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(54) **PROVIDING DIGITAL DATA SERVICES IN OPTICAL FIBER-BASED DISTRIBUTED RADIO FREQUENCY (RF) COMMUNICATIONS SYSTEMS, AND RELATED COMPONENTS AND METHODS**

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CPC ***H04B 10/25752*** (2013.01); ***H04B 10/25753*** (2013.01); ***H04J 14/02*** (2013.01); ***H04J 14/0282*** (2013.01); ***H04J 14/0298*** (2013.01)

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See application file for complete search history.

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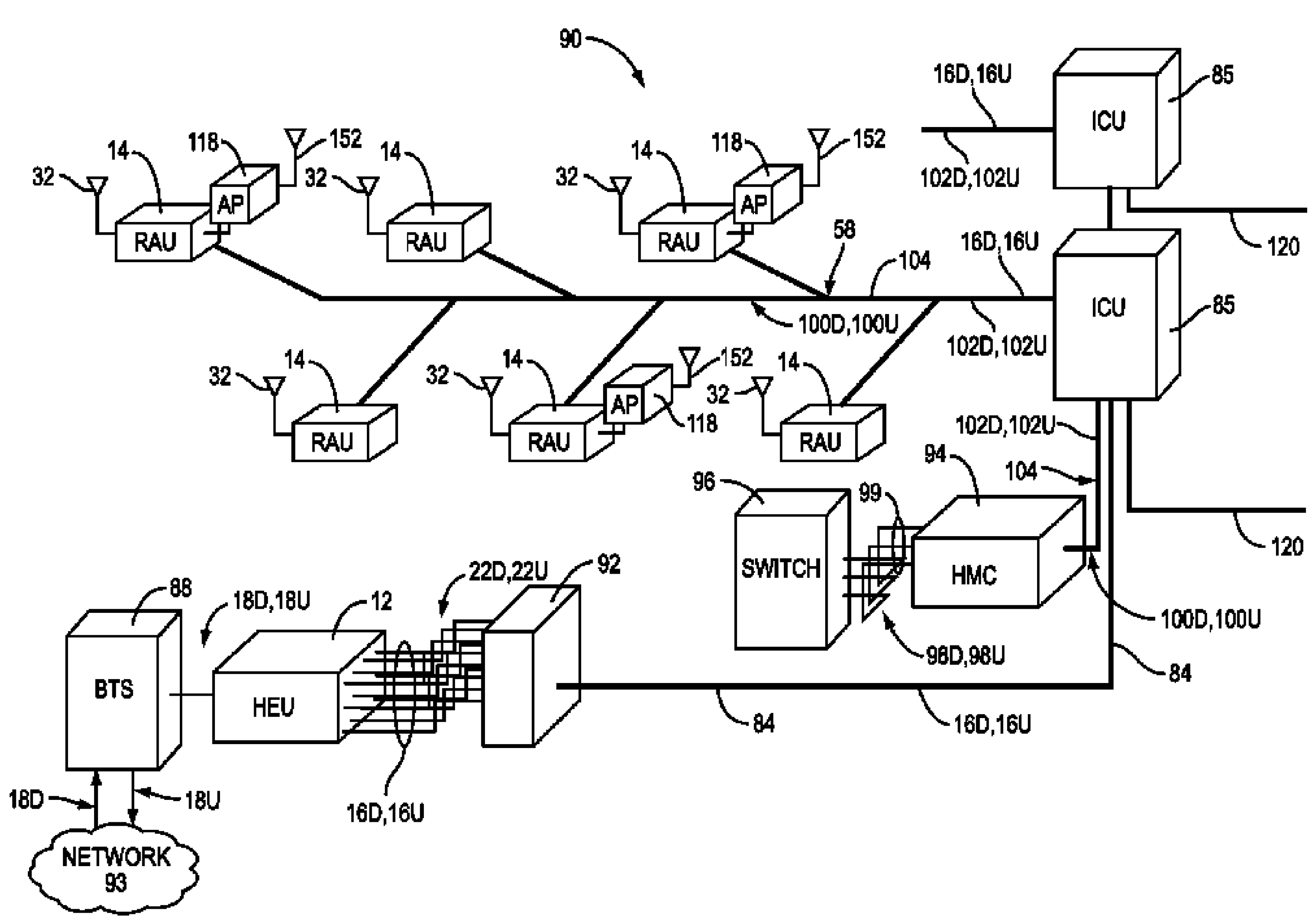
(57) **ABSTRACT**

Optical fiber-based distributed communications systems that provide and support both RF communication services and digital data services are disclosed herein. The RF communication services and digital data services can be distributed over optical fiber to client devices, such as remote antenna units for example. In certain embodiments, digital data services can be distributed over optical fiber separate from optical fiber distributing RF communication services. In other embodiments, digital data services can be distributed over common optical fiber with RF communication services. For example, digital data services can be distributed over common optical fiber with RF communication services at different wavelengths through wavelength-division multiplexing (WDM) and/or at different frequencies through frequency-division multiplexing (FDM). Power distributed in the optical fiber-based distributed communications system to provide power to remote antenna units can also be accessed to provide power to digital data service components.

8 Claims, 15 Drawing Sheets



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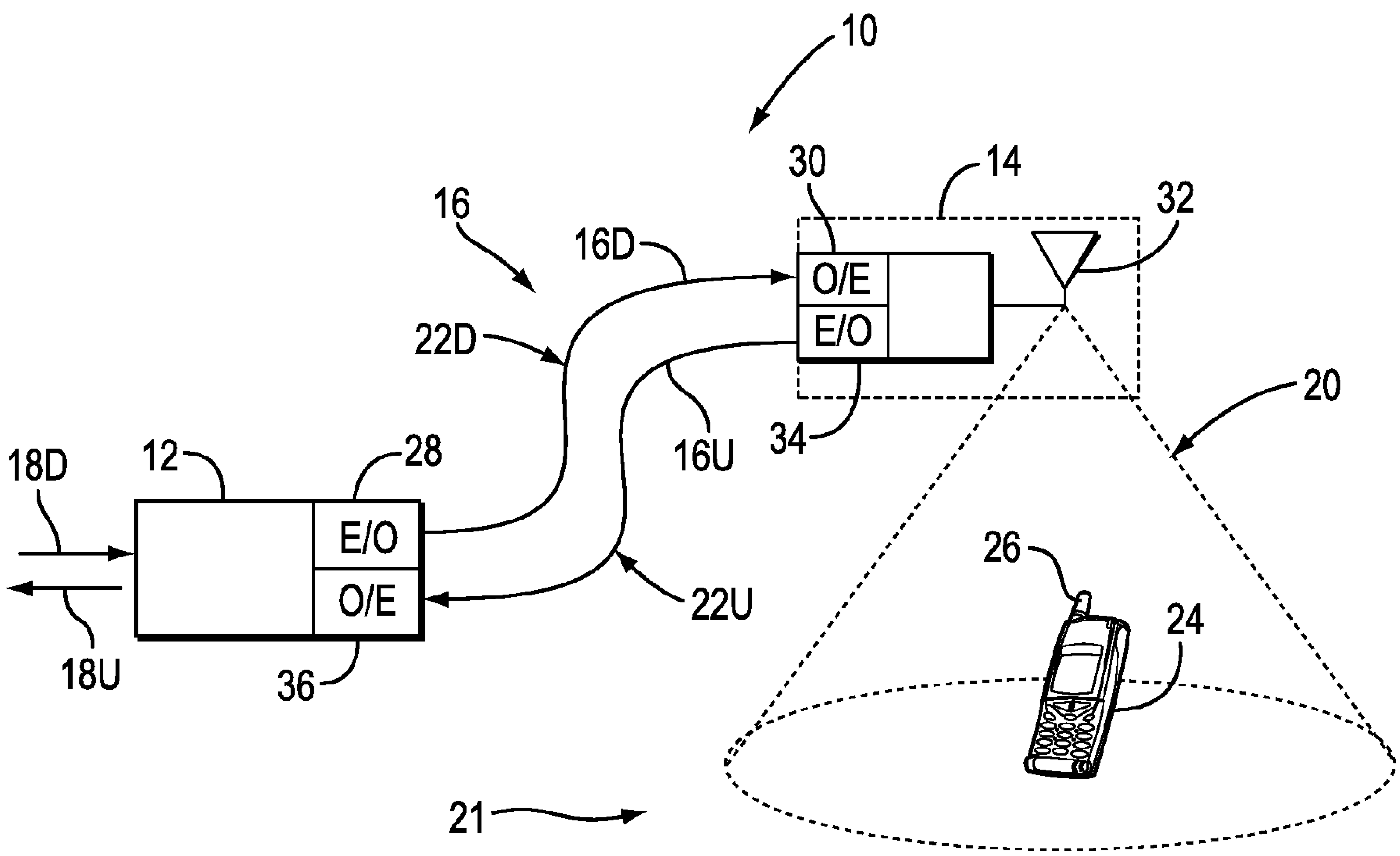
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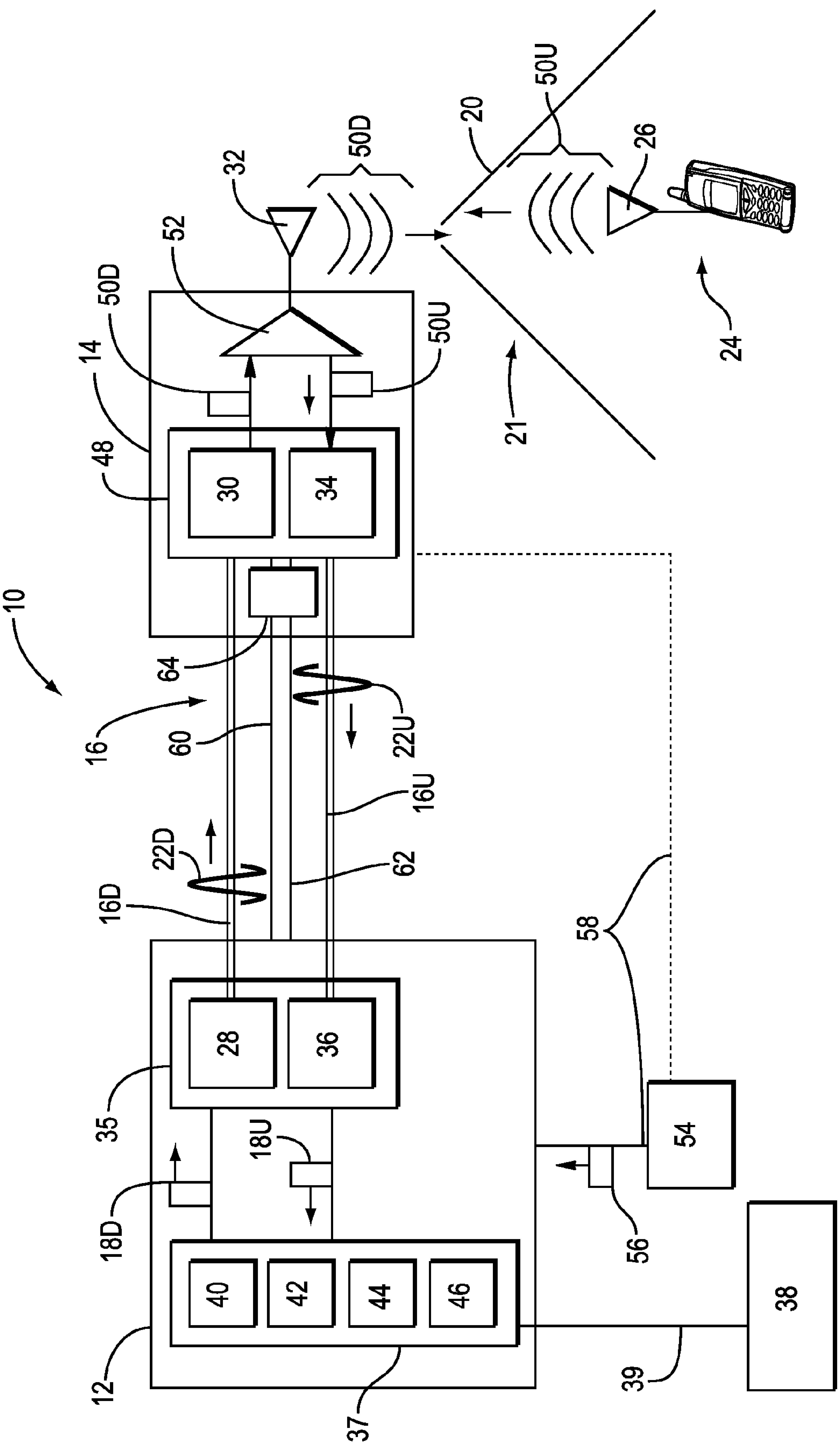
O/E
22U
26
24
18U
36
21

FIG. 1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18U
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35
36
37
38
39
40
42
44
46
48
50D
50U
52
54
56
58
60
62
64

FIG. 2

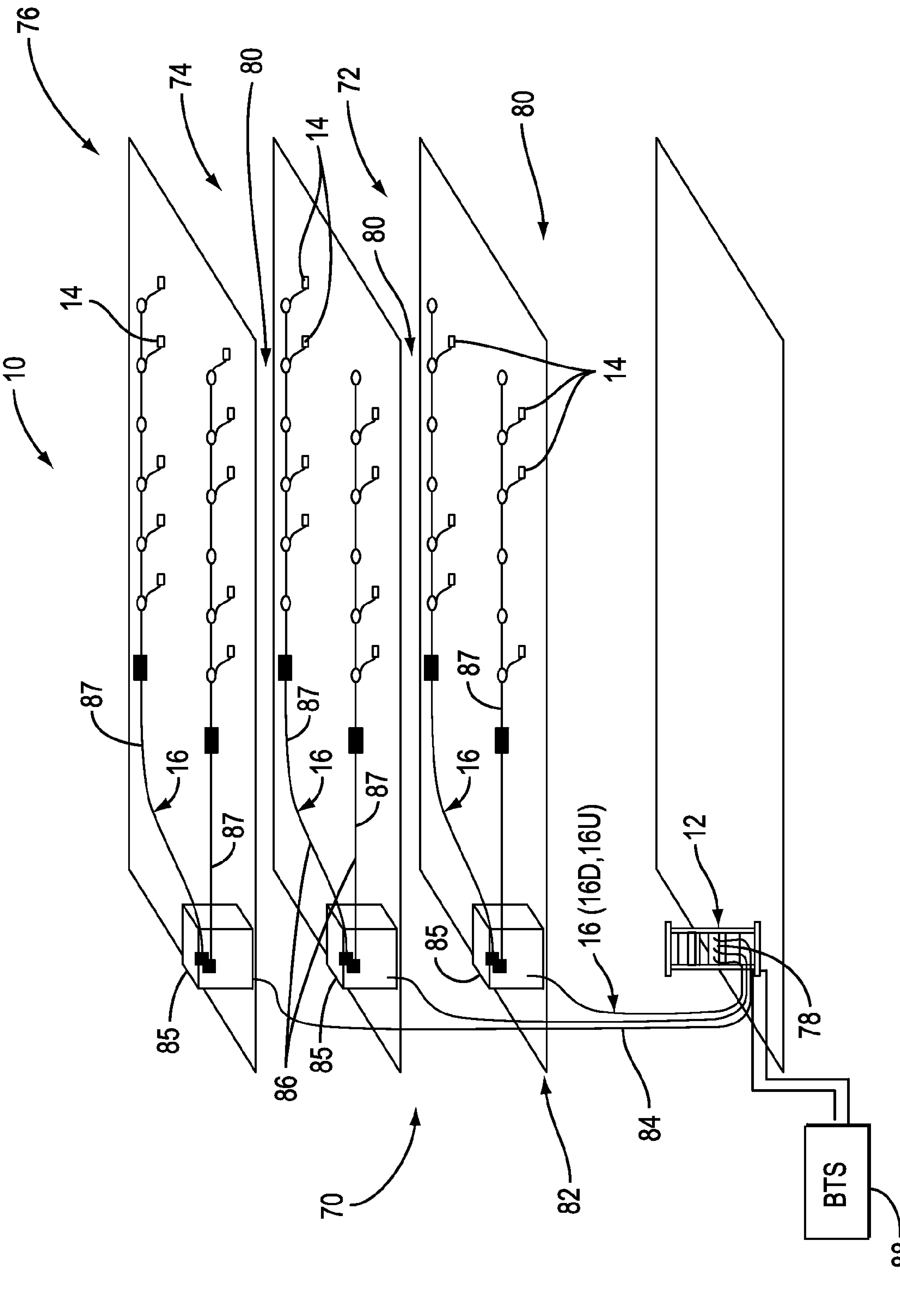
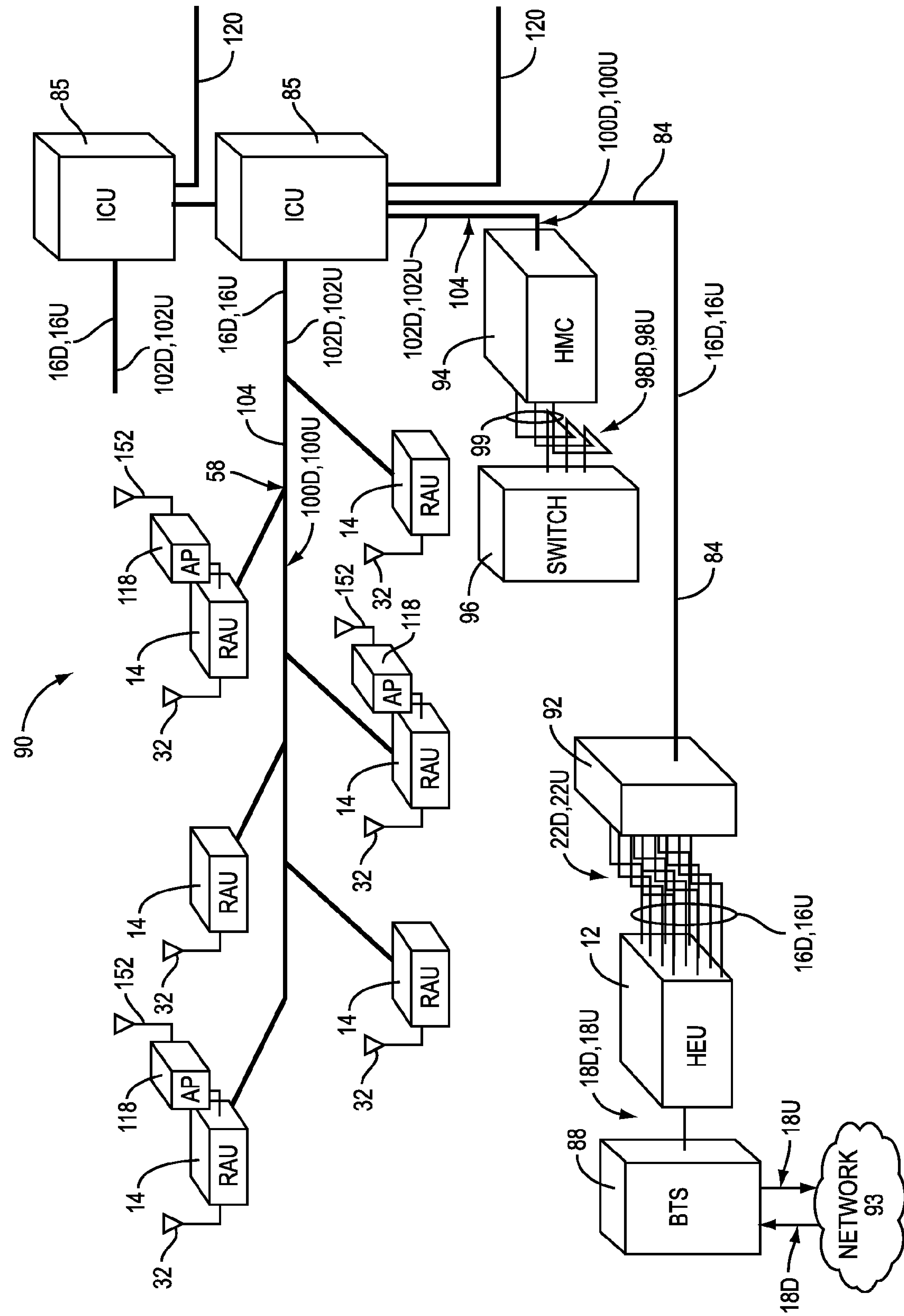


FIG. 3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SWITCH
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RAU
AP
14
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118
152
92
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HEU
18D,18U
88
BTS
18U
18D
NETWORK
93

FIG. 4

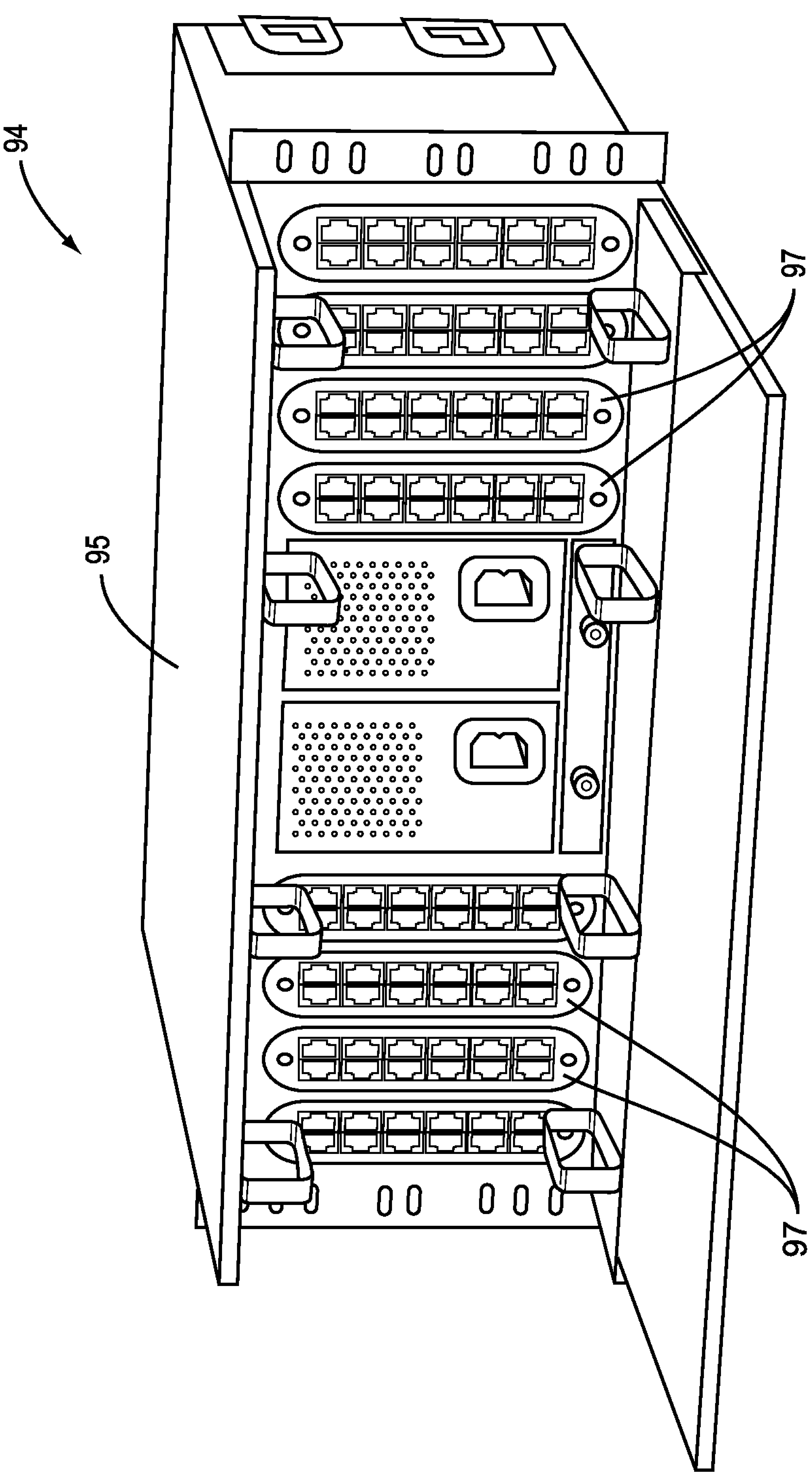


FIG. 5

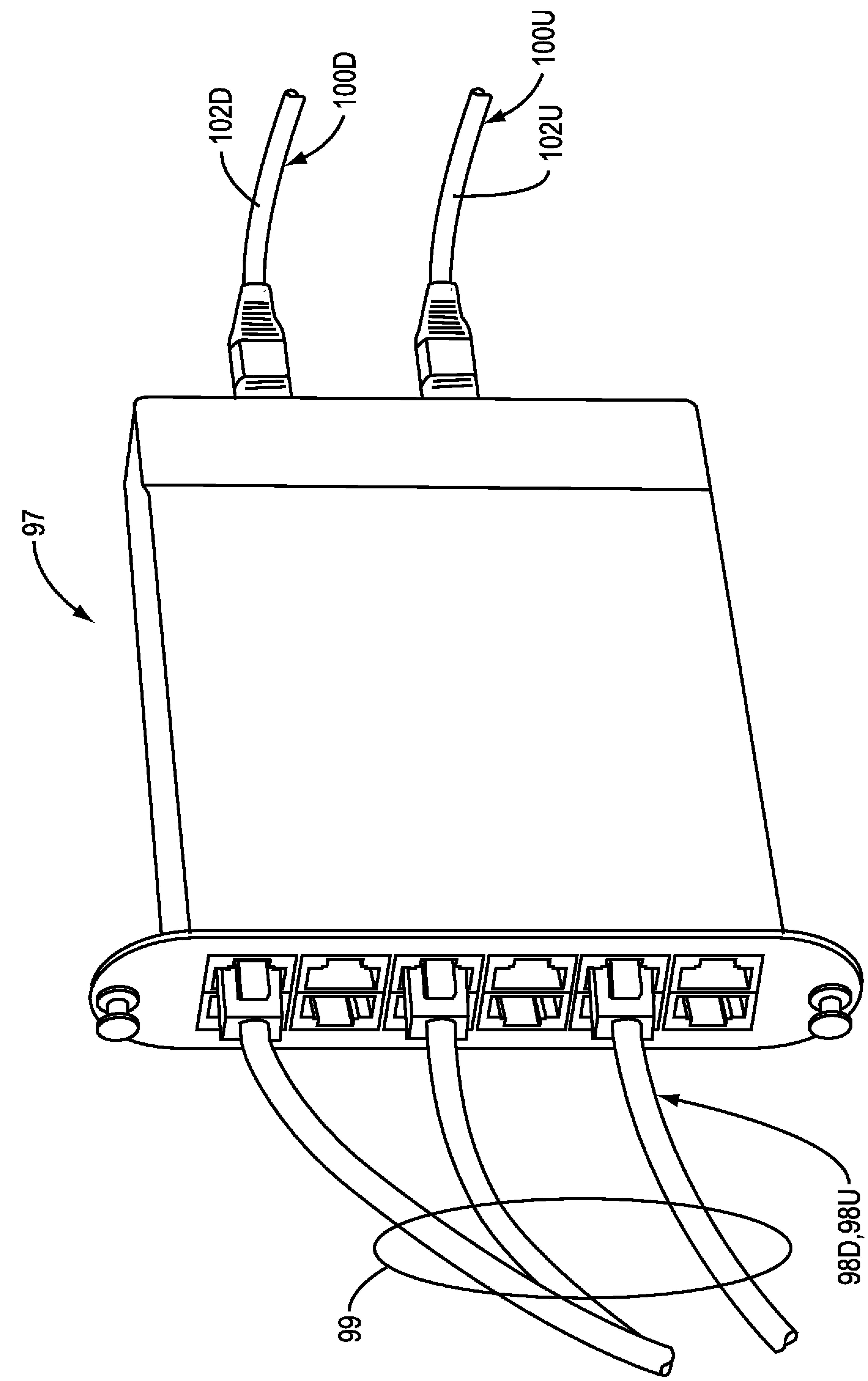
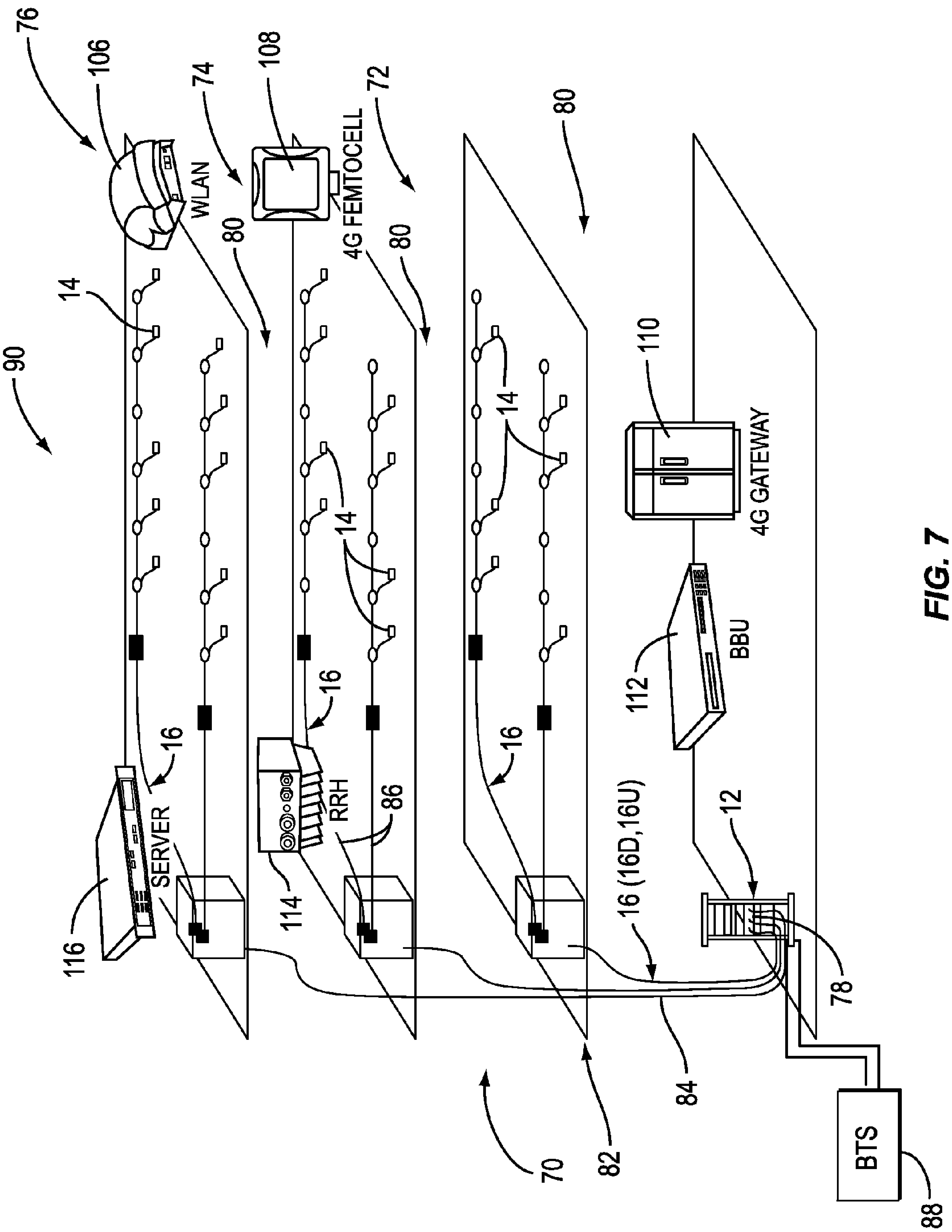


FIG. 6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WLAN
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14
16
4G GATEWAY
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RRH
86
114
SERVER
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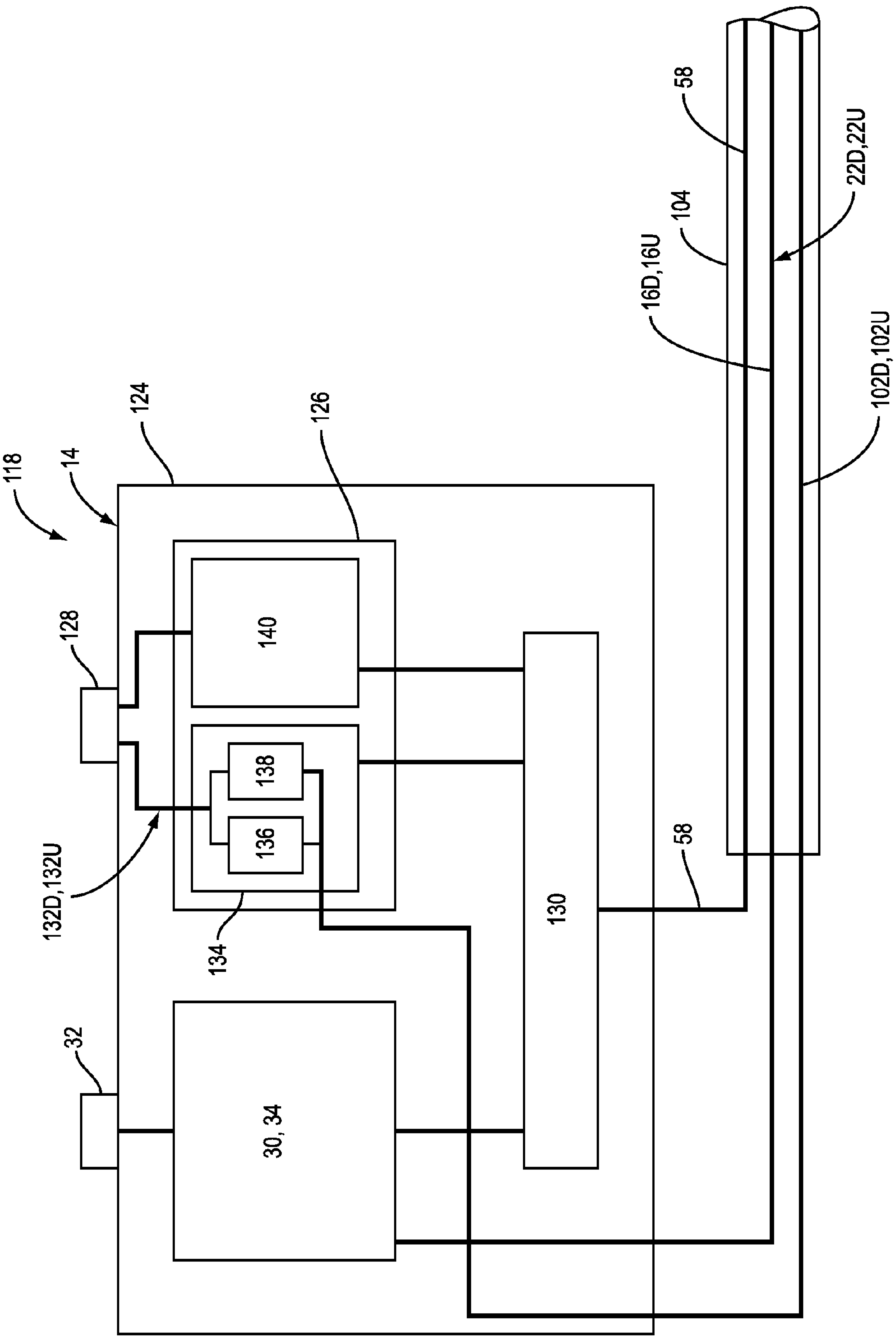
16 (16D,16U)
12
78
84
82
70
BTS
88

FIG. 7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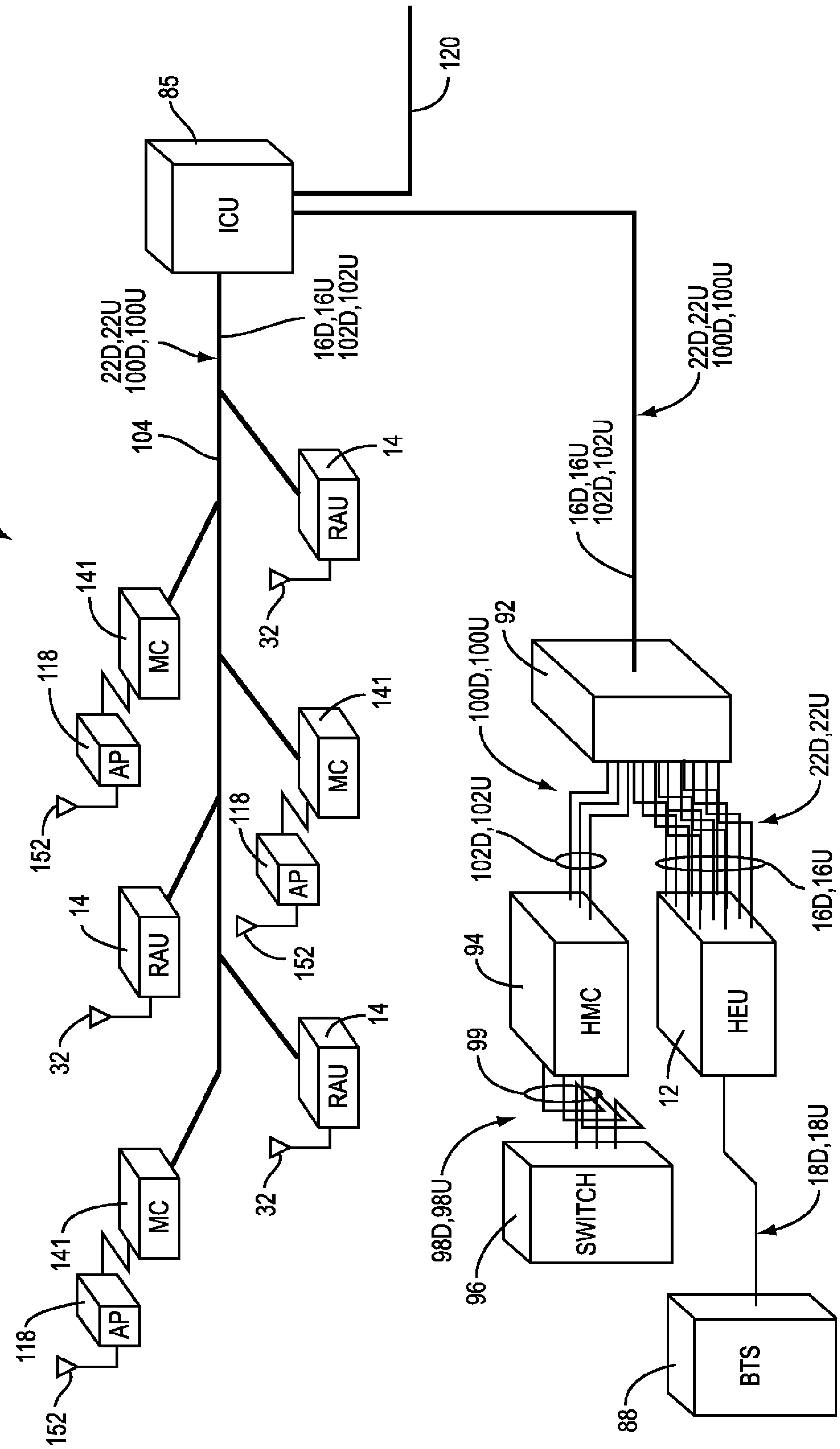
22D,22U
102D,102U

FIG. 8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14
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MC
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152
92
100D,100U
102D,102U
22D,22U
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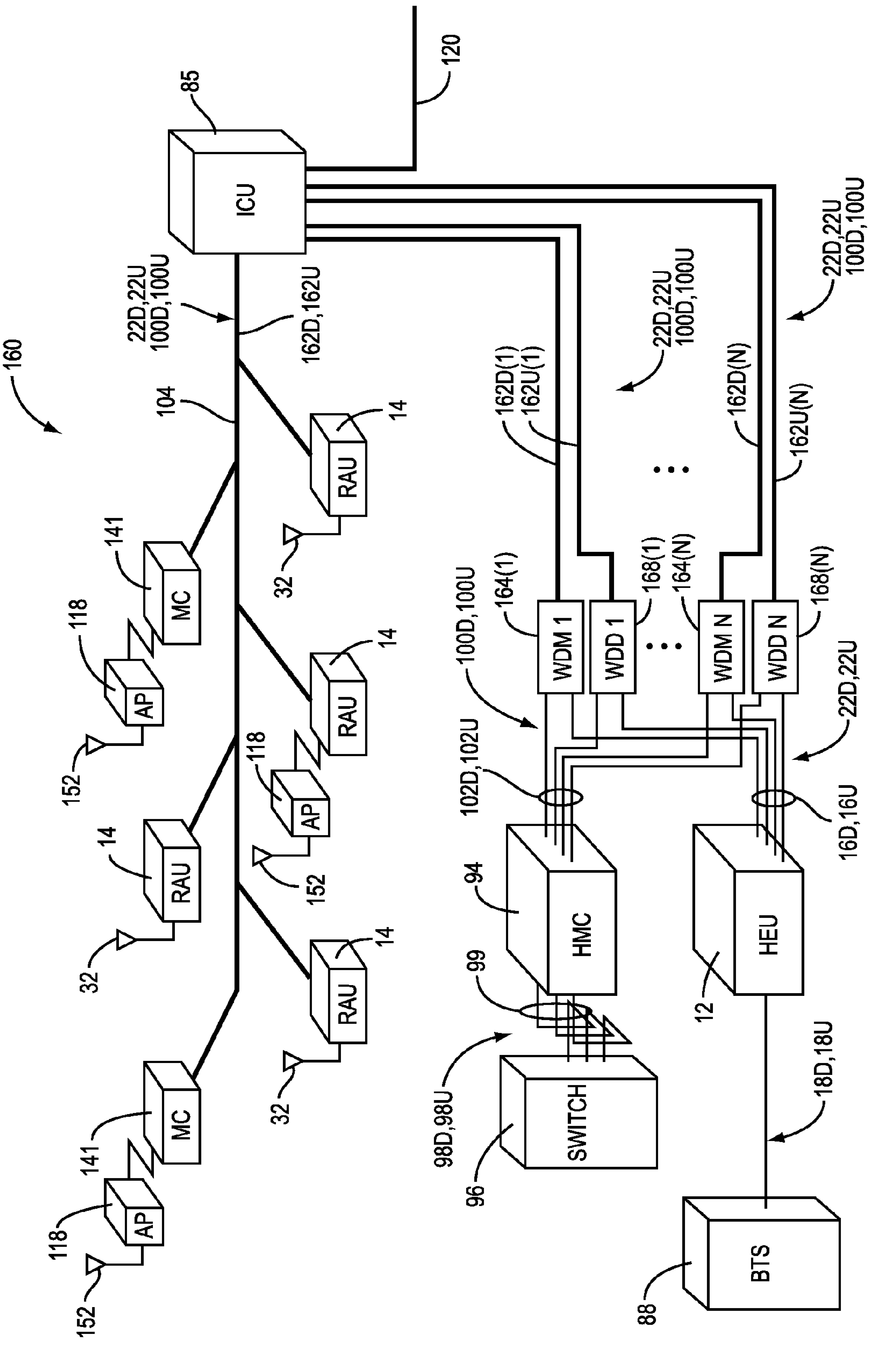
HMC
94
HEU
12
99
98D,98U
SWITCH
96
18D,18U
BTS
88

FIG. 9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RAU
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MC
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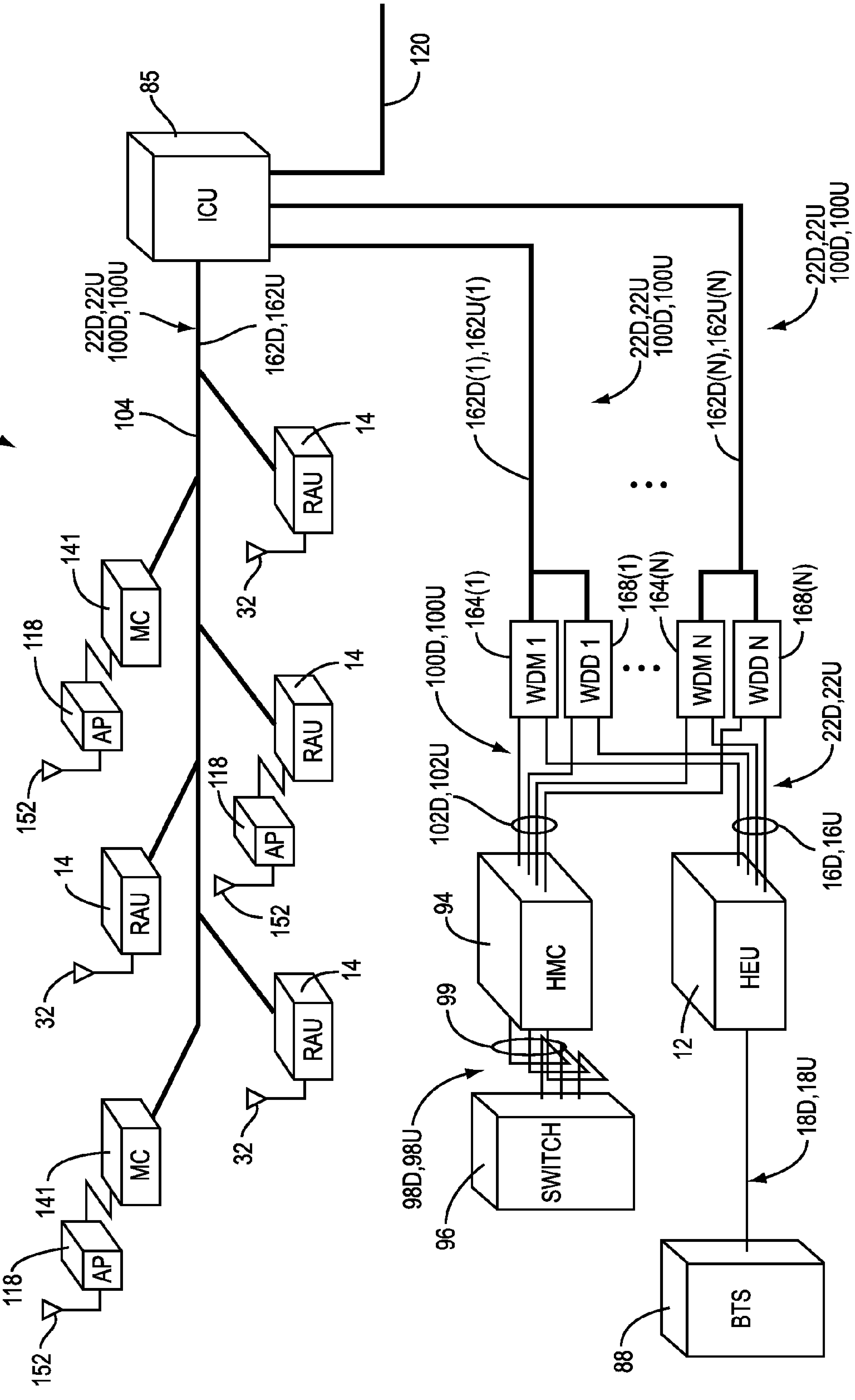
162U(1)
162D(N)
162U(N)
164(1)
168(1)
164(N)
168(N)
WDM 1
WDD 1
WDM N
WDD N
100D,100U
102D,102U
16D,16U
HMC
94
HEU
12
99
98D,98U
SWITCH
96
18D,18U
BTS
88

FIG. 10A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22D,22U
100D,100U
RAU
14
32
MC
141
AP
118
152
100D,100U
164(1)
168(1)
164(N)
168(N)
WDM 1
WDD 1
WDM N
WDD N
22D,22U
102D,102U
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HEU
12
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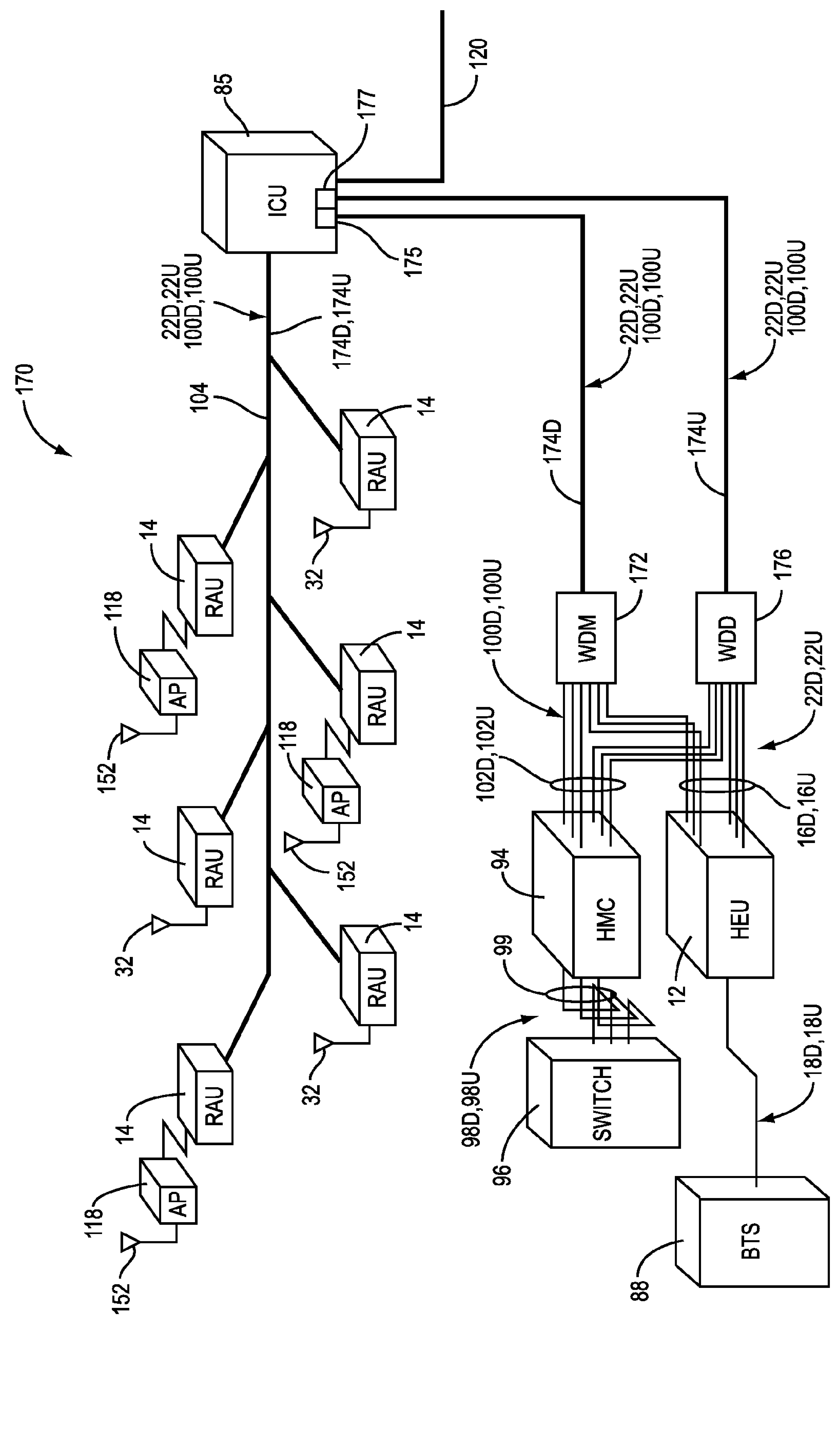
SWITCH
96
18D,18U
BTS
88

FIG. 10B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174U
WDM
172
WDD
176
100D,100U
102D,102U
22D,22U
16D,16U
HMC
94
HEU
12
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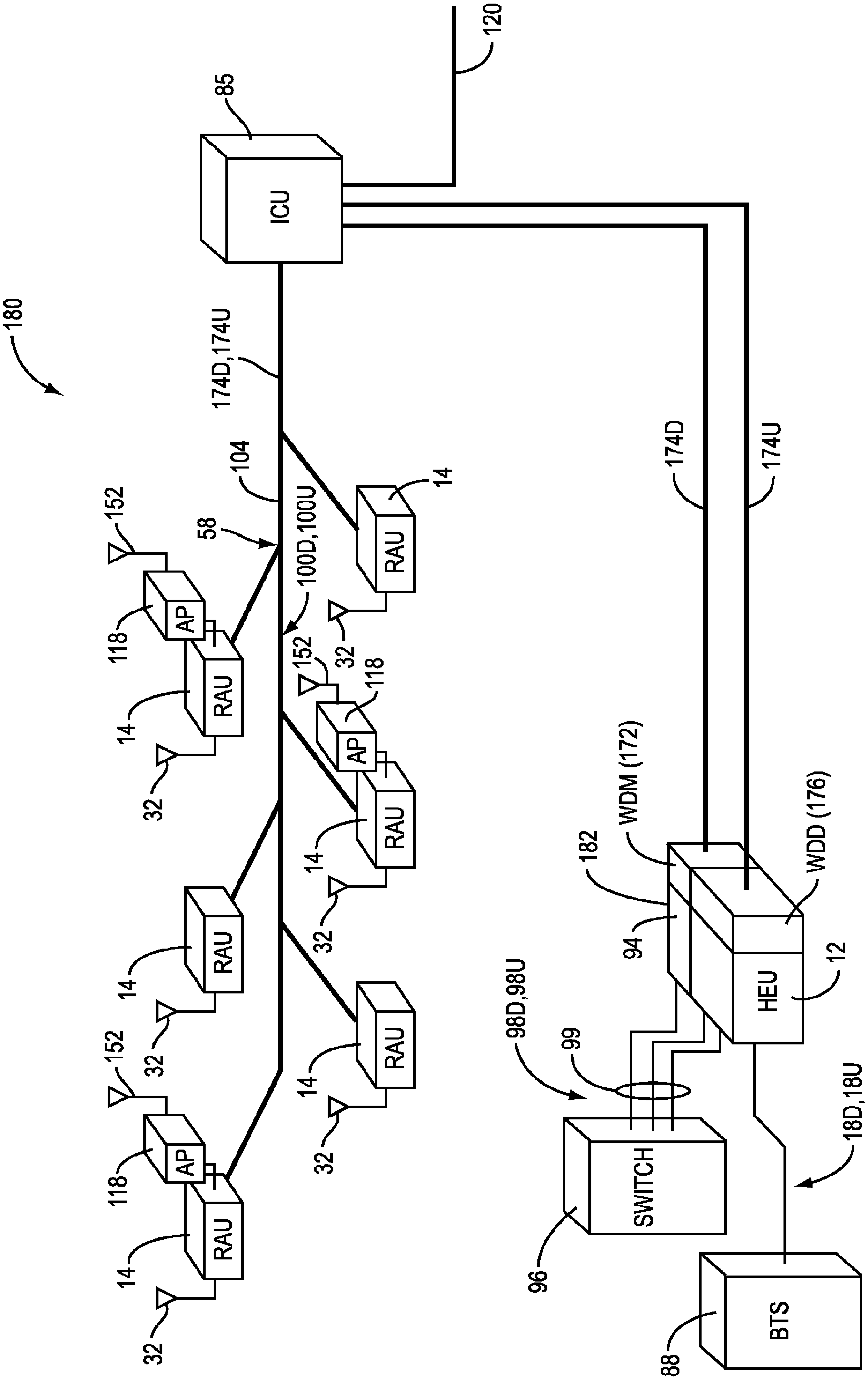
SWITCH
96
18D,18U
BTS
88

FIG. 11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174U
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58
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RAU
AP
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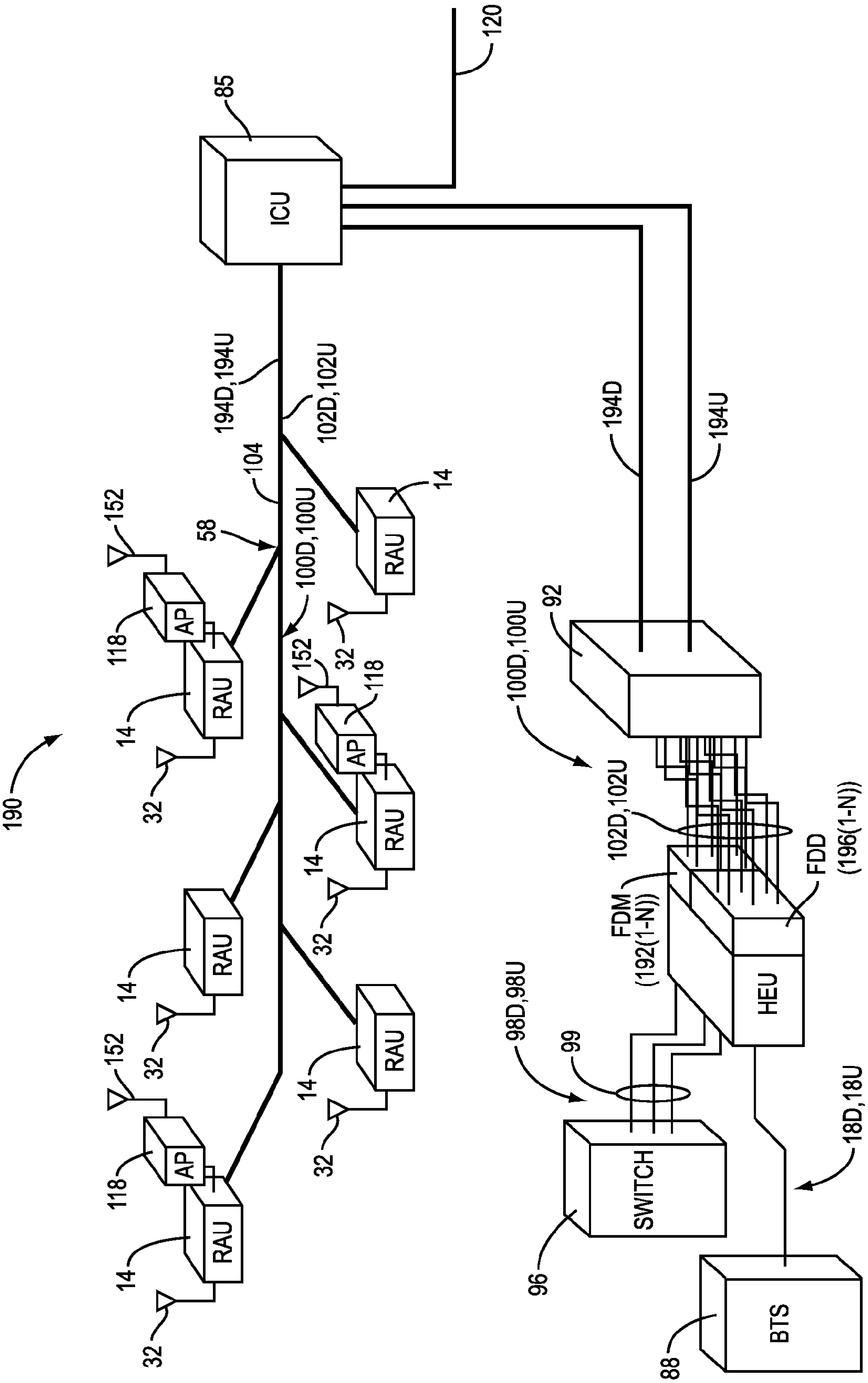
32
152
118
WDM (172)
WDD (176)
182
94
HEU
12
98D,98U
99
SWITCH
96
18D,18U
BTS
88

FIG. 12



120
85
ICU
194D,194U
102D,102U
104
58
100D,100U
152
118
AP
RAU
14
32
190
194D
194U
92
100D,100U
102D,102U
FDD
(196(1-N))
FDM
(192(1-N))
HEU
98D,98U
99
SWITCH
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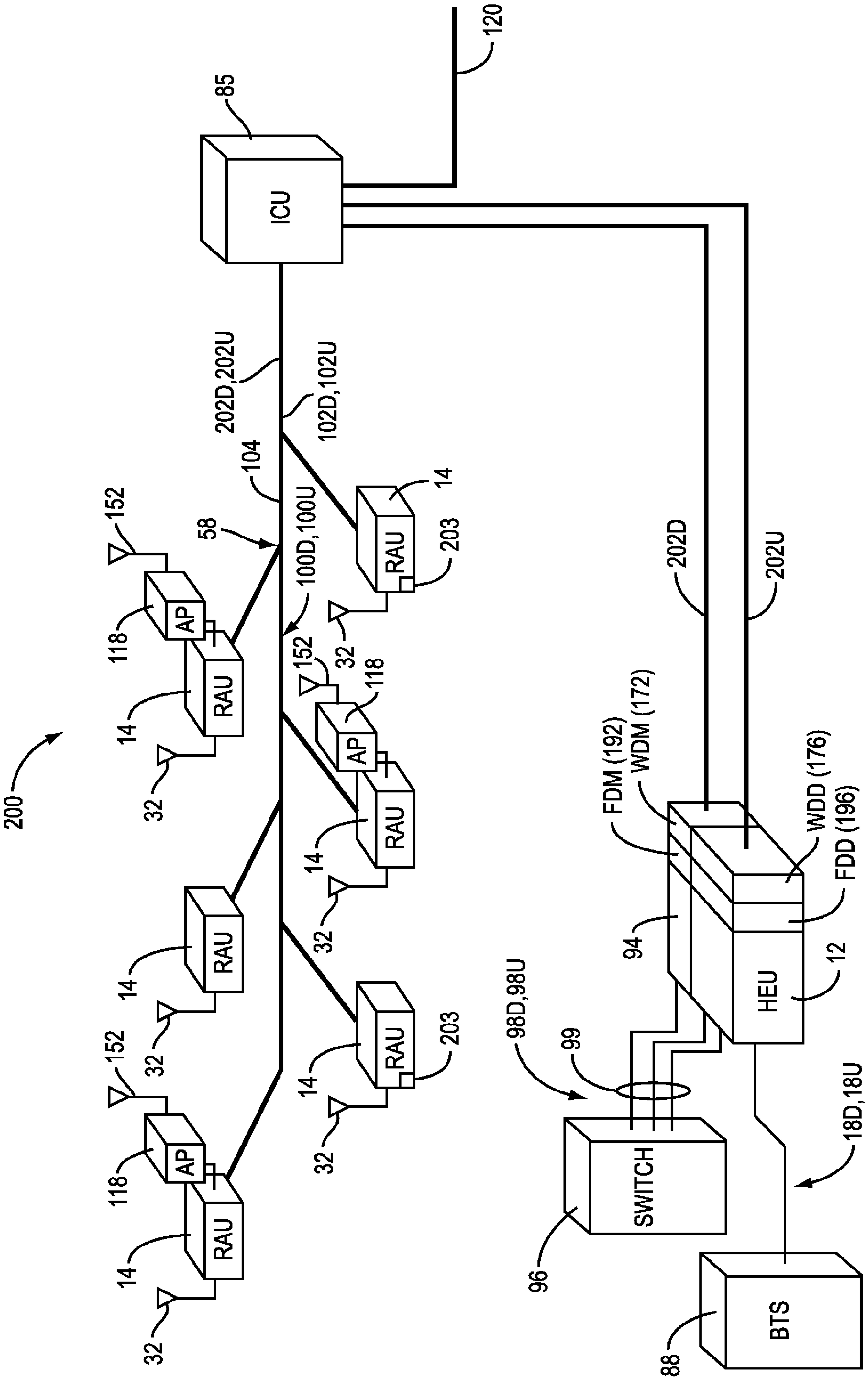
18D,18U
BTS
88

FIG. 13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202U
FDM (192)
WDM (172)
WDD (176)
FDD (196)
94
HEU
12
98D,98U
99
SWITCH
96
18D,18U
BTS
88

FIG. 14

PROVIDING DIGITAL DATA SERVICES IN OPTICAL FIBER-BASED DISTRIBUTED RADIO FREQUENCY (RF) COMMUNICATIONS SYSTEMS, AND RELATED COMPONENTS AND METHODS

PRIORITY APPLICATION

This application is a continuation of and claims priority to U.S. patent application Ser. No. 13/785,603 filed on Mar. 5, 2013, which is a continuation of and claims priority to U.S. patent application Ser. No. 12/892,424 filed on Sep. 28, 2010, which claims priority to U.S. Provisional Patent Application Ser. No. 61/330,386 filed on May 2, 2010, the contents of which are relied upon and incorporated herein by reference in their entireties.

RELATED APPLICATIONS

The present application is related to U.S. Provisional Patent Application No. 61/330,385 filed on May 2, 2010 entitled, "Power Distribution in Optical Fiber-based Distributed Communications Systems Providing Digital Data and Radio Frequency (RF) Communications Services, and Related Components and Methods," which is incorporated herein by reference in its entirety.

The present application is also related to U.S. Provisional Patent Application No. 61/330,383 filed on May 2, 2010 entitled, "Optical Fiber-based Distributed Communications Systems, and Related Components and Methods," which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field of the Disclosure

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

2. Technical Background

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.

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. Benefits of optical fiber include increased bandwidth.

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 provides antenna coverage areas. The remote antenna units can each include RF transceivers coupled to an antenna to transmit RF signals wirelessly, wherein the remote antenna units are coupled to the head-end station via optical fiber links. 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., 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

Embodiments disclosed in the detailed description include optical fiber-based distributed communications systems that provide and support both radio frequency (RF) communication services and digital data services. The RF communication services and digital data services can be distributed over optical fiber to client devices, such as remote antenna units for example. Digital data services can be distributed over optical fiber separate from optical fiber distributing RF communication services. Alternatively, digital data services can be distributed over common optical fiber with RF communication services. For example, digital data services can be distributed over common optical fiber with RF communication services at different wavelengths through wavelength-division multiplexing (WDM) and/or at different frequencies through frequency-division multiplexing (FDM). Power distributed in the optical fiber-based distributed communications system to provide power to remote antenna units can also be accessed to provide power to digital data service components.

In one embodiment, a distributed antenna system for distributing RF communications and digital data services (DDS) to at least one remote antenna unit (RAU) is provided. The distributed antenna system includes a head-end unit (HEU). The HEU is configured to receive at least one downlink electrical RF communications signal. The HEU is also configured to convert the at least one downlink electrical RF communications signal into at least one downlink optical RF communications signal to be communicated over at least one communications downlink to the at least one RAU. The HEU is also configured to receive at least one uplink optical RF communications signal over at least one communications uplink from the at least one RAU. The HEU is also configured to convert the at least one uplink optical RF communications signal into at least one uplink electrical RF communications signal. The distributed antenna system also includes a DDS controller. The DDS controller is configured to receive at least one downlink optical digital signal containing at least one DDS, and provide the at least one downlink optical digital signal over at least one second communications downlink to the at least one RAU.

In another embodiment, a method of distributing RF communications and DDS to at least one RAU in a distributed antenna system is provided. The method includes receiving at an HEU at least one downlink electrical RF communications signal. The method also includes converting the at least one downlink electrical RF communications signal into at least one downlink optical RF communications signal to be communicated over at least one communications downlink to the at least one RAU. The method also includes receiving at the HEU at least one uplink optical RF communications signal over at least one communications uplink from the at least one RAU. The method also includes converting the at least one uplink optical RF communications signal into at least one uplink electrical RF communications signal. The method also includes receiving at a DDS controller at least one downlink optical digital signal containing at least one DDS, and providing the at least one downlink optical digital signal over at least one second communications downlink to the at least one RAU.

In another embodiment, an RAU for use in a distributed antenna system is provided. The RAU includes an optical-to-electrical (O-E) converter configured to convert received downlink optical RF communications signals to downlink electrical RF communications signals and provide the downlink electrical RF communications signals at least one first port. The RAU also includes an electrical-to-optical (E-O) converter configured to convert uplink electrical RF communications signals received from the at least one first port into uplink optical RF communications signals. The RAU also includes a DDS interface coupled to at least one second port. The DDS interface is configured to convert downlink optical digital signals into downlink electrical digital signals to provide to the at least one second port, and convert uplink electrical digital signals received from the at least one second port into uplink optical digital signals.

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 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.

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

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

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**;

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;

FIG. **4** is a schematic diagram of an exemplary embodiment of providing digital data services over downlink and uplink optical fibers separate from optical fibers providing radio frequency (RF) communication services to RAUs in an optical fiber-based distributed communications system;

FIG. **5** is a diagram of an exemplary head-end media converter (HMC) employed in the optical fiber-based distributed communications system of FIG. **4** containing digital media converters (DMCs) configured to convert electrical digital signals to optical digital signals and vice versa;

FIG. **6** is a diagram of exemplary DMCs employed in the HMC of FIG. **5**;

FIG. **7** 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;

FIG. **8** is a schematic diagram of an exemplary RAU that can be employed in an optical fiber-based distributed communications system providing exemplary digital data services and RF communication services;

FIG. **9** is a schematic diagram of another exemplary embodiment of providing digital data services over separate downlink and uplink optical fibers from RF communication services to RAUs in an optical fiber-based distributed communications system;

FIG. **10**A is a schematic diagram of an exemplary embodiment of employing wavelength-division multiplexing (WDM) to multiplex digital data services and RF communication services at different wavelengths over downlink and uplink optical fibers in an optical fiber-based distributed communications system;

FIG. **10**B is a schematic diagram of an exemplary embodiment of employing WDM to multiplex uplink and downlink communications for each channel over a common optical fiber;

FIG. **11** is a schematic diagram of another exemplary embodiment of employing WDM in a co-located HEU and HMC to multiplex digital data services and RF communication services at different wavelengths over common downlink optical fibers and common uplink optical fibers in an optical fiber-based distributed communications system;

FIG. **12** is a schematic diagram of another exemplary embodiment of employing WDM in a common housing HEU and MC to multiplex digital data services and RF communication services at different wavelengths over a common downlink optical fiber and a common uplink optical fiber in an optical fiber-based distributed communications system;

FIG. **13** is a schematic diagram of another exemplary embodiment of employing frequency-division multiplexing (FDM) to multiplex digital data services and RF communication services at different frequencies over downlink optical fibers and uplink optical fibers in an optical fiber-based distributed communications system; and

FIG. **14** is a schematic diagram of another exemplary embodiment of employing FDM and WDM to multiplex digital data services and RF communication services at different frequencies and at different wavelengths over downlink optical fibers and uplink optical fibers in an optical fiber-based distributed communications system.

DETAILED DESCRIPTION

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.

Embodiments disclosed in the detailed description include optical fiber-based distributed communications systems that provide and support both radio frequency (RF) communication services and digital data services. The RF communication services and digital data services can be distributed over optical fiber to client devices, such as remote antenna units for example. For example, non-limiting examples of digital data services include Ethernet, WLAN, Worldwide Interoperability for Microwave Access (WiMax), Wireless Fidelity (WiFi), Digital Subscriber Line (DSL), and Long Term Evolution (LTE), etc. Digital data services can be distributed over optical fiber separate from optical fiber distributing RF communication services. Alternatively, digital data services can be distributed over common optical fiber with RF communication services. For example, digital data services can be distributed over common optical fiber with RF communication services at different wavelengths through wavelength-division multiplexing (WDM) and/or at different frequencies through frequency-division multiplexing (FDM). Power distributed in the optical fiber-based distributed communications system to provide power to remote antenna units can also be accessed to provide power to digital data service components.

In this regard, an exemplary optical fiber-based distributed communications system that provides RF communication services without providing digital data services is described with regard to FIGS. **1**-**3**. Various embodiments of additionally providing digital data services in conjunction with RF communication services in optical fiber-based distributed communications systems starts at FIG. **4**.

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 **18**D 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 **18**U, back to the source or sources. In this regard in this embodiment, the optical fiber **16** includes at least one downlink optical fiber **16**D to carry signals communicated from the HEU **12** to the RAU **14** and at least one uplink optical fiber **16**U to carry signals communicated from the RAU **14** back to the HEU **12**.

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.

With continuing reference to FIG. **1**, to communicate the electrical RF signals over the downlink optical fiber **16**D 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 **18**D to downlink optical RF signals **22**D to be communicated over the downlink optical fiber **16**D. The RAU **14** includes an optical-to-electrical (O/E) converter **30** to convert received downlink optical RF signals **22**D 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**.

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 **22**U to be communicated over the uplink optical fiber **16**U. An O/E converter **36** provided in the HEU **12** converts the uplink optical RF signals **22**U into uplink electrical RF signals, which can then be communicated as uplink electrical RF signals **18**U 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**.

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. 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**.

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 **18**D from the service unit **37** and converts them to corresponding downlink optical RF signals **22**D. 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).

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 **22**U and converts them to corresponding uplink electrical RF signals **18**U. 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**.

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 **18**D and the uplink electrical RF signals **18**U, 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 **18**D. The digital signal processor **42** is also configured to process a demodulation signal provided by the demodulation of the uplink electrical RF signal **18**U 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.

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 **22**D from the HEU **12** back into downlink electrical RF signals **50**D. The E-O converter **34** converts uplink electrical RF signals **50**U received from the client device **24** into the uplink optical RF signals **22**U 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 **50**D and the uplink electrical RF signals **50**U, 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 Ser. No. 11/504,999, filed Aug. 16, 2006 entitled "Radio-over-Fiber Transponder With A Dual-Band Patch Antenna System," and U.S. patent application Ser. No. 11/451,553, filed Jun. 12, 2006 entitled "Centralized Optical Fiber-Based Wireless Picocellular Systems and Methods," both of which are incorporated herein by reference in their entireties.

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.

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.

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 **16**D, **16**U 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 **16**D, **16**U 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 **16**D, **16**U, along with an electrical power line, to a number of optical fiber cables **86**.

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.

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**.

It may be desirable to provide both digital data services and RF communication services for client devices. For example, it may be desirable to provide digital data services and RF communication services in the building infrastructure **70** to client devices located therein. Wired and wireless devices may be located in the building infrastructure **70** that are configured to access digital data services. Examples of digital data services include, but are not limited to, Ethernet, WLAN, WiMax, WiFi, DSL, and LTE, etc. Ethernet standards could be supported, including but not limited to 100 Megabits per second (Mbs) (i.e., fast Ethernet) or Gigabit (Gb) Ethernet, or ten Gigabit (10 G) Ethernet. Example of digital data devices include, but are not limited to, wired and wireless servers, wireless access points (WAPs), gateways, desktop computers, hubs, switches, remote radio heads (RRHs), baseband units (BBUs), and femtocells. A separate digital data services network can be provided to provide digital data services to digital data devices.

In this regard, embodiments disclosed herein provide optical fiber-based distributed communications systems that support both RF communication services and digital data services. The RF communication services and digital data services can be distributed over optical fiber to client devices, such as remote antenna units for example. Digital data services can be distributed over optical fiber separate from the optical fiber distributing RF communication services. Alternatively, digital data services can be both distributed over common optical fiber with RF communication services in an optical fiber-based distributed communications system. For example, digital data services can be distributed over common optical fiber with RF communication services at different wavelengths through wavelength-division multiplexing (WDM) and/or at different frequencies through frequency-division multiplexing (FDM).

FIG. **4** is a schematic diagram of an exemplary embodiment of providing digital data services over separate downlink and uplink optical fibers from radio frequency (RF) communication services to RAUs in an optical fiber-based distributed communications system **90**. The optical fiber-based distributed communications system **90** includes some optical communication components provided in the optical fiber-based distributed communications system **10** of FIGS. **1-3**. These common components are illustrated in FIG. **4** with common element numbers with FIGS. **1-3**. As illustrated in FIG. **4**, the HEU **12** is provided. The HEU **12** receives the downlink electrical RF signals **18**D from the BTS **88**. As previously discussed, the HEU **12** converts the downlink electrical RF signals **18**D to downlink optical RF signals **22**D to be distributed to the RAUs **14**. The HEU **12** is also configured to convert the uplink optical RF signals **22**U received from the RAUs **14** into uplink electrical RF signals **18**U to be provided to the BTS **88** and on to a network **93** connected to the BTS **88**. A patch panel **92** may be provided to receive the downlink and uplink optical fibers **16**D, **16**U configured to carry the downlink and uplink optical RF signals **22**D, **22**U. The downlink and uplink optical fibers **16**D, **16**U may be bundled together in one or more riser cables **84** and provided to one or more ICU **85**, as previously discussed and illustrated in FIG. **3**.

To provide digital data services in the optical fiber-based distributed communications system **90** in this embodiment, a digital data service controller (also referred to as "DDS controller") in the form of a head-end media converter (HMC) **94** in this example is provided. The DDS controller **94** can include only a media converter for provision media conversion functionality or can include additional functionality to facilitate digital data services. A DDS controller is a controller configured to provide digital data services over a communications link, interface, or other communications channel or line, which may be either wired, wireless, or a combination of both. FIG. **5** illustrates an example of the HMC **94**. The HMC **94** includes a housing **95** configured to house digital media converters (DMCs) **97** to interface to a digital data services switch **96** to support and provide digital data services. For example, the digital data services switch **96** could be an Ethernet switch. The digital data services switch **96** may be configured to provide Gigabit (Gb) Ethernet digital data service as an example. The DMCs **97** are configured to convert electrical digital signals to optical digital signals, and vice versa. The DMCs **97** may be configured for plug and play installation (i.e., installation and operability without user configuration required) into the HMC **94**. FIG. **6** illustrates an exemplary DMC **97** that can be disposed in the housing **95** of the HMC **94**. For example, the DMC **97** may include Ethernet input connectors or adapters (e.g., RJ-45) and optical fiber output connectors or adapters (e.g., LC, SC, ST, MTP).

With reference to FIG. **4**, the HMC **94** (via the DMCs **97**) in this embodiment is configured to convert downlink electrical digital signals (or downlink electrical digital data services signals) **98**D over digital line cables **99** from the digital data services switch **96** into downlink optical digital signals (or downlink optical digital data services signals) **100**D that can be communicated over downlink optical fiber **102**D to RAUs **14**. The HMC **94** (via the DMCs **97**) is also configured to receive uplink optical digital signals **100**U from the RAUs **14** via the uplink optical fiber **102**U and convert the uplink optical digital signals **100**U into uplink electrical digital signals **98**U to be communicated to the digital data services switch **96**. In this manner, the digital data services can be provided over optical fiber as part of the optical fiber-based distributed communications system **90** to provide digital data services in addition to RF communication services. Client devices located at the RAUs **94** can access these digital data services and/or RF communication services depending on their configuration. For example, FIG. **7** 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. **7**, exemplary digital data services include WLAN **106**, femtocells **108**, gateways **110**, baseband units (BBU) **112**, remote radio heads (RRH) **114**, and servers **116**.

With reference back to FIG. **4**, in this embodiment, the downlink and uplink optical fibers **102**D, **102**U are provided in a fiber optic cable **104** that is interfaced to the ICU **85**. The ICU **85** provides a common point in which the downlink and uplink optical fibers **102**D, **102**U carrying digital optical signals can be bundled with the downlink and uplink optical fibers **16**U, **16**D carrying RF optical signals. One or more of the fiber optic cables **104**, also referenced herein as array cables **104**, can be provided containing the downlink and uplink optical fibers **16**D, **16**U for RF communication services and downlink and uplink optical fibers **102**D, **102**U for digital data services to be routed and provided to the RAUs **14**. Any combination of services or types of optical fibers can be provided in the array cable **104**. For example, the array cable **104** may include single mode and/or multi-mode optical fibers for RF communication services and/or digital data services.

Examples of ICUs that may be provided in the optical fiber-based distributed communications system **90** to distribute both downlink and uplink optical fibers **16**D, **16**U for RF communication services and downlink and uplink optical fibers **102**D, **102**U for digital data services are described in U.S. patent application Ser. No. 12/466,514 filed on May 15, 2009 and entitled "Power Distribution Devices, Systems, and Methods For Radio-Over-Fiber (RoF) Distributed Communication," incorporated herein by reference in its entirety, and U.S. Provisional Patent Application Ser. No. 61/330,385, filed on May 2, 2010 and entitled "Power Distribution in Optical Fiber-based Distributed Communication Systems Providing Digital Data and Radio-Frequency (RF) Communication Services, and Related Components and Methods," both of which are incorporated herein by reference in their entireties.

With continuing reference to FIG. **4**, some RAUs **14** can be connected to access points (APs) **118** or other devices supporting digital data services. APs **118** are illustrated, but the APs **118** could be any other device supporting digital data services. In the example of APs, the APs **118** provide access to the digital data services provided by the digital data services switch **96**. This is because the downlink and uplink optical fibers **102**D, **102**U carrying downlink and uplink optical digital signals **100**D, **100**U converted from downlink and uplink electrical digital signals **98**D, **98**U from the digital data services switch **96** are provided to the APs **118** via the array cables **104** and RAUs **14**. Digital data client devices can access the APs **118** to access digital data services provided through the digital data services switch **96**.

Digital data service clients, such as APs, require power to operate and to receive digital data services. By providing digital data services as part of an optical fiber-based distributed communications system, power distributed to the RAUs in the optical fiber-based distributed communications system can also be used to provide access to power for digital data service clients. This may be a convenient method of providing power to digital data service clients as opposed to providing separate power sources for digital data service clients. For example, power distributed to the RAUs **14** in FIG. **4** by or through the ICU **85** can also be used to provide power to the APs **118** located at RAUs **14** in the optical fiber-based distributed communications system **90**. In this regard, the ICUs **85** may be configured to provide power for both RAUs **14** and the APs **118**. A power supply may be located within the ICU **85**, but could also be located outside of the ICU **85** and provided over an electrical power line **120**, as illustrated in FIG. **4**. The ICU **85** may receive either alternating current (AC) or direct current (DC) power. The ICU **85** may receive 110 Volts (V) to 240V AC or DC power. The ICU **85** can be configured to produce any voltage and power level desired. The power level is based on the number of RAUs **14** and the expected loads to be supported by the RAUs **14** and any digital devices connected to the RAUs **14** in FIG. **4**. It may further be desired to provide additional power management features in the ICU **85**. For example, one or more voltage protection circuits may be provided.

FIG. **8** is a schematic diagram of exemplary internal components in the RAU **14** of FIG. **4** to further illustrate how the downlink and uplink optical fibers **16**D, **16**D for RF communications, the downlink and uplink optical fibers **102**D, **102**U for digital data services, and electrical power are provided to the RAU **14** and can be distributed therein. As illustrated in FIG. **8**, the array cable **104** is illustrated that contains the downlink and uplink optical fibers **16**D, **16**D for RF communications, the downlink and uplink optical fibers **102**D, **102**U for digital data services, and the electrical power line **58** (see also, FIG. **2**) carrying power from the ICU **85**. As previously discussed in regard to FIG. **2**, the electrical power line **58** may comprise two wires **60**, **62**, which may be copper lines for example.

The downlink and uplink optical fibers **16**D, **16**U for RF communications, the downlink and uplink optical fibers **102**D, **102**U for digital data services, and the electrical power line **58** come into a housing **124** of the RAU **14**. The downlink and uplink optical fibers **16**D, **16**U for RF communications are routed to the O-E converter **30** and E-O converter **34**, respectively, and to the antenna **32**, as also illustrated in FIG. **2** and previously discussed. The downlink and uplink optical fibers **102**D, **102**U for digital data services are routed to a digital data services interface **126** provided as part of the RAU **14** to provide access to digital data services via a port **128**, which will be described in more detail below. The electrical power line **58** carries power that is configured to provide power to the O-E converter **30** and E-O converter **34** and to the digital data services interface **126**. In this regard, the electrical power line **58** is coupled to a voltage controller **130** that regulates and provides the correct voltage to the O-E converter **30** and E-O converter **34** and to the digital data services interface **126** and other circuitry in the RAU **14**.

In this embodiment, the digital data services interface **126** is configured to convert downlink optical digital signals **100**D on the downlink optical fiber **102**D into downlink electrical digital signals **132**D that can be accessed via the port **128**. The digital data services interface **126** is also configured to convert uplink electrical digital signals **132**U received through the port **128** into uplink optical digital signals **100**U to be provided back to the HMC **94** (see FIG. **4**). In this regard, a media converter **134** is provided in the digital data services interface **126** to provide these conversions. The media converter **134** contains an O-E digital converter **136** to convert downlink optical digital signals **100**D on the downlink optical fiber **102**D into downlink electrical digital signals **132**D. The media converter **134** also contains an E-O digital converter **138** to convert uplink electrical digital signals **132**U received through the port **128** into uplink optical digital signals **100**U to be provided back to the HMC **94**. In this regard, power from the electrical power line **58** is provided to the digital data services interface **126** to provide power to the O-E digital converter **136** and E-O digital converter **138**.

Because electrical power is provided to the RAU **14** and the digital data services interface **126**, this also provides an opportunity to provide power for digital devices connected to the RAU **14** via the port **128**. In this regard, a power interface

140 is also provided in the digital data services interface 126, as illustrated in FIG. 8. The power interface 140 is configured to receive power from the electrical power line 58 via the voltage controller 130 and to also make power accessible through the port 128. In this manner, if a client device contains a compatible connector to connect to the port 128, not only will digital data services be accessible, but power from the electrical power line 58 can also be accessed through the same port 128. Alternatively, the power interface 140 could be coupled to a separate port from the port 128 for digital data services.

For example, if the digital data services are provided over Ethernet, the power interface 140 could be provided as a Power-over-Ethernet (PoE) interface. The port 128 could be configured to receive a RJ-45 Ethernet connector compatible with PoE as an example. In this manner, an Ethernet connector connected into the port 128 would be able to access both Ethernet digital data services to and from the downlink and uplink optical fibers 102D, 102U to the HMC 94 as well as access power distributed by the ICU 85 over the array cable 104 provided by the electrical power line 58.

Further, the HEU 12 could include low level control and management of the media converter 134 using communication supported by the HEU 12. For example, the media converter 134 could report functionality data (e.g., power on, reception of optical digital data, etc.) to the HEU 12 over the uplink optical fiber 16U that carries communication services. The RAU 14 can include a microprocessor that communicates with the media converter 134 to receive this data and communicate this data over the uplink optical fiber 16U to the HEU 12.

Other configurations are possible to provide digital data services in an optical fiber-based distributed communications system. For example, FIG. 9 is a schematic diagram of another exemplary embodiment of providing digital data services in an optical fiber-based distributed communications system configured to provide RF communication services. In this regard, FIG. 9 provides an optical fiber-based distributed communications system 150. The optical fiber-based distributed communications system 150 may be similar to and include common components provided in the optical fiber-based distributed communications system 90 in FIG. 4. In this embodiment, instead of the HMC 94 being provided separate from the HEU 12, the HMC 94 is co-located with the HEU 12. The downlink and uplink optical fibers 102D, 102U for providing digital data services from the digital data services switch 96 are also connected to the patch panel 92. The downlink and uplink optical fibers 16D, 16U for RF communications and the downlink and uplink optical fibers 102D, 102U for digital data services are then routed to the ICU 85, similar to FIG. 2.

The downlink and uplink optical fibers 16D, 16U for RF communications, and the downlink and uplink optical fibers 102D, 102U for digital data services, may be provided in a common fiber optic cable or provided in separate fiber optic cables. Further, as illustrated in FIG. 9, standalone media converters (MCs) 141 may be provided separately from the RAUs 14 in lieu of being integrated with RAUs 14, as illustrated in FIG. 4. The stand alone MCs 141 can be configured to contain the same components as provided in the digital data services interface 126 in FIG. 8, including the media converter 134. The APs 118 may also each include antennas 152 to provide wireless digital data services in lieu of or in addition to wired services through the port 128 through the RAUs 14.

FIG. 10A is a schematic diagram of another exemplary embodiment of providing digital data services in an optical fiber-based distributed communications system. In this regard, FIG. 10A provides an optical fiber-based distributed communications system 160. The optical fiber-based distributed communications system 160 may be similar to and include common components provided in the optical fiber-based distributed communications systems 90, 150 in FIGS. 4 and 9.

In this embodiment, as illustrated in FIG. 10A, wavelength-division multiplexing (WDM) is employed to multiplex digital data services and RF communication services together at different wavelengths over downlink and uplink optical fibers 162D(1-N), 162U(1-N) in the optical fiber-based distributed communications system 160. "1-N" downlink and uplink optical fiber pairs are provided to the ICU 85 to be distributed to the RAUs 14 and stand alone MCs 141. Multiplexing could be used to further reduce the cost for the digital data services overlay. By using WDM, digital data signals are transmitted on the same optical fibers as the RF communication signals, but on different wavelengths. Separate media conversion and WDM filters at the transmit locations and at the receive locations (e.g., HMC 96 and RAUs 14) would be employed to receive signals at the desired wavelength.

The HMC 94 and HEU 12 are co-located in the optical fiber-based distributed communications system 160 in FIG. 10A. A plurality of wavelength-division multiplexers 164(1)-164(N) are provided that each multiplex the downlink optical RF signal(s) 22D for RF communications and the downlink optical digital signal(s) 100D for digital data services together on a common downlink optical fiber(s) 162D(1-N). Similarly, a plurality of wavelength-division de-multiplexers 168(1)-168(N) (e.g., wavelength filters) are provided that each de-multiplex the uplink optical RF signal(s) 22U from the uplink optical digital signal(s) 100U from a common uplink optical fiber(s) 162U(1-N) to provide the uplink optical RF signals 22U to the HEU 12 and the uplink optical digital signal 100U to the HMC 94. Wavelength-division de-multiplexing (WDD) and WDM are also employed in the RAUs 14 to de-multiplex multiplexed downlink optical RF signals 22D and downlink optical digital signals 100D on the common downlink optical fibers 162D(1-N) and to multiplex uplink optical RF signals 22U and uplink optical digital signals 100U on the common uplink optical fibers 162U(1-N).

FIG. 10B is a schematic diagram of another exemplary embodiment of providing digital data services in an optical fiber-based distributed communications system 160'. The optical fiber-based distributed communications system 160' in FIG. 10B is the same as the optical fiber-based distributed communications system 160 in FIG. 10A, except that WDM is employed to multiplex uplink and downlink communication services at different wavelengths over common optical fiber that includes both downlink and uplink optical fibers 162D(1-N), 162U(1-N),

FIG. 11 is a schematic diagram of another exemplary embodiment of providing digital data services in an optical fiber-based distributed communications system. As illustrated in FIG. 11, an optical fiber-based distributed communications system 170 is provided that can also deliver digital data services. Instead of wavelength-division multiplexing the downlink optical RF signal(s) 22D for RF communications with the downlink optical digital signal(s) 100D for digital data services together on a common downlink optical fiber(s) 162D(1-N) as provided in FIG. 10A, a wavelength-division multiplexer 172 is provided. The wavelength-division multiplexer 172 multiplexes all downlink optical RF signals 22D with all downlink optical digital signal 100D to a single downlink optical fiber 174D. Similarly, a wavelength-division de-multiplexer **176** is provided to de-multiplex all uplink optical RF signals **22**U from all uplink optical digital signals **100**U from the common uplink optical fiber **174**U at the desired wavelength. A wavelength-division de-multiplexer **175** and a wavelength-division multiplexer **177** are also employed in the ICU **85** to de-multiplex wavelength-division multiplexed downlink optical RF signals **22**D and uplink optical digital signals **100**U on the common downlink optical fiber **174**D, and to wavelength-division multiplex uplink optical RF signals **22**U and uplink optical digital signals **100**U on the common uplink optical fiber **174**U, respectively.

Alternatively, WDD and WDM could also be employed in the RAUs **14** to de-multiplex wavelength-division multiplexed downlink optical RF signals **22**D and downlink optical digital signals **100**D on the common downlink optical fiber **174**D, and to wavelength-division multiplex uplink optical RF signals **22**U and uplink optical digital signals **100**U on the common uplink optical fiber **174**U. In this alternative embodiment, de-multiplexing at the RAUs **14** could be done where a common WDM signal would be distributed from RAU **14** to RAU **14** in a daisy-chain configuration. Alternatively, optical splitters could be employed at break-out points in the fiber optic cable **104**.

FIG. **12** is a schematic diagram of another exemplary embodiment of providing digital data services in an optical fiber-based distributed communications system. As illustrated in FIG. **12**, an optical fiber-based distributed communications system **180** is provided that can also deliver digital data services. The optical fiber-based distributed communications system **180** is the same as the optical fiber-based distributed communications system **170** in FIG. **11**, except that the HEU **12** and HMC **94** are provided in a common housing **182** that also houses the wavelength-division multiplexer **172** and wavelength-division de-multiplexer **176**. Alternatively, a plurality of wavelength-division multiplexers and plurality of wavelength-division de-multiplexers like provided in FIG. **10**A (**164**(**1**-N)) and **168**(**1**-N)) can be provided in the common housing **182**.

FIG. **13** is a schematic diagram of another exemplary embodiment of an optical fiber-based distributed communications system providing digital data services. As illustrated in FIG. **13**, an optical fiber-based distributed communications system **190** is provided. In this embodiment, frequency-division multiplexing (FDM) is employed to multiplex digital data services and RF communication services at different frequencies over downlink optical fibers and uplink optical fibers. One advantage of employing FDM is that E-O converters would be used simultaneously for converting RF communication signals and digital data signals into respective optical signals. Therefore, additional media converters for converting electrical digital signals to optical digital signals can be avoided to reduce complexity and save costs. For example, fast Ethernet (e.g., 100 Megabits/second (Mbs)) could be transmitted below the cellular spectrum (e.g., below 700 MHz). More than one (1) channel could be transmitted simultaneously in this frequency range.

In this regard, the HEU **12** and HEC **94** are both disposed in the common housing **182**, as illustrated in FIG. **13**. A plurality of frequency-division multiplexers **192**(**1**-N) are provided in the common housing **182** and are each configured to multiplex the downlink electrical digital signal(s) **98**D with the downlink electrical RF signal(s) **18**D at different frequencies prior to optical conversion. In this manner, after optical conversion, a common optical fiber downlink **194**D(**1**-N) can carry frequency-division multiplexed downlink optical RF signal **22**D and downlink optical digital signal **102**D on the same downlink optical fiber **194**D(**1**-N). Similarly, a plurality of frequency-division de-multiplexers **196**(**1**-N) are provided in the common housing **182** to de-multiplex an uplink optical RF signal **22**U and an uplink optical digital signal **100**U on an uplink optical fiber **194**U(**1**-N). Frequency-division de-multiplexing (FDD) and FDM are also employed in the RAUs **14**. FDD is employed in the RAU **14** to de-multiplex frequency multiplexed downlink electrical RF signals **18**D and downlink electrical digital signals **98**D after being converted from optical signals from the common downlink optical fiber **174**D to electrical signals. FDM is also provided in the RAU **14** to frequency multiplex uplink electrical signals in the RAU **14** before being converted to uplink optical RF signals **22**U and uplink optical digital signals **100**U provided on the common uplink optical fiber **174**U.

FIG. **14** is a schematic diagram of another exemplary embodiment of an optical fiber-based distributed communications system that employs both WDM and FDM. In this regard, FIG. **14** illustrates an optical fiber-based distributed communications system **200**. The optical fiber-based distributed communications system **200** employs the WDM and WDD of the optical fiber-based distributed communications system **180** of FIG. **12** combined with FDM and FDD of the optical fiber-based distributed communications system **190** of FIG. **13**. The wavelength-division multiplexed and frequency-division multiplexed downlink signals are provided over downlink optical fiber **202**D. The wavelength-division multiplexed and frequency-division multiplexed uplink signals are provided over uplink optical fiber **202**U.

Options and alternatives can be provided for the above-described embodiments. A digital data services interface provided in an RAU or stand alone MC could include more than one digital data services port. For example, referring to FIG. **14** as an example, a switch **203**, such as an Ethernet switch for example, may be disposed in the RAUs **14** to provide RAUs **14** that can support more than one digital data services port. An HMC could have an integrated Ethernet switch so that, for example, several APs could be attached via cables (e.g., Cat 5/6/7 cables) in a star architecture. The Ethernet channel could be used for control, management, and/or communication purposes for an optical fiber-based distributed communications system as well as the Ethernet media conversion layer. The HMC could be either single channel or multi-channel (e.g., twelve (12) channel) solutions. The multi-channel solution may be cheaper per channel than a single channel solution. Further, uplink and downlink electrical digital signals can be provided over mediums other than optical fiber, including electrical conducting wire and/or wireless communications, as examples.

Frequency up conversions or down conversions may be employed when providing FDM if RF communication signals have frequencies too close to the frequencies of the digital data signals to avoid interference. While digital baseband transmission of a baseband digital data signals below the spectrum of the RF communication signals can be considered, intermodulation distortion on the RF communication signals may be generated. Another approach is to up convert the digital data signals above the frequencies of the RF communication signals and also use, for example, a constant envelope modulation format for digital data signal modulation. Frequency Shift Keying (FSK) and Minimum Shift Keying (MSK) modulation are suitable examples for such modulation formats. Further, in the case of FDM for digital data services, higher-level modulation formats can be considered to transmit high data rates (e.g., one (1) Gb, or ten (10) Gb) over the same optical fiber as the RF communication signals.

Multiple solutions using single-carrier (with e.g., 8-FSK or 16-QAM as examples) or multi-carrier (OFDM) are conceivable.

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.

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 imitation.

We claim:

1. A distributed antenna system for distributing radio frequency (RF) communications and digital data services (DDS) to at least one remote antenna unit (RAU), comprising:

a head-end unit (HEU) configured to:

receive at least one downlink electrical RF communications signal;

convert the at least one downlink electrical RF communications signal into at least one downlink optical RF communications signal to be communicated over at least one communications downlink to the at least one RAU;

receive at least one uplink optical RF communications signal over at least one communications uplink from the at least one RAU; and

convert the at least one uplink optical RF communications signal into at least one uplink electrical RF communications signal;

a DDS controller configured to:

receive at least one downlink signal containing at least one DDS;

convert the at least one downlink signal containing at least one DDS to at least one downlink optical digital signal containing at least one DDS;

provide the at least one downlink optical digital signal containing at least one DDS over at least one second communications downlink to the at least one RAU;

receive at least one uplink optical digital signal over at least one second communications uplink from the at least one RAU;

convert the at least one uplink optical digital signal to at least one uplink electrical digital signal; and

at least one RAU, wherein each RAU of the at least one RAU comprises:

an optical-to-electrical (O/E) converter configured to convert received downlink optical RF communications signals to downlink electrical RF communications signals and provide the downlink electrical RF communications signals to at least one first port;

an electrical-to-optical (E/O) converter configured to convert uplink electrical RF communications signals received from the at least one first port to uplink optical RF communications signals; and

a DDS interface coupled to at least one second port and configured to:

convert downlink optical digital signals into downlink electrical digital signals to provide to the at least one second port; and

convert uplink electrical digital signals received from the at least one second port into uplink optical digital signals; and

at least one device supporting digital data services and connected to at least one RAU via the at least one second port, and

wherein the DDS interface further comprises a power interface configured to receive electrical power and provide the electrical power to the at least one second port, the electrical power configured to power the at least one device supporting digital data services and connected to the at least one RAU.

2. The distributed antenna system of claim **1**, wherein the at least one RAU comprises a plurality of remote antenna units.

3. The distributed antenna system of claim **1**, wherein the at least one communications downlink and the at least one communications uplink are the same optical fiber.

4. The distributed antenna system of claim **1**, wherein the at least one communications downlink and the at least one communications uplink comprise separate, different optical fibers.

5. A distributed antenna system for distributing radio frequency (RF) communications and digital data services (DDS) to at least one remote antenna unit (RAU) comprising:

a head-end unit (HEU) configured to:

receive at least one downlink electrical RF communications signal;

convert the at least one downlink electrical RF communications signal into at least one downlink optical RF communications signal to be communicated over at least one communications downlink to the at least one RAU;

receive at least one uplink optical RF communications signal over at least one communications uplink from the at least one RAU; and

convert the at least one uplink optical RF communications signal into at least one uplink electrical RF communications signal;

a DDS controller configured to:

receive at least one downlink signal containing at least one DDS;

convert the at least one downlink signal containing at least one DDS to at least one downlink optical digital signal containing at least one DDS;

provide the at least one downlink optical digital signal containing at least one DDS over at least one second communications downlink to the at least one RAU;

receive at least one uplink optical digital signal over at least one second communications uplink from the at least one RAU;

convert the at least one uplink optical digital signal to at least one uplink electrical digital signal; and

at least one RAU, wherein each RAU of the at least one RAU comprises:
 an optical-to-electrical (O/E) converter configured to convert received downlink optical RF communications signals to downlink electrical RF communications signals and provide the downlink electrical RF communications signals to at least one first port;
 an electrical-to-optical (E/O) converter configured to convert uplink electrical RF communications signals received from the at least one first port to uplink optical RF communications signals; and
 a DDS interface coupled to at least one second port and configured to:
 convert downlink optical digital signals into downlink electrical digital signals to provide to the at least one second port; and
 convert uplink electrical digital signals received from the at least one second port into uplink optical digital signals; and
 a media converter associated with the at least one RAU and configured to report functionality data to the HEU over the at least one second communications uplink to the HEU, and wherein the HEU is configured to provide control and management of the media converter based on the functionality data.

6. The distributed antenna system of claim **5**, wherein the at least one RAU comprises a plurality of remote antenna units.

7. The distributed antenna system of claim **5**, wherein the at least one communications downlink and the at least one communications uplink are the same optical fiber.

8. The distributed antenna system of claim **5**, wherein the at least one communications downlink and the at least one communications uplink comprise separate, different optical fibers.

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