medium for transmitting light signals. An example of a bend-insensitive, or bend resistant, optical fiber is ClearCurve[®] Multimode fiber commercially available from Corning Incorporated. Suitable fibers of this type are disclosed, for example, in U.S. Patent Application Publication Nos. 2008/0166094 and 2009/0169163, the disclosures of which are incorporated herein by reference in their entireties.

[0073] Many modifications and other embodiments of the embodiments set forth herein will come to mind to one skilled in the art to which the embodiments pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the description and claims are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. It is intended that the embodiments cover the modifications and variations of the embodiments provided they come within the scope of the appended claims and their equivalents. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What we claim is:

1. An apparatus configured to distribute radio-frequency (RF) communications signals in given radio bands in a distributed communications system, comprising:
 - a plurality of radio interface modules (RIMs) each configured to:
 - support a given radio band; and
 - distribute received downlink electrical RF communications signals at a frequency in the given radio band into a plurality of downlink electrical RF communications signals at the frequency in the given radio band to a plurality of remote antenna units (RAUs);
 - wherein at least two of the plurality of RIMs are configured to support different radio bands; and
 - a plurality of optical interfaces each configured to:
 - receive the plurality of downlink electrical RF communications signals from the plurality of RIMs; and
 - convert the received plurality of downlink electrical RF communications signals into a plurality of downlink optical RF communications signals.
2. The apparatus according to claim 1, wherein each of the plurality of optical interfaces is further configured to provide the plurality of downlink optical RF communications signals to the plurality of RAUs.
3. The apparatus according to claims 1 or 2, further comprising a downlink distribution matrix configured to distribute the plurality of downlink electrical RF communications signals to the plurality of RAUs.
4. The apparatus according to claims 1, 2, or 3, wherein each of the plurality of RIMs is further configured to filter the received downlink electrical RF communications signals in the given radio band.
5. The apparatus according to claims 1, 2, 3, or 4, wherein each of the plurality of RIMs further comprises a plurality of attenuators configured to control a power level for the received downlink electrical RF communications signals.

6. The apparatus according to claims 1, 2, 3, 4, or 5, further comprising a controller configured to control distribution of the plurality of downlink electrical RF communications signals for each of the plurality of RIMs.
7. The apparatus according to claims 1, 2, 3, 4, 5, or 6, further comprising a controller configured to control distribution of the plurality of downlink optical RF communications signals to the plurality of RAUs.
8. The apparatus according to claims 1, 2, 3, 4, 5, 6, or 7, wherein:
each of the the plurality of optical interfaces is further configured to:
 split a received uplink optical RF communications signal into a plurality of uplink optical RF communications signals;
 convert the plurality of uplink optical RF communications signals into a plurality of uplink electrical RF communications signals; and
 control providing each of the split plurality of uplink optical RF communications signals to the plurality of RIMs; and
each of the plurality of RIMs is further configured to receive the plurality of uplink electrical RF communications signals from the plurality of optical interfaces.
9. The apparatus of claim 8, wherein each of the plurality of RIMs is further configured to provide the received plurality of uplink electrical RF communications signals to one or more carriers.
10. The apparatus according to claim 8, further comprising an uplink distribution matrix configured to distribute the plurality of uplink optical RF communications signals.
11. The apparatus according to claim 8, further comprising a controller configured to control providing the plurality of uplink electrical RF communications signals from the plurality of optical interfaces to the plurality of RIMs.
12. A method of distributing RF communications signals in given radio bands in a distributed communications system, comprising:
 distributing received downlink electrical radio frequency (RF) communications signals at a plurality of frequencies in a plurality of given radio band in a plurality of

radio interface module (RIM) supporting a given radio band, wherein at least two of the plurality of RIMs are configured to support different radio bands, into a plurality of downlink electrical RF communications signals at the frequency in the given radio band to a plurality of remote antenna units (RAUs);

receiving the plurality of downlink electrical RF communications signals from the plurality of RIMs in a plurality of optical interfaces; and

converting the received plurality of downlink electrical RF communications signals into a plurality of downlink optical RF communications signals in the plurality of optical interfaces.

13. The method according to claim 12, further comprising the plurality of optical interfaces providing the plurality of downlink optical RF communications signals to the plurality of RAUs.

14. The method according to claims 12 or 13, further comprising distributing the plurality of downlink electrical RF communications signals to the plurality of RAUs in downlink distribution matrix.

15. The method according to claims 12, 13, or 14, further comprising filtering the received downlink electrical RF communications signals in the given radio band in each of the plurality of RIMs.

16. The method according to claims 12, 13, 14, or 15, further comprising attenuating the power level for the received downlink electrical RF communications signals.

17. The method according to claims 12, 13, 14, 15, or 16, further comprising a controller controlling distribution of the plurality of downlink electrical RF communications signals for each of the plurality of RIMs.

18. The method according to claims 12, 13, 14, 15, 16, or 17, further comprising a controller controlling distribution of the plurality of downlink optical RF communications signals to the plurality of RAUs.

19. The method according to claims 12, 13, 14, 15, 16, 17 or 18, further comprising

splitting a received uplink optical RF communications signal into a plurality of uplink optical RF communications signals in each of the plurality of optical interfaces;

converting the plurality of uplink optical RF communications signals into a plurality of uplink electrical RF communications signals in each of the plurality of optical interfaces;

providing the uplink optical RF communications signals from the plurality of optical interfaces to the plurality of RIMs; and

receiving the plurality of uplink electrical RF communications signals from the plurality of optical interfaces in the plurality of RIMs.

20. The method of claim 19, further comprising providing the received plurality of uplink electrical RF communications signals from the plurality of RIMs to one or more carriers.

21. The method according to claims 19 or 20, distributing the plurality of uplink optical RF communications signals in an uplink distribution matrix.

22. The method according to claims 19, 20, or 21 further comprising a controller controlling providing the plurality of uplink electrical RF communications signals from the plurality of optical interfaces to the plurality of RIMs.

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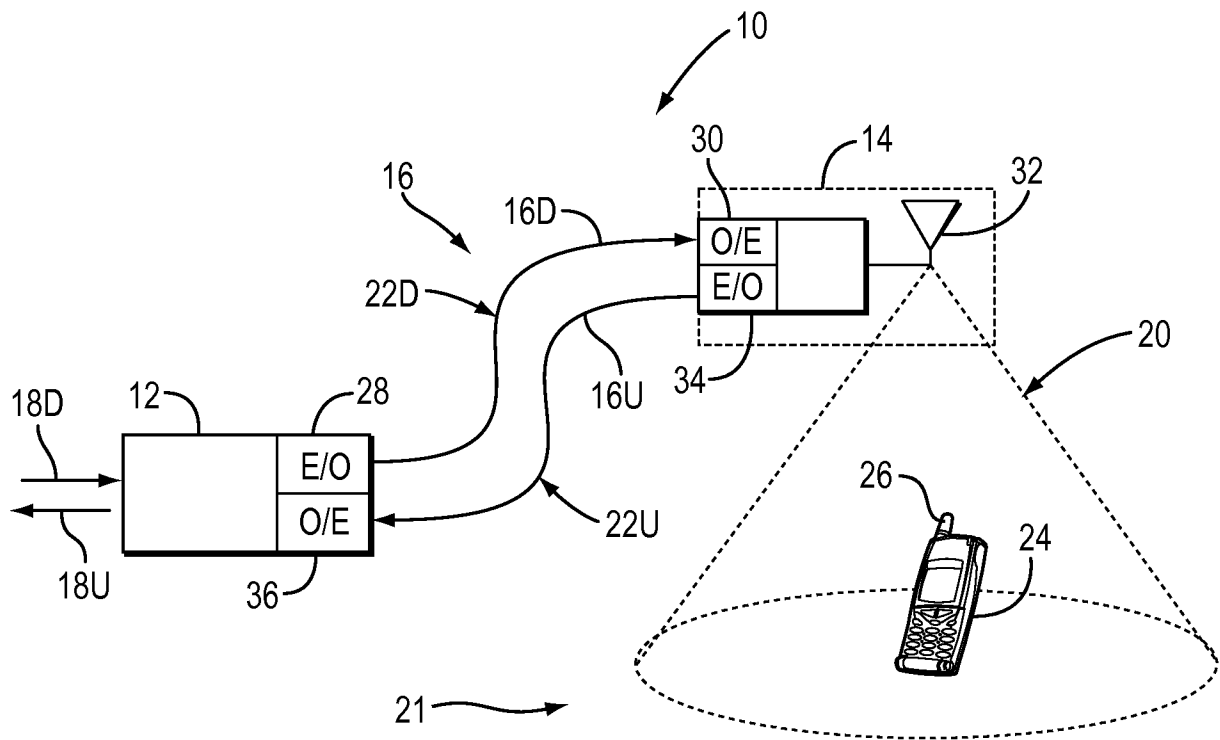


FIG. 1

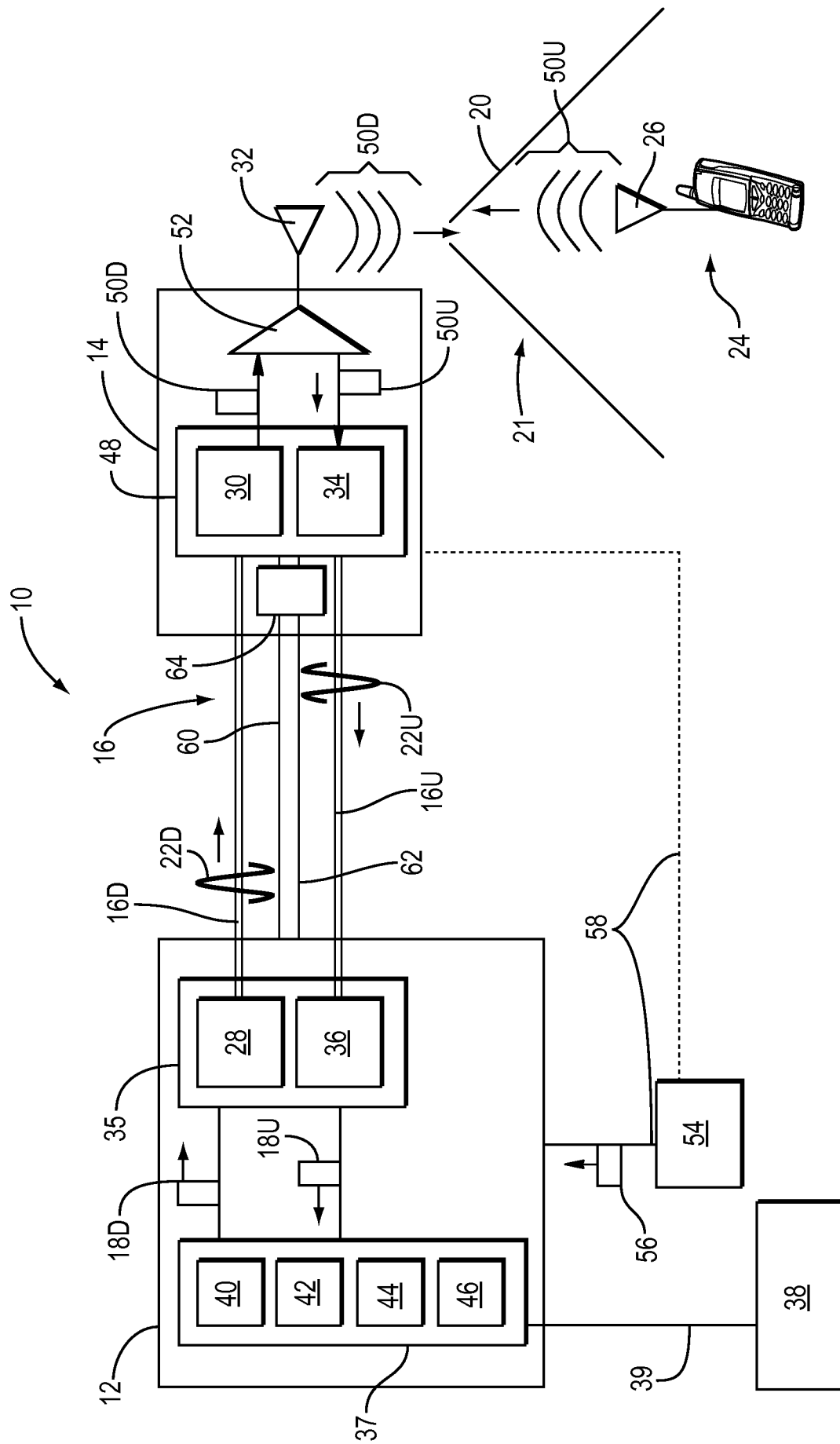


FIG. 2

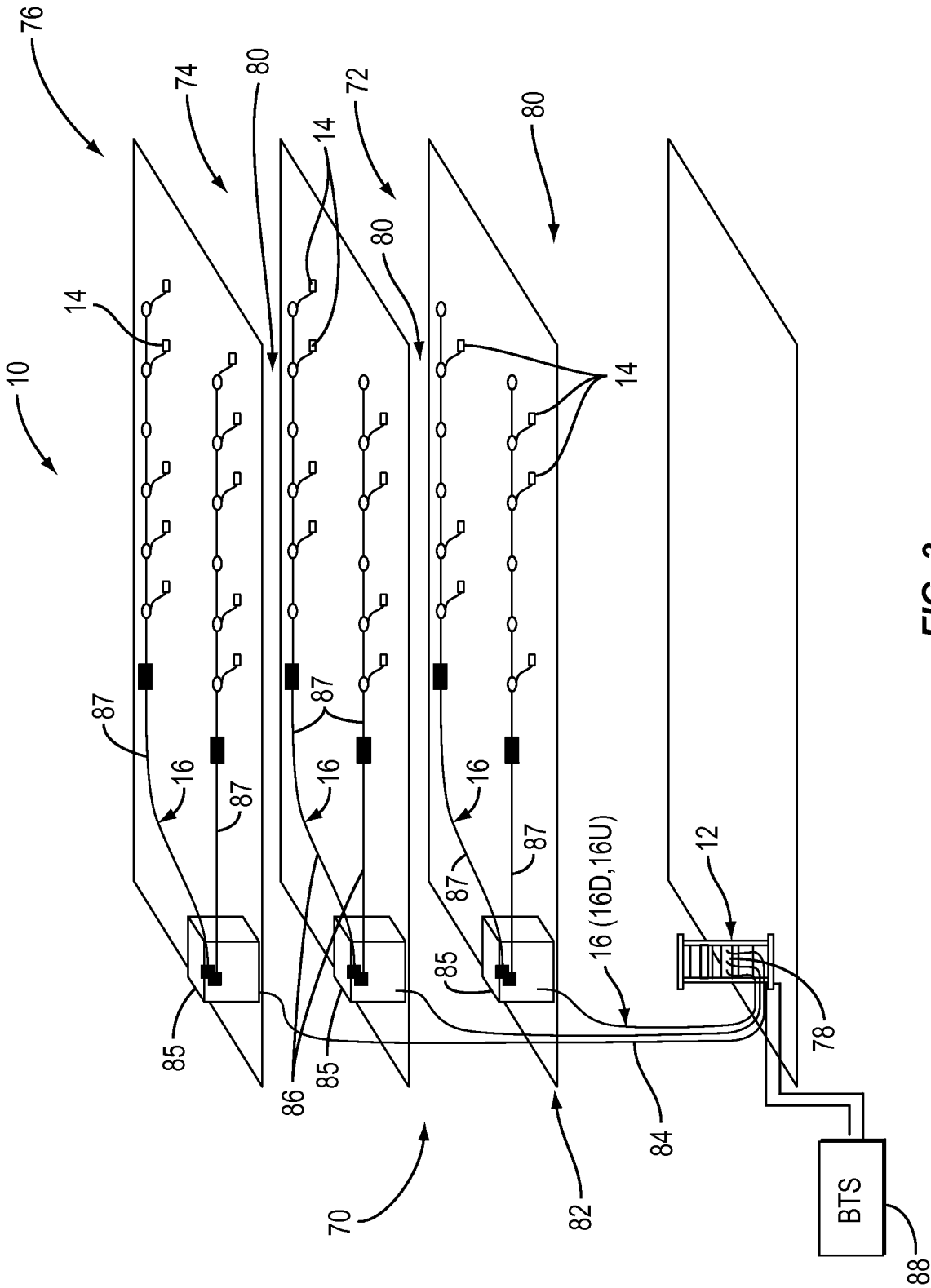


FIG. 3

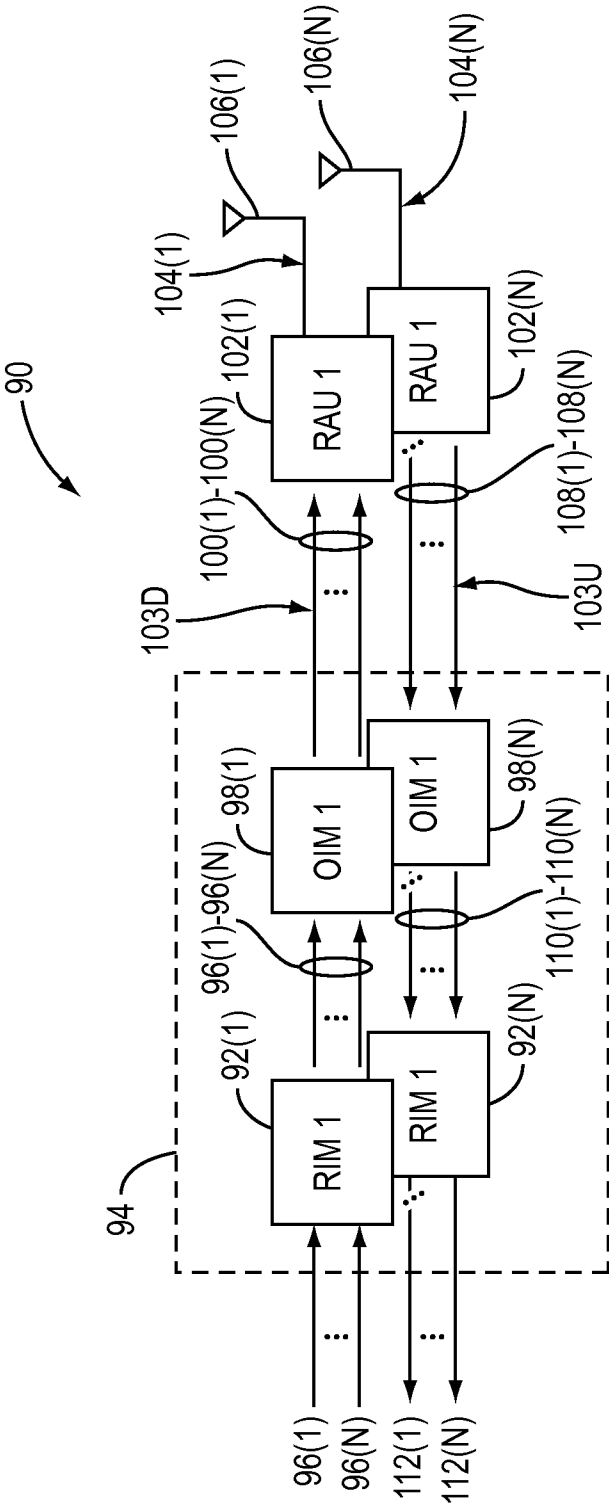
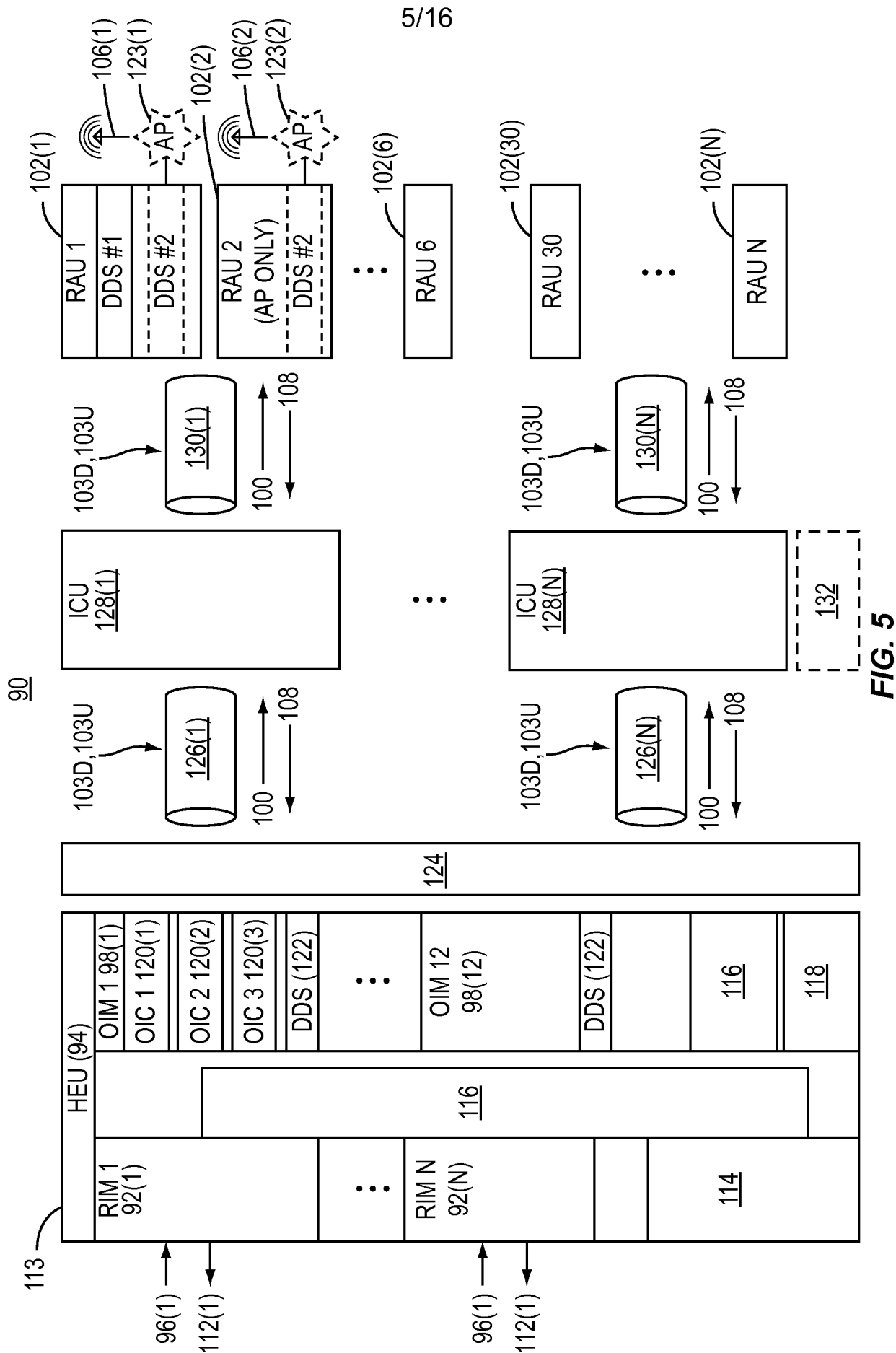


FIG. 4



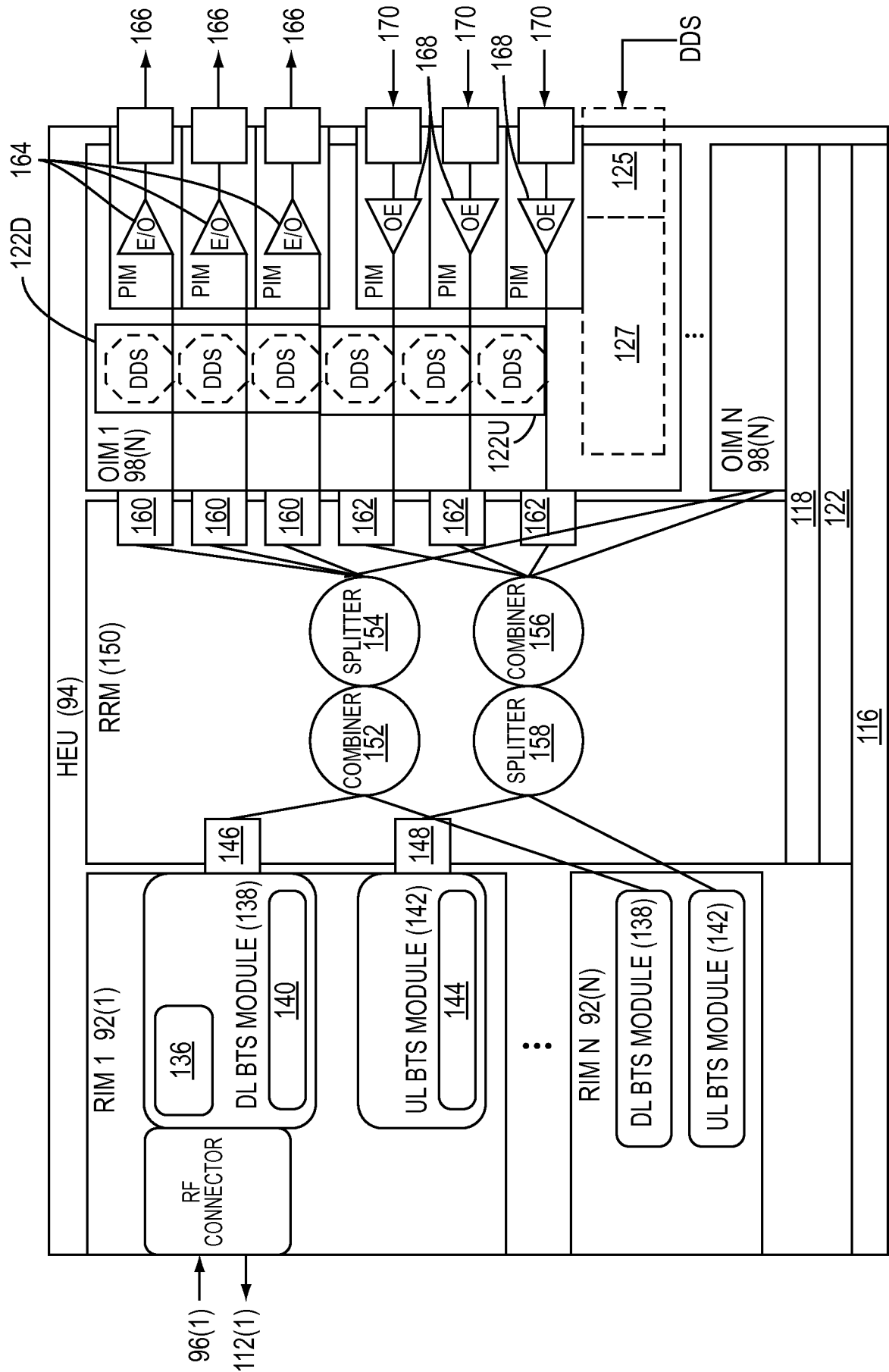


FIG. 6

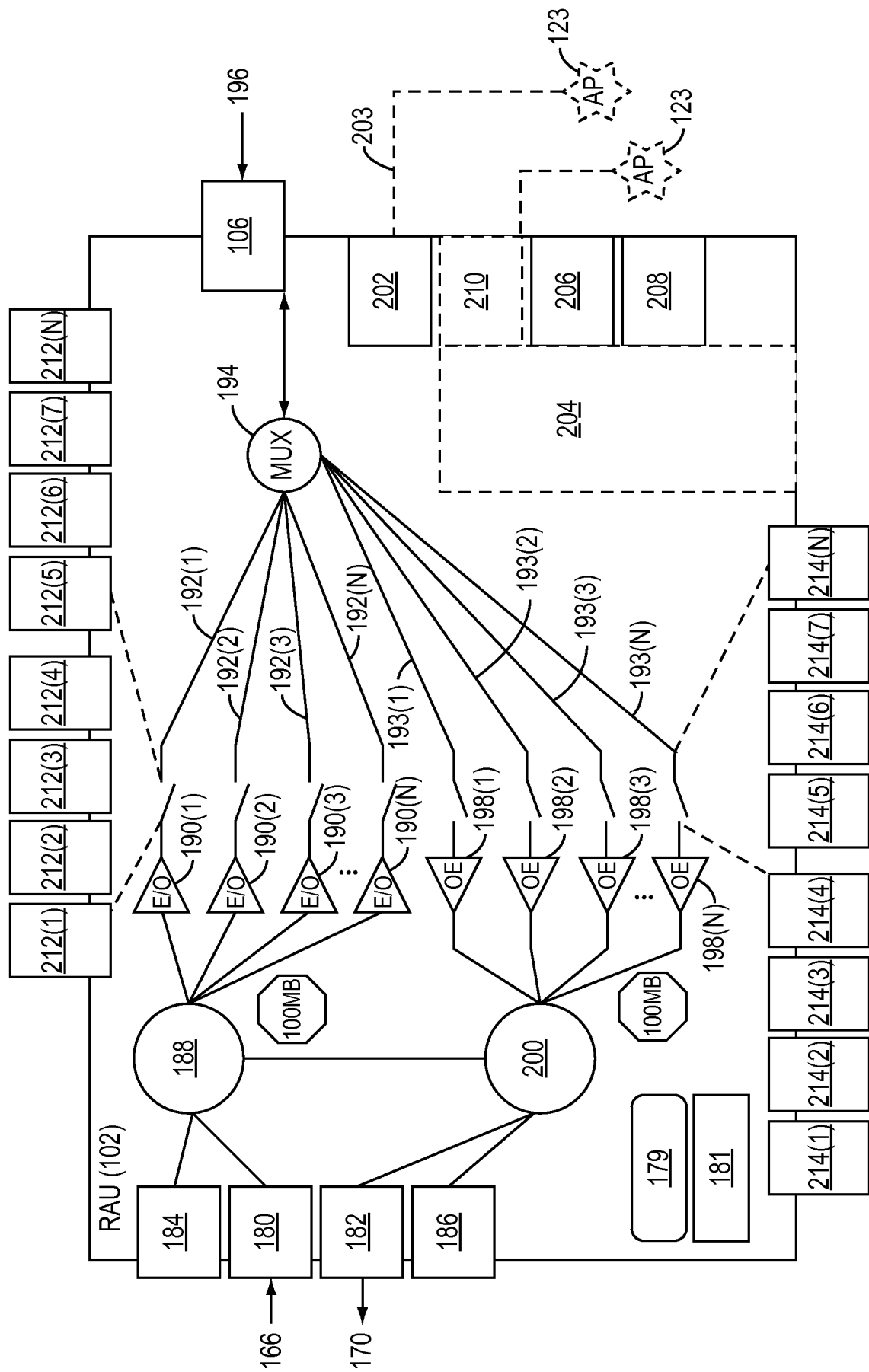
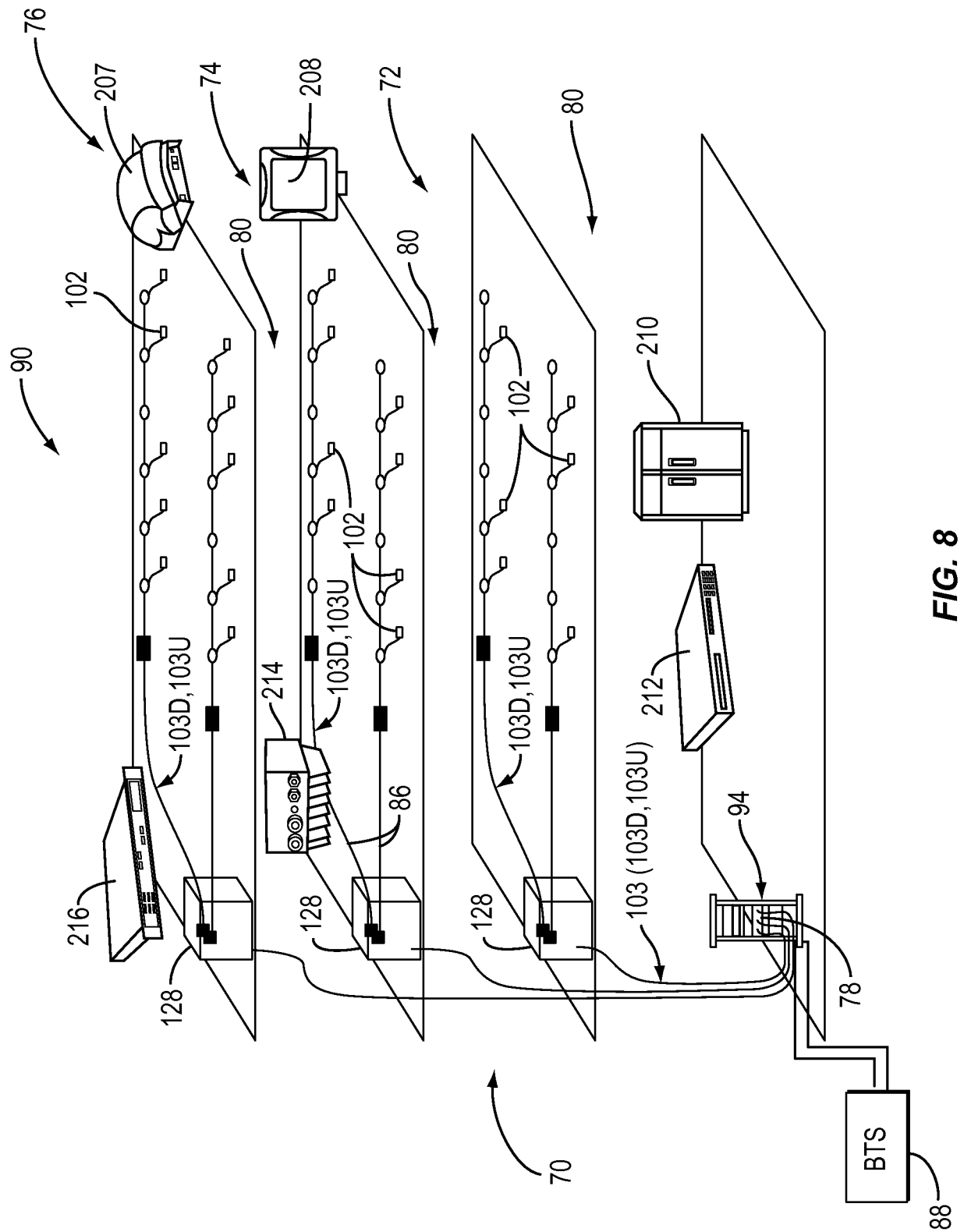


FIG. 7



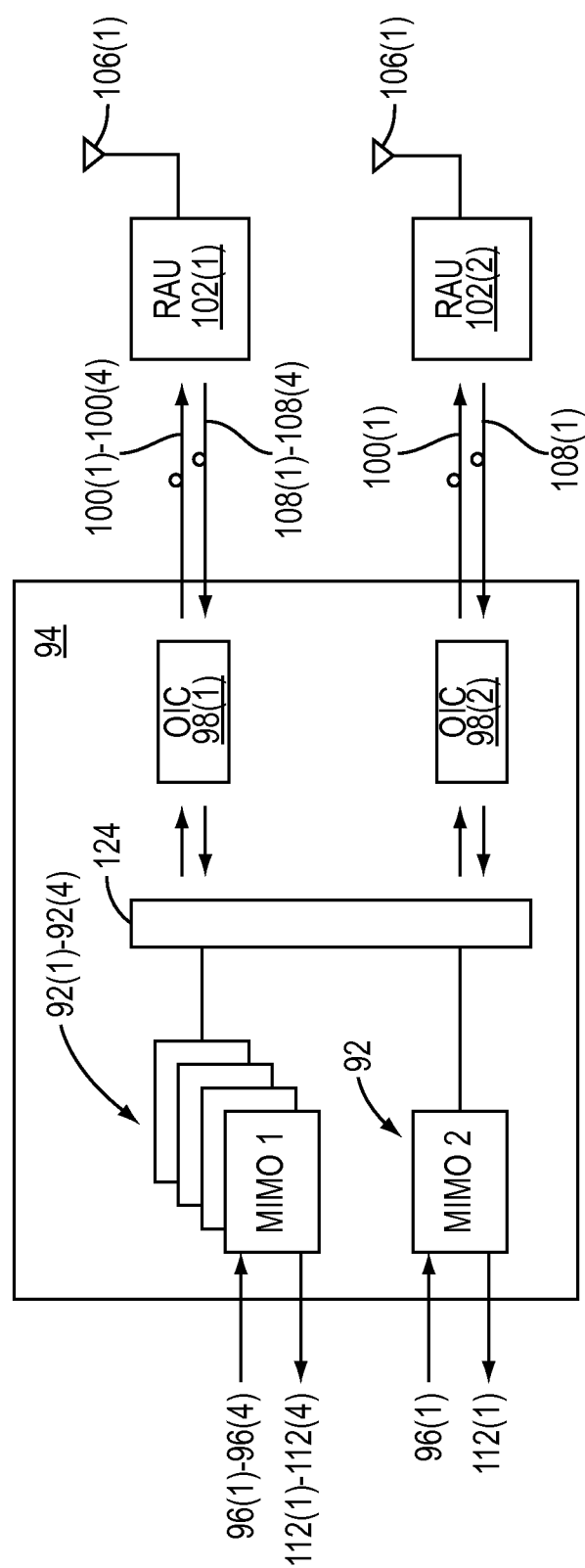


FIG. 9

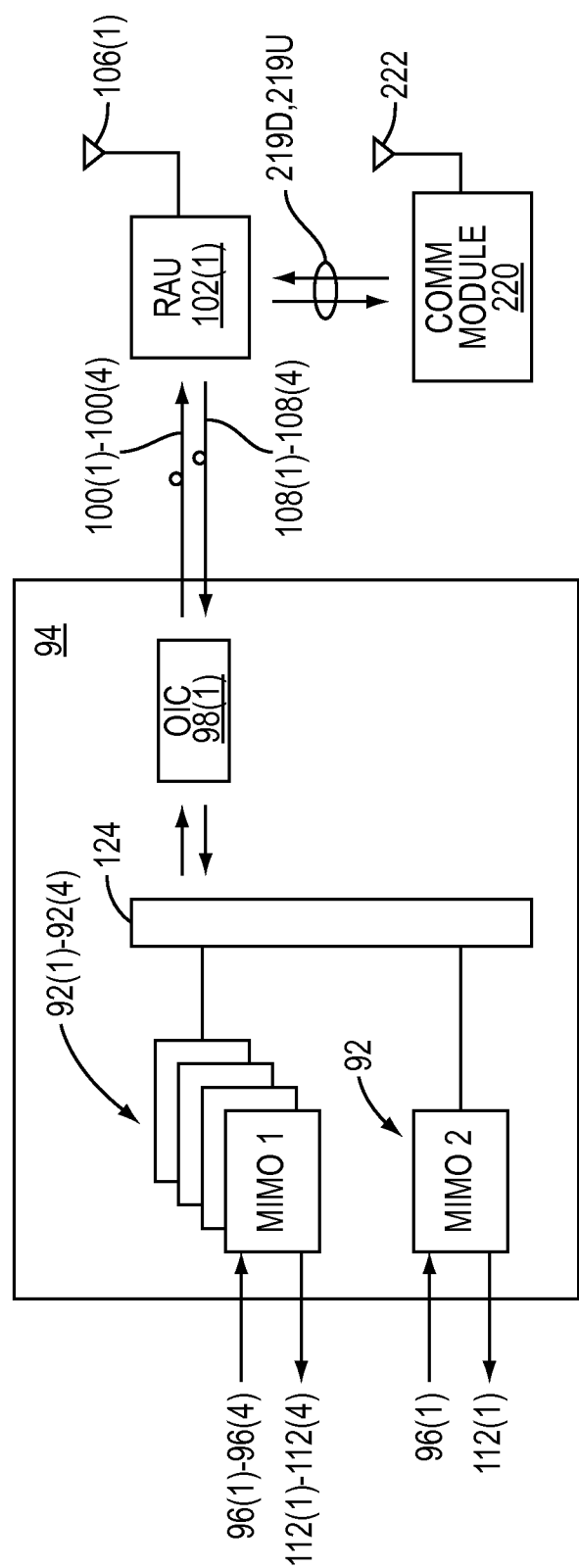


FIG. 10

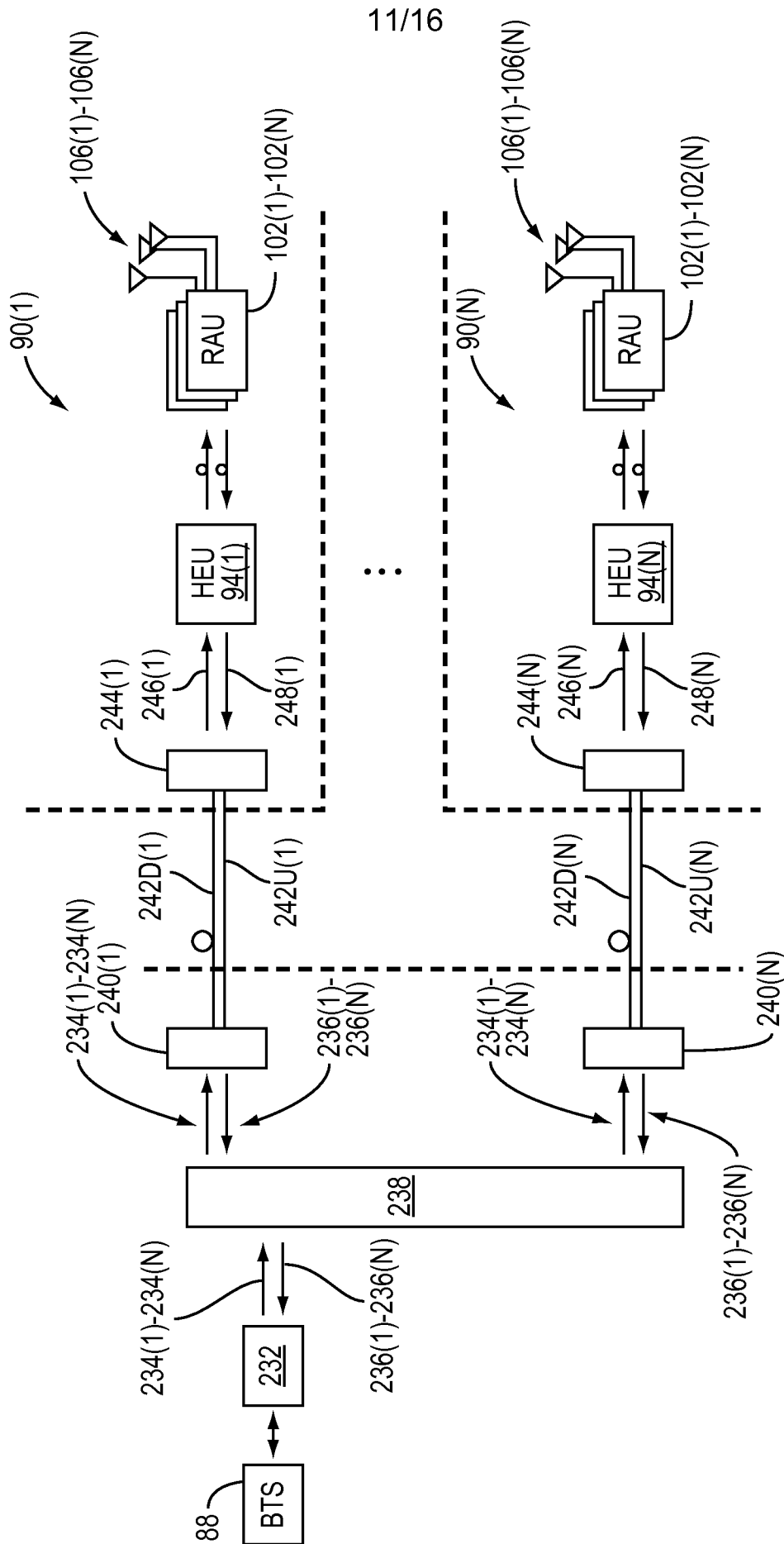


FIG. 11

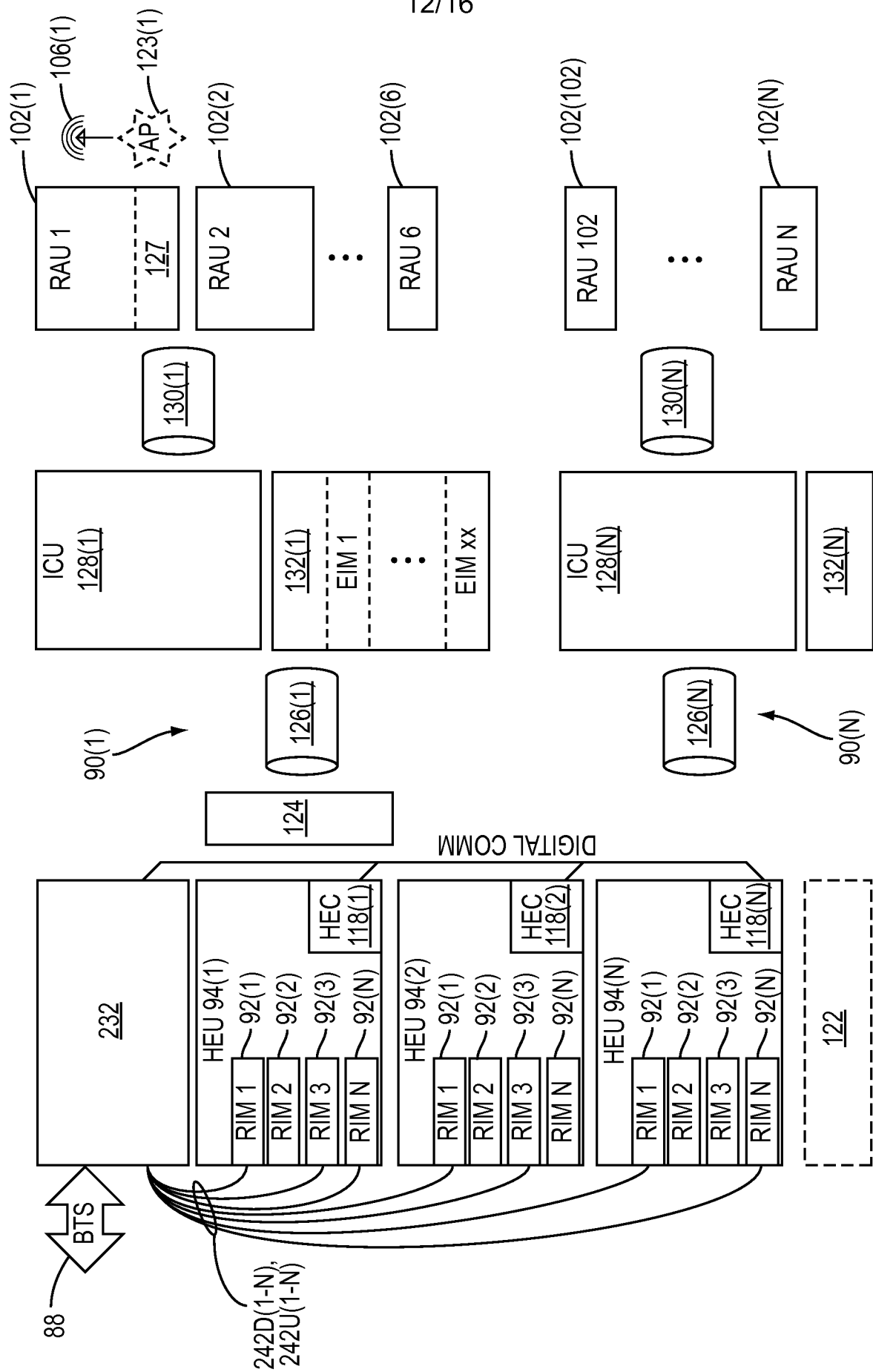


FIG. 12

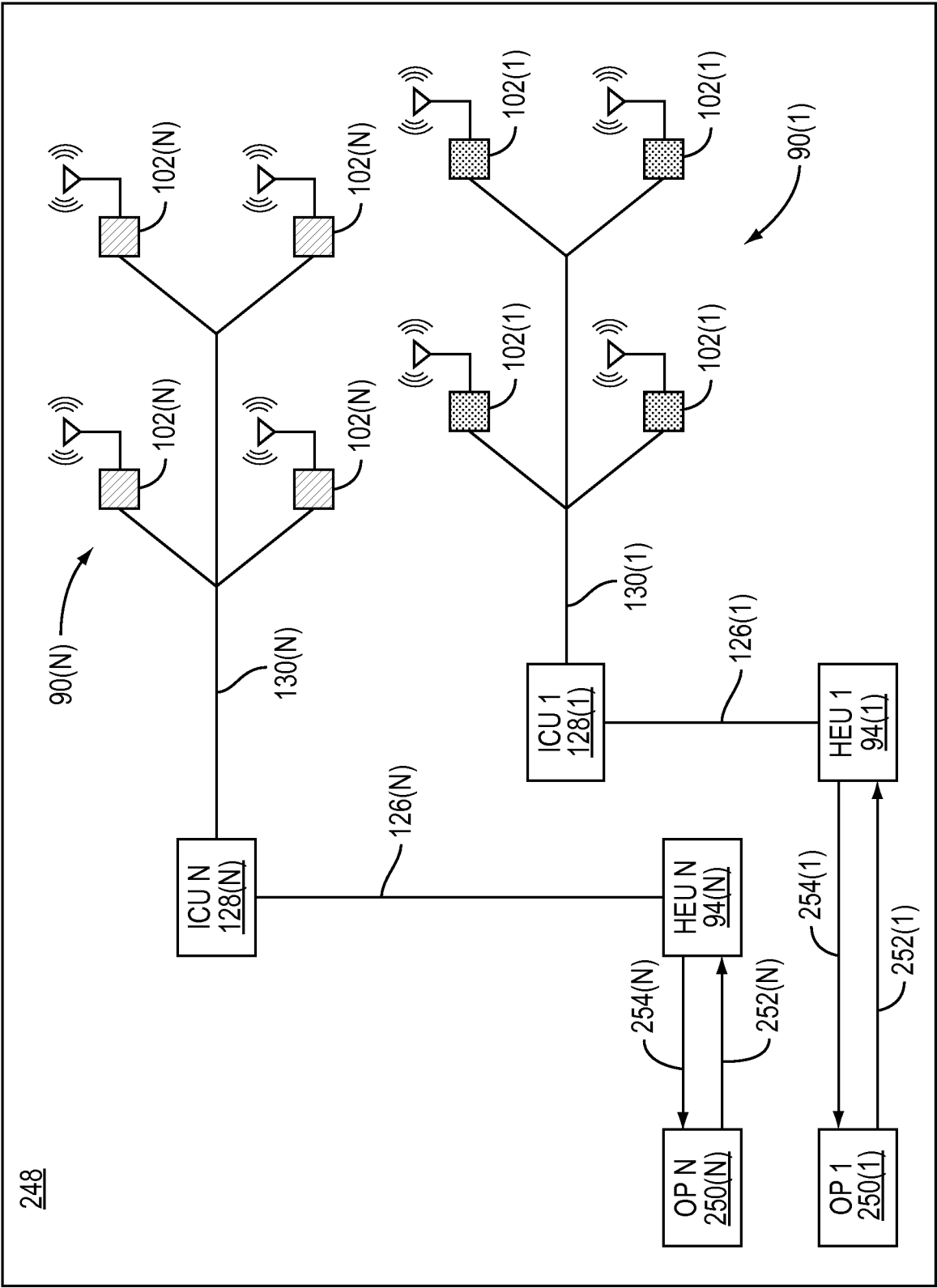


FIG. 13

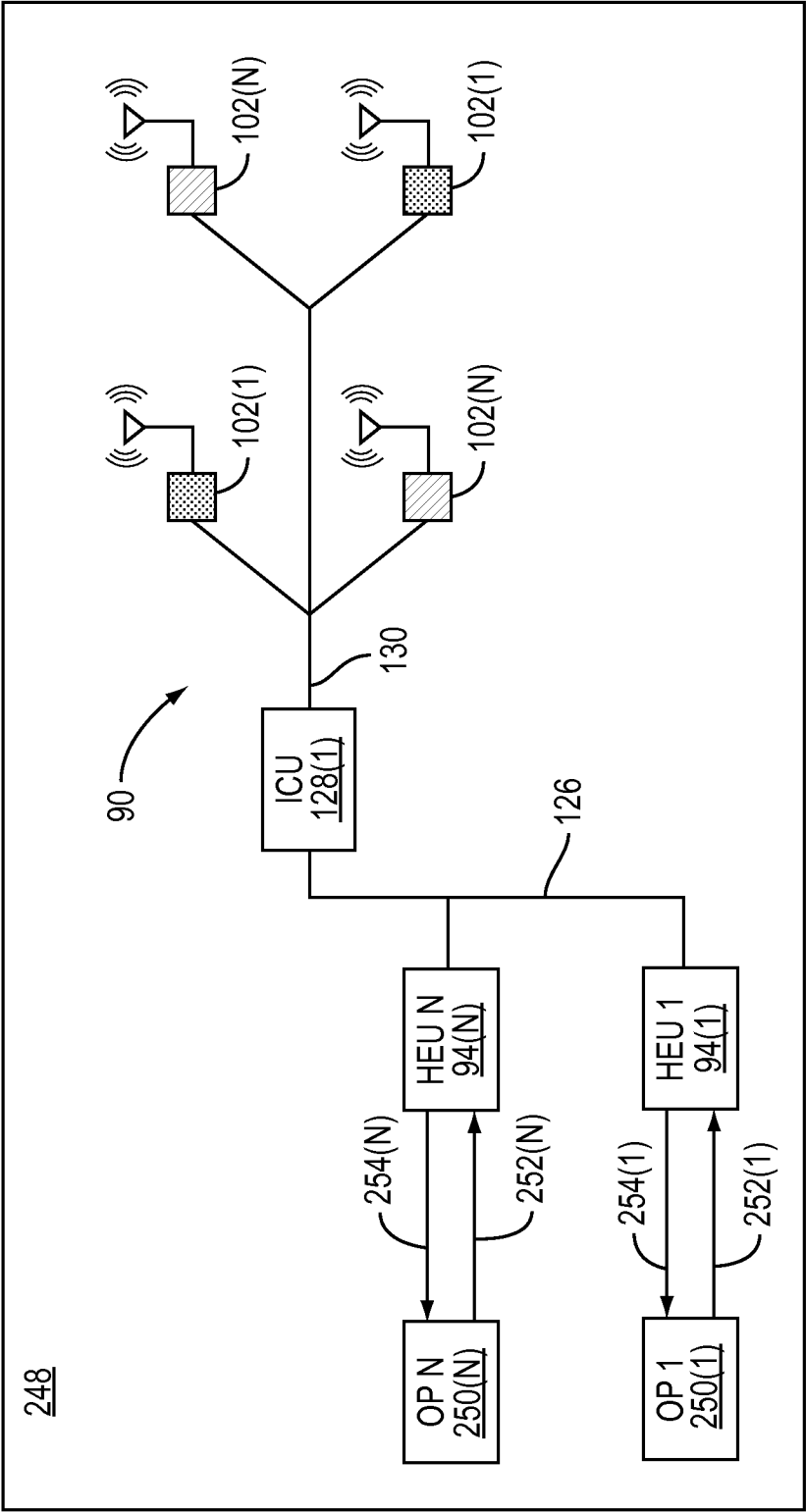


FIG. 14

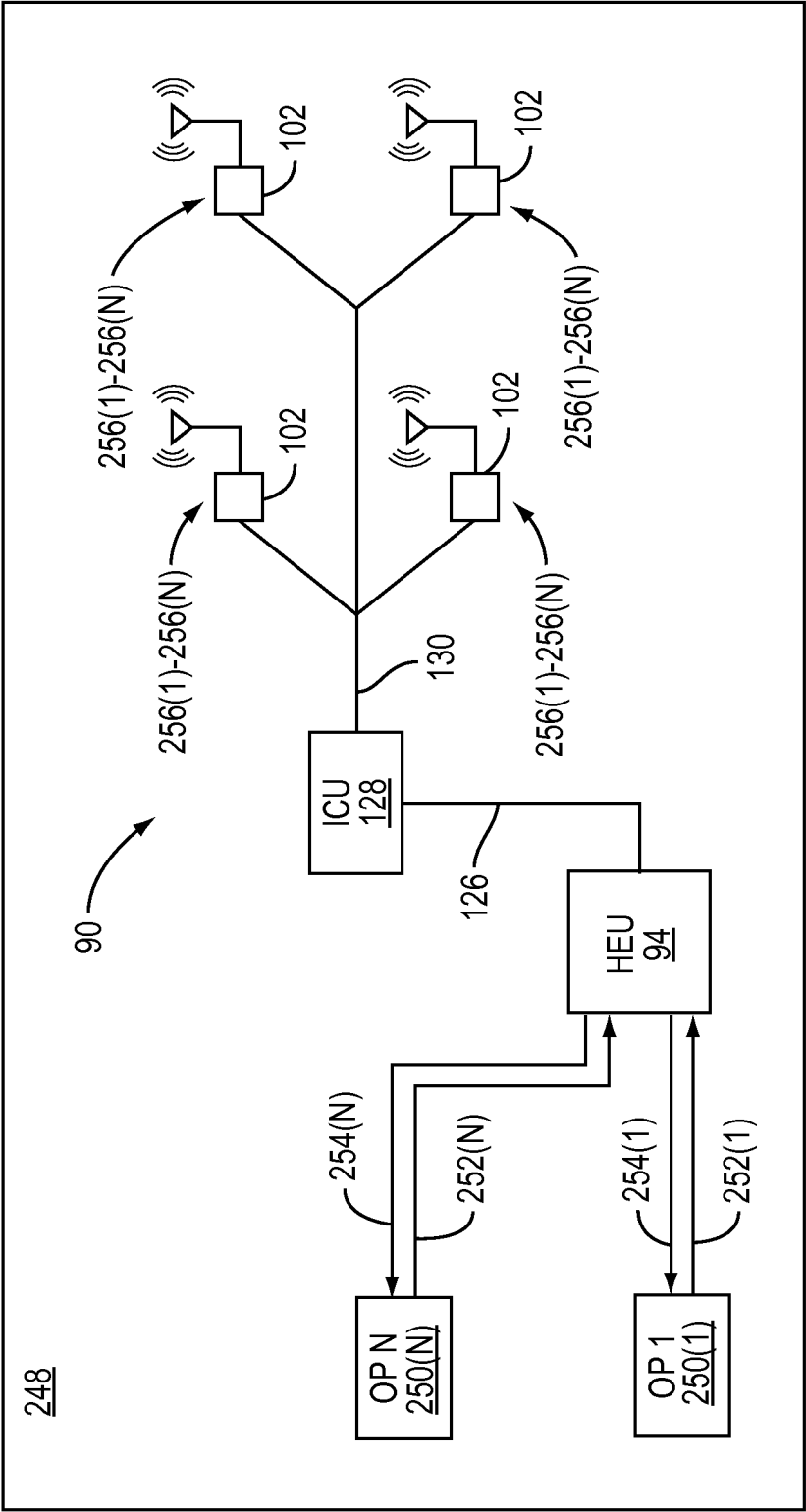


FIG. 15

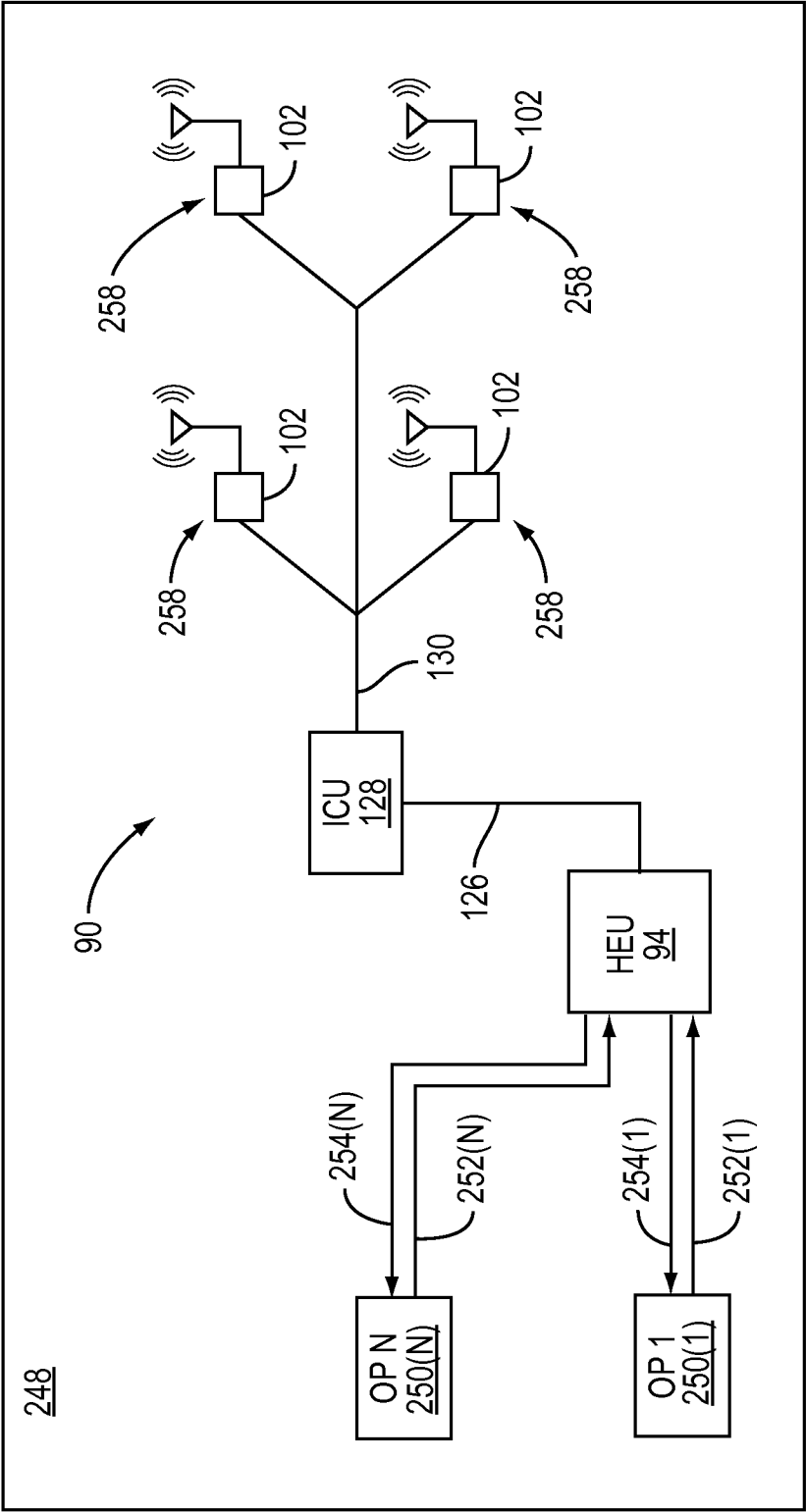


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/034733

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04B10/12
ADD.

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

B. FIELDS SEARCHED

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

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

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

EP0-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 370 170 A (NTL GROUP LTD [GB]) 19 June 2002 (2002-06-19) page 31, line 1 - page 33, line 20 figure 7	1-22
X	----- EP 1 227 605 A2 (LGC WIRELESS INC [US]) 31 July 2002 (2002-07-31) abstract paragraphs [0031] - [0033] paragraphs [0046] - [0048] paragraphs [0058] - [0060] figures 1, 3A, 4A ----- - / - -	1-22

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

25 July 2011

Date of mailing of the international search report

01/08/2011

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Authorized officer

Rolan Cisneros, E

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2011/034733

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ARSHAD CHOWDHURY ET AL: "Multi-service multi-carrier broadband MIMO distributed antenna systems for in-building optical wireless access", OPTICAL FIBER COMMUNICATION (OFC), COLLOCATED NATIONAL FIBER OPTIC ENGINEERS CONFERENCE, 2010 CONFERENCE ON (OFC/NFOEC), IEEE, PISCATAWAY, NJ, USA, 21 March 2010 (2010-03-21), pages 1-3, XP031677054, the whole document	1-22
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X,P	----- US 2011/008042 A1 (STEWART JAMES N [US]) 13 January 2011 (2011-01-13) abstract paragraphs [0004] - [0006] paragraphs [0016] - [0021] figures 1-5	1-22
A	----- US 2001/036163 A1 (SABAT JOHN [US] ET AL SABAT JR JOHN [US] ET AL) 1 November 2001 (2001-11-01) abstract paragraphs [0009] - [0020] paragraphs [0031] - [0042] paragraphs [0059] - [0068] figures 1, 3, 6 -----	1-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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