Title: DIGITAL-ANALOG INTERFACE MODULES (DAIMs) FOR FLEXIBLY DISTRIBUTING DIGITAL AND/OR ANALOG COMMUNICATIONS SIGNALS IN WIDE AREA ANALOG DISTRIBUTED ANTENNA SYSTEMS (DASS)

Abstract: Embodiments of the disclosure relate to digital-analog interface modules (PAIMs) for flexibly distributing digital and/or analog communications signals in wide-area analog distributed antenna systems (DAS). In this regard, in one aspect, a DAIM is a multi-functional device capable of distributing the digital and/or analog communications signals to a local-area DAS in a wide-area DAS. The DAIM comprises an analog radio frequency (RF) communications signal interface for coupling with an analog signal source, a digital communications interface for coupling with a digital signal source, an analog local distribution interface for coupling with a remote antenna unit (RAU), and at least one digital remote distribution interface for coupling with a head-end unit (HEU) of the local-area DAS. By employing the DAIM in the wide-area DAS, it is possible to flexibly reconfigure the wide-area DAS for distributing digital and/or analog communications signals over the digital communications mediums.
DIGITAL-ANALOG INTERFACE MODULES (DAMS) FOR FLEXIBLY DISTRIBUTING DIGITAL AND/OR ANALOG COMMUNICATIONS SIGNALS IN WIDE-AREA ANALOG DISTRIBUTED ANTENNA SYSTEMS (DASS)

PRIORITY APPLICATION

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application No. 62/093,643 filed on December 18, 2014, the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

[0002] The disclosure relates generally to distribution of communications signals in a distributed antenna system (DAS), and more particularly to flexibly distributing digital and/or analog communications signals between analog DASs over digital communications mediums.

[0003] Wireless customers are increasingly demanding digital data services, such as streaming video signals. Concurrently, some wireless customers use their wireless devices in areas that are poorly served by conventional cellular networks, such as inside certain buildings or areas where there is little cellular coverage. One response to the intersection of these two concerns has been the use of DASs. DASs can be particularly useful when deployed inside buildings or other indoor environments where client devices may not otherwise be able to effectively receive radio frequency (RF) signals from a source. DASs include remote antenna units (RAUs) configured to receive and transmit communications signals to client devices within the antenna range of the RAUs.

[0004] A typical DAS comprises a head-end unit communicatively coupled to one or more remote unit groups, each comprising at least one remote unit. The remote unit may be an RAU that is configured to wirelessly distribute communications signals to and from the head-end unit. The head-end unit is configured to receive and distribute the communications signals to a variety of wireless sendees, such as wideband code division multiple access (WCDMA), long-term evolution (LTE), and wireless local area network (WLAN) communications services. To distribute such wireless communications services in a DAS, the wireless communications services can be provided in the form of digital communications signals and/or analog communications signals to the head-end unit of the DAS. Thus, the DAS may be configured to receive and distribute the digital communications signals and/or analog communications signals in either analog or digital form. Analog communications signals may be directly modulated onto a carrier signal for transmission over an analog...
communications medium. Digital communications signals, in contrast, are signals generated by sampling and digitizing an analog communications signal before modulating onto the carrier signal. DASs configured to directly distribute analog communications signals may be referred to as analog DASs. DASs configured to directly distribute digital communications signals may be referred to as digital DASs.

[0005] No admission is made that any reference cited herein constitutes prior art. Applicant expressly reserves the right to challenge the accuracy and pertinency of any cited documents.

SUMMARY

[0006] Embodiments of the disclosure relate to digital-analog interface modules (DAIMs) and digital interface modules (DIMs) for flexibly distributing digital and/or analog communications signals in wide-area analog distributed antenna systems (DASs). A wide-area DAS typically comprises a plurality of local-area DASs interconnected via digital communications mediums. Any of the plurality of local-area DASs may be configured as a main DAS to efficiently receive and redistribute digital and/or analog communications signals to rest of the local-area DASs in the wide-area DAS. In a non-limiting example, the main DAS in the wide-area DAS may be collocated with installed telecommunications equipment (e.g., base transceiver stations and digital baseband units) to avoid additional installation costs, reduce power consumption, and improve operation efficiency.

[0007] In this regard, in one embodiment, a DAIM is provided as multi-functional equipment in the main DAS for receiving and redistributing digital and/or analog communications signals to rest of the local-area DASs in the wide-area DAS. The DAIM comprises an analog radio frequency (RF) communications signal interface for coupling with an analog signal source, a digital communications interface for coupling with a digital signal source, an analog local distribution interface for coupling with a remote antenna unit (RAU), and at least one digital remote distribution interface for coupling with a head-end unit (HEU) of a local-area DAS. Furthermore, a plurality of DAIMs may be interconnected via respective digital bus interfaces to concurrently support the plurality of local-area DASs in the wide-area DAS. In another embodiment, a DIM is provided in the main DAS as an alternative to the DAIM. The DIM is a modified DAIM and comprises a digital communications interface for coupling with a digital signal source, an analog local distribution interface for coupling with an analog signal source, and at least one digital
remote distribution interface for coupling with the HEU of the remote local-area DAS. **Furthermore,** a plurality of D|Ms may be interconnected via the respective digital bus interfaces to concurrently support the plurality of local-area DASs in the wide-area DAS. By employing the DAIM or the DIM in the wide-area DAS, it is possible to flexibly reconfigure the wide-area DAS for distributing digital and/or analog communications signals over the digital communications mediums.

[0008] An additional embodiment of the disclosure relates to a DAIM in a main DAS to support a wide-area DAS. The DAIM comprises an analog communications interface configured to receive a downlink analog communications signal from at least one of an analog signal source and a baseband signal source. The DAIM also comprises at least one digital remote distribution interface to be coupled with a remote DAS component in a remote DAS in the wide-area DAS. The DAIM also comprises an analog local distribution interface configured to distribute a downlink analog RF signal to an RAU in the main DAS. The DAIM also comprises an RF conditioning circuit coupled to the analog communications interface and the analog local distribution interface. The RF conditioning circuit is configured to receive the downlink analog communications signal from the analog signal source. The RF conditioning circuit is also configured to convert the downlink analog communications signal into the downlink analog RF signal adapted for distribution in the wide-area DAS. The RF conditioning circuit is also configured to provide the downlink analog RF signal to the analog local distribution interface. The RF conditioning circuit is also configured to provide the downlink analog RF signal to an analog-to-digital (A/D) converter.

[0009] The DAIM also comprises the A/D converter coupled to the RF conditioning circuit. The A/D converter is configured to convert the downlink analog RF signal to generate a downlink digital RF signal. The DAIM also comprises a digital signal processing circuit coupled to the A/D converter and the at least one digital remote distribution interface. The digital signal processing circuit is configured to receive the downlink digital RF signal from the A/D converter. The digital signal processing circuit is also configured to convert the downlink digital RF signal to generate one or more first downlink digital RF signals. The digital signal processing circuit is also configured to combine one or more respective first downlink digital RF signals to generate a combined downlink digital RF signal. The digital signal processing circuit is also configured to provide the combined downlink digital RF signal to the at least one digital remote distribution interface to be distributed to the remote
DAS component.

An additional embodiment of the disclosure relates to a optical fiber-based wide-area DAS. The optical fiber-based wide-area DAS comprises a main DAS comprising a main HEU, wherein the main HEU comprises one or more DAIMs. Each of the one or more DAIMs is coupled to a respective optical fiber-based downlink digital communications medium via a respective electrical-to-optical (E/O) converter and is coupled to a respective optical fiber-based uplink digital communications medium via a respective optical-to-electrical (O/E) converter. The optical fiber-based wide-area DAS also comprises one or more remote DASs comprising one or more remote HEUs, respectively. A remote HEU among the one or more remote HEUs comprises one or more remote-HEU DIMs corresponding to one or more RF bands, respectively, wherein at least one remote-HEU DIM among the one or more remote-HEU DIMs comprised in the remote HEU is configured to interface with a respective DAIM in the main HEU. The at least one at least one remote-HEU DIM configured to interface with the respective DAIM in the main HEU is coupled to the respective optical fiber-based downlink digital communications medium via a respective remote-HEU O/E converter and is coupled to the respective optical fiber-based uplink digital communications medium via a respective remote-HEU E/O converter. The remote HEU among the one or more remote HEUs also comprises a remote-HEU RF combiner/splitter coupled to the one or more remote-HEU DIMs. The remote HEU among the one or more remote HEUs also comprises a remote-HEU optical splitter/combiner coupled to the remote-HEU RF combiner/splitter. The remote HEU among the one or more remote HEUs also comprises one or more remote-HEU optical interface modules (OIMs) coupled to the remote-HEU optical splitter/combiner, wherein the one or more remote-HEU OIMs are coupled with one or more remote-DAS RAUs.

An additional embodiment of the disclosure relates to a method for reconfiguring an existing HEU in a DAS with DAIMs. The method comprises replacing one or more radio interface modules (RIMs) in the existing HEU with one or more DAIMs. For each of the one or more DAIMs, the method comprises coupling an analog communications interface comprised in the DAIM to a respective analog signal source. For each of the one or more DAIMs, the method also comprises coupling a digital communications interface comprised in the DAIM to a respective digital signal source. For each of the one or more DAIMs, the method also comprises coupling at least one digital remote distribution interface comprised in the DAIM to a respective downlink digital communications medium and a respective uplink
digital communications medium. For each of the one or more DAIMs, the method also comprises coupling an analog local distribution interface comprised in the DAIM to a respective RAJ.

[0012] Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the embodiments as described in the written description and claims hereof, as well as the appended drawings.

[0013] The drawings illustrate one or more embodiments, and together with the description serve to explain principles and operation of the various embodiments.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0014] FIG. 1 is a schematic diagram of an exemplary analog distributed antenna system (DAS);

[0015] FIG. 2 is a schematic diagram of an exemplary wide-area analog DAS consisting of a plurality of local-area analog DASs wherein a local-area analog DAS among the plurality of local-area analog DASs is configured as a main analog DAS of the wide-area analog DAS;

[0016] FIG. 3 is a schematic diagram of an exemplary digital-analog interface module (DAIM) configured to be retrofitted into the chassis of a main head-end unit (HEU) in the wide-area analog DAS of FIG. 2 for distributing digital and/or analog communications signals in the wide-area analog DAS over digital communications mediums;

[0017] FIG. 4 is a schematic diagram of an exemplary digital interface module (DIM) that configured to be retrofitted into the chassis of a plurality of remote HEUs as well as a main HEU in the wide-area analog DAS of FIG. 2 for distributing digital and/or analog communications signals in the wide-area analog DAS over digital communications mediums;

[0018] FIG. 5A is a schematic diagram of an exemplary main HEU comprising a plurality of DAIMs that are interconnected to an interconnection digital bus via a plurality of digital bus interfaces and configured to share a plurality of downlink communications signals;

[0019] FIG. 5B is a schematic diagram of an exemplary main HEU comprising the plurality of DAIMs in FIG. 5A that are interconnected to the interconnection digital bus in FIG. 5A via the plurality of digital bus interfaces in FIG. 5A and configured to share a plurality of uplink communications signals;

[0020] FIG. 6 is a schematic diagram of an exemplary optical fiber-based wide-area DAS configured to distribute digital and analog communications signals from a main HEU to one
or more remote HEUs over optical fiber-based digital communications mediums, wherein the main HEU is reconfigured by retrofitting one or more of the DAIMs illustrated in FIG. 3 into the existing chassis of a main HEU in FIG. 2;

[0021] FIG. 7 is a flowchart of an exemplary HEU configuration process reconfiguring the main HEU in FIG. 2 with one or more of the DAIMs in FIG. 6;

[0022] FIG. 8 is a schematic diagram of an exemplary optical fiber-based wide-area DAS configured to distribute digital and analog communications signals from a main HEU to the one or more remote HEUs in FIG. 6 over the optical fiber-based digital communications mediums in FIG. 6, wherein the main HEU is reconfigured by retrofitting one or more of the DIMs illustrated in FIG. 4 into the existing chassis of a main HEU in FIG. 2;

[0023] FIG. 9 is a flowchart of an exemplary HEU configuration process reconfiguring the main HEU in FIG. 2 with one or more main-HEU DIMs in FIG. 8;

[0024] FIG. 10 is a schematic diagram of an exemplary DAS comprising a main HEU coupled to a remote HEU over a plurality of optical fiber-based communications mediums;

[0025] FIG. 11 is a schematic diagram of an exemplary DAS comprising a main HEU coupled to a remote HEU using wavelength-division multiplexing (WDM);

[0026] FIG. 12 is a schematic diagram of an exemplary DAS wherein a main HEU and a remote HEU are configured to concurrently distribute digital and/or analog communications signals using a plurality of DAIMs and a plurality of DIMs;

[0027] FIG. 13 is a schematic diagram of an exemplary DAS wherein a main HEU and a remote HEU are configured to concurrently distribute digital and/or analog communications signals using WDM; and

[0028] FIG. 14 is a partially schematic cut-away diagram of an exemplary building infrastructure in which an analog DAS, which can include the DAIM in FIG. 3 or the DIM in FIG. 4 to support the distribution of digital and/or communications signals, can be employed.

D ETAILED DESCRIPTION

[0029] Embodiments of the disclosure relate to digital-analog interface modules (DAIMs) and digital interface modules (DIMs) for flexibly distributing digital and/or analog communications signals in wide-area analog distributed antenna systems (DASs). A wide-area DAS typically comprises a plurality of local-area DASs interconnected via digital communications mediums. Any of the plurality of local-area DASs may be configured as a main DAS to efficiently receive and redistribute digital and/or analog communications
signals to rest of the local-area DASs in the wide-area DAS. In a non-limiting example, the main DAS in the wide-area DAS may be collocated with installed telecommunications equipment (e.g., base transceiver stations and digital baseband units) to avoid additional installation costs, reduce power consumption, and improve operation efficiency.

[0030] In this regard, in one aspect, a DAIM is provided as multi-functional equipment in the main DAS for receiving and redistributing digital and/or analog communications signals to rest of the local-area DASs in the wide-area DAS. The DAIM comprises an analog radio frequency (RF) communications signal interface for coupling with an analog signal source, a digital communications interface for coupling with a digital signal source, an analog local distribution interface for coupling with a remote antenna unit (RAU), and at least one digital remote distribution interface for coupling with a head-end unit (HEU) of a local-area DAS. Furthermore, a plurality of DAIMs may be interconnected via respective digital bus interfaces to concurrently support the plurality of local-area DASs in the wide-area DAS.

[0031] In another aspect, a DIM is provided in the main DAS as an alternative to the DAIM. The DIM is a modified DAIM and comprises a digital communications interface for coupling with a digital signal source, an analog local distribution interface for coupling with an analog signal source, and at least one digital remote distribution interface for coupling with the HEU of the remote local-area DAS. Furthermore, a plurality of DAIMs may be interconnected via the respective digital bus interfaces to concurrently support the plurality of local-area DASs in the wide-area DAS.

[0032] By employing the DAIM or the DIM in the wide-area DAS, it is possible to flexibly reconfigure the wide-area DAS for distributing digital and/or analog communications signals over the digital communications mediums.

[0033] Before discussing examples of a DAIM supporting flexible distribution of digital and/or analog communications signals between analog DASs starting at FIG. 3, discussions of an exemplary local-area analog DAS and an exemplary wide-area analog DAS that support only analog wireless communications services are first provided with references to FIGS. 1 and 2. The discussion of specific exemplary aspects of flexibly distributing digital and/or analog communications signals between analog DASs using the DAIM is provided starting at FIG. 3.

[0034] In this regard, FIG. 1 illustrates distribution of wireless communications services to coverage areas 10(1)-10(N) of an analog DAS 12, wherein 'N' is the number of coverage areas. These wireless communications services can include cellular services, wireless
services such as radio frequency (RF) identification (RFID) tracking. Wireless Fidelity (Wi-Fi), local area network (LAN), and combinations thereof, as examples. The coverage areas 10(1)-10(N) may be remotely located. In this regard, the remote coverage areas 10(1)-10(N) are created by and centered on remote antenna units (RAUs) 14(1)-14(N) connected to a head-end unit (HEU) 16 (e.g., a head-end controller or head-end equipment or central unit). The HEU 16 may be communicatively coupled to a base transceiver station (BTS) 18. In this regard, the HEU 16 receives downlink analog RF communications signals 20D from the BTS 18 to be distributed to the remote antenna units 14(1)-14(N). The remote antenna units 14(1)-14(N) are configured to receive the downlink analog RF communications signals 20D from the HEU 16 over an analog communications medium 22 to be distributed to the respective remote coverage areas 10(1)-10(N) of the remote antenna units 14(1)-14(N). In a non-limiting example, the analog communications medium 22 may be a wired communications medium, a wireless communications medium, or an optical fiber-based communications medium. Each remote antenna unit 14(1)-14(N) may include an RF transmitter/receiver (not shown) and a respective antenna 24(1)-24(N) operably connected to the RF transmitter/receiver to wirelessly distribute the wireless communications services to client devices 26 within their respective remote coverage areas 10(1)-10(N). The remote antenna units 14(1)-14(N) are also configured to receive analog uplink RF communications signals 20U from the client devices 26 in their respective remote coverage areas 10(1)-10(N) to be distributed to the BTS 18. The size of a given remote coverage area 10(1)-10(N) is determined by the amount of RF power transmitted by the respective remote antenna unit 14(1)-14(N), the receiver sensitivity, antenna gain and the RF environment, as well as by the RF transmitter/receiver sensitivity of the client device 26. The client devices 26 usually have a fixed maximum RF receiver sensitivity, so that the above-mentioned properties of the remote antenna units 14(1)-14(N) mainly determine the size of their respective remote coverage areas 10(1)-10(N).

0035) The analog DAS 12 is typically deployed to extend indoor coverage of the wireless communications services inside a building. In this regard, the analog DAS 12 may be considered as a local-area DAS for the building. In some cases, a wide-area analog DAS is deployed to provide the wireless communications service to multiple buildings each covered by a local-area DAS like the analog DAS 12. In this regard, FIG. 2 is a schematic diagram of an exemplary wide-area analog DAS 30 consisting of a plurality of local-area analog DASs 32(1)-32(N) wherein a local-area analog DAS 32(X) (1 ≤ X ≤ N) among the
plurality of local-area analog DASs 32(1)-32(N) is configured as a main analog DAS 34 of the wide-area analog DAS 30. In this regard, the wide-area analog DAS 30 is configured according to a star-topology, wherein the main analog DAS 34 serves as a gateway for rest of the plurality of local-area analog DASs 32(1)-32(N) in the wide-area analog DAS 30. The star-topology allows adding a new local-area analog DAS or removing an existing local-area analog DAS without impacting operations of the wide-area analog DAS 30.

In this regard, with continuing reference to FIG. 2, in a non-limiting example, the main analog DAS 34 comprised in the local-area analog DAS 32(X) may be collocated with one or more BTSs 36(1)-36(M). The main analog DAS 34 comprises a main HEU 38, which is a main DAS component and comprises a main-HEU DAS radio interface unit (RIU) (DAS-RIU) 40 and a main-HEU DAS optical interface unit (OIU) (DAS-QIU) 42. In a non-limiting example, the main HEU 38 may be a central unit. The main-HEU DAS-RIU 40 comprises one or more main-HEU RIMs 44(1)-44(M) coupled to the one or more BTSs 36(1)-36(M) for communicating one or more downlink analog RF communications signals 46(1)-46(M) and one or more uplink analog RF communications signals 48(1)-48(M), respectively. On a downlink direction 50, the one or more main-HEU RIMs 44(1)-44(M) adapt the one or more downlink analog RF communications signals 46(1)-46(M) into one or more downlink analog RF signals 52(1)-52(M) that are suited for distribution in the wide-area analog DAS 30. The one or more downlink analog RF signals 52(1)-52(M) are provided to an RF combiner/splitter 54 wherein the one or more downlink analog RF signals 52(1)-52(M) are combined to generate a combined downlink analog RF signal 56. The combined downlink analog RF signal 56 is subsequently received by an optical splitter/combiner 58 in the main-HEU DAS-OIU 42, wherein the combined downlink analog RF signal 56 is first split and then recombined to generate a plurality of second downlink analog RF signals 60(1)-60(N). The main-HEU DAS-OIU 42 comprises a plurality of OIMs 62(1)-62(N) that correspond to the plurality of local-area analog DASs 32(1)-32(N), respectively. Among the plurality of OIMs 62(1)-62(N), the OIM 62(X) (1 ≤ X ≤ N) is configured to be coupled to an RAU 64 that is associated with the main analog DAS 34. In this regard, the RAU 64 is also a main DAS component. The plurality of OIMs 62(1)-62(N) receives and converts the plurality of second downlink analog RF signals 60(1)-60(N) into a plurality of combined downlink optical RF signals 66(1)-66(N), respectively. Among the plurality of combined downlink optical RF signals 66(1)-66(N), the combined downlink optical RF signal 66(X) (1 ≤ X ≤ N) is provided to the RAU 64 while the rest of the plurality of combined downlink optical RF
signals 66(1)-66(N) are provided to the plurality of local-area analog DASs 32(1)-32(N), respectively.

With continuing reference to FIG. 2, in an uplink direction 68, the plurality of OiMs 62(1)-62(N) receive a plurality of combined uplink optical RF signals 70(1)-70(N) from the plurality of local-area analog DASs 32(1)-32(N), respectively. Among the plurality of combined uplink optical RF signals 70(1)-70(N), the combined uplink optical RF signal 70(X) (1 ≤ X ≤ N) may be received from the RAH 64. The plurality of OiMs 62(1)-62(N) convert the plurality of combined uplink optical RF signals 70(1)-70(N) into a plurality of second uplink analog RF signals 72(1)-72(N). The plurality of second uplink analog RF signals 72(1)-72(N) are received by the optical splitter/combiner 58 wherein the plurality of second uplink analog RF signals 72(1)-72(N) are split and recombined to generate a combined uplink analog RF signal 74. The combined uplink analog RF signal 74 is subsequently received by the RF combiner/splitter 54 wherein the combined uplink analog RF signal 74 is split into one or more uplink analog RF signals 76(1)-76(M). The one or more main-HEU RIMs 44(1)-44(M) adapt the one or more uplink analog RF signals 76(1)-76(M) to generate the one or more uplink analog RF communications signals 48(1)-48(M) that are suited for distribution to the one or more BTSs 36(1)-36(M).

With continuing reference to FIG. 2, in contrast to the local-area analog DAS 32(X) that is configured as the main analog DAS 34, the rest of the plurality of local-area analog DASs 32(1)-32(N) may be treated as remote local-area analog DASs in the wide-area analog DAS 30. On the downlink direction 50, each of the plurality of local-area analog DASs 32(1)-32(N) receives a respective downlink optical RF signal among the plurality of combined downlink optical RF signals 66(1)-66(N) from the main analog DAS 34 and distributes to one or more respective RAUs 78(1)-78(R), wherein 'R' may represent a different positive integer number among the plurality of local-area analog DASs 32(1)-32(N). In this regard, the one or more respective RAUs 78(1)-78(R) are one or more remote DAS components. In the uplink direction 68, each of the plurality of local-area analog DASs 32(1)-32(N) provides a respective uplink optical RF signal among the plurality of combined uplink optical RF signals 70(1)-70(N) to the main analog DAS 34. In this regard, the local-area analog DAS 32(1) is discussed next as a non-limiting example of the functional aspects involved in the plurality of local-area analog DASs 32(1)-32(N) (N ≠ X).

With continuing reference to FIG. 2, the local-area analog DAS 32(1) comprises an optical-to-electrical (O/E) converter 80(1) and an electrical-to-optical (E/O) converter
The local-area analog DAS 32(1) also comprises a remote HEU 84(1) that is coupled to the O/E converter 80(1) and the E/O converter 82(1). In this regard, the plurality of local-area analog DASs 32(1)-32(N) comprises a plurality of remote HEUs 84(1)-84(N), respectively. In a non-limiting example, the plurality of remote HEUs 84(1)-84(N) is also a plurality of remote DAS components. The remote HEU 84(1) further comprises a remote-HEU DAS-R1U 86(1) and a remote-HEU DAS-OIU 88(1). The remote-HEU DAS-R1U 86(1) comprises one or more remote-HEU' RiMs 90(I)-90(S), wherein 'S' may represent a different positive integer number among the plurality of local-area analog DASs 32(S)-32(N). The O/E converter 80(1) converts the combined downlink optical RF signal 66(1) into a remote-HEU combined downlink analog RF signal 92(1), which is subsequently received by the one or more remote-HEU RiMs 90(1)-90(S). The one or more remote-HEU RiMs 90(1)-90(S) then generates one or more remote-HEU downlink analog RF signals 94(!)-94(S), wherein each of the one or more remote-HEU downlink analog RF signals 94(1)-94(S) corresponds to a respective RF band (not shown). The one or more remote-HEU downlink analog RF signals 94(1)-94(S) are received by a remote-HEU RF combiner/splitter 96(1) and combined into a second remote-HEU combined downlink analog RF signal 98(1). The second remote-HEU combined downlink analog RF signal 98(1) is received by a remote-HEU optical splitter/combiner 100(1), wherein second remote-HEU combined downlink analog RF signal 98(1) is first split and then recombined to generate one or more third remote-HEU combined downlink analog RF signals 102(1)-102(H). Each of the one or more third remote-HEU combined downlink analog RF signals 102(1)-102(R) corresponds to a RAU among the one or more RAUs 78(1)-78(R) and may comprise one or more RF bands. The remote-HEU DAS-OIU 88(1) comprises one or more remote-HEU OIMs 104(1)-104(R) that correspond to the one or more respective RAUs 78(1)-78(R), respectively. The one or more remote-HEU OIMs 104(1)-104(R) receive and convert the one or more third remote-HEU combined downlink analog RF signals 102(1)-102(R) into one or more remote-HEU combined downlink optical RF signals 106(1)-106(R), respectively. The one or more remote-HEU combined downlink optical RF signals 106(1)-106(R) are then distributed to the one or more respective RAUs 78(J)-78(R).

With continuing reference to FIG. 2, on the uplink direction 68, the one or more remote-HEU OIMs 104(1)-104(R) receive one or more remote-HEU combined uplink optical RF signals 108(1)-108(R) from the one or more remote-HEU OIMs 104(1)-104(R) then convert the one or more remote-
HEU combined uplink optical RF signals 108(1)-108(R) into one or more third remote-HEU combined uplink analog RF signals 110(1)-110(R). Each of the one or more third remote-HEU combined uplink analog RF signals 110(1)-110(R) corresponds to one or more RF bands. The one or more third remote-HEU combined uplink analog RF signals 110(1)-110(R) are received by the remote-HEU optical splitter/combiner 10.0(1), wherein the one or more third remote-HEU combined uplink analog RF signals 110(1)-110(R) are combined into a second remote-HEU combined uplink analog RF signal 112(1). The second remote-HEU combined uplink analog RF signal 112(1) is subsequently received by the remote-HEU RF combiner/splitter 96(1) wherein the second remote-HEU combined uplink analog RF signal 112(1) is split into one or more remote-HEU uplink analog RF signals 114(1)-114(S). Each of the one or more remote-HEU uplink analog RF signals 114(1)-114(S) corresponds to the respective RF band. The one or more remote-HEU uplink analog RF signals -114(1)-114(8) are then combined into a remote-HEU combined uplink analog RF signal 116(1), which is subsequently converted to the combined uplink optical RF signal 70(1) and provided to the OIM 62(1) in the main analog DAS 34.

[0041] As digital communication technologies become increasingly reliable and cost-effective, the wide-area analog DAS 30 may need to be upgraded to distribute digital and/or analog communications signals between the plurality of local-area analog DASs 32(1)-32(N) over digital communications mediums. As a result, the main analog DAS 34 and the plurality of local-area analog DASs 32(1)-32(N) may need to be upgraded for distributing the digital and/or analog communications signals over the digital communications mediums. It may be desirable to retrofit new multi-functional equipment into the chassis of the installed equipment to reduce upgrade costs and minimize sendee disruptions to the wide-area analog DAS 30. In a non-Hmiting example, it is desirable to be able to retrofit the new multi-functional equipment into the chassis of the main HEU 38 and/or the plurality of remote HEUs 84(1)-84(N).

[0042] In this regard, FIG. 3 is a schematic diagram of an exemplary digital-analog interface module (DAIM) 120 that is retrofitted into the chassis of the main HEU 38 in the wide-area analog DAS 30 of FIG. 2 for distributing digital and/or analog communications signals in the wide-area analog DAS 30 over digital communications mediums. In essence, the DAIM 120 is multi-functional device capable of distributing digital and/or analog communications signals to the plurality of local-area analog DASs 32(1)-32(N) in the wide-area analog DAS 30. Elements in FIG. 2 are referenced in connection with FIG. 3 and will
not be re-described herein.

With reference to FIG. 3, the DAIM 120 comprises an analog communications interface (P1) 122 configured to be coupled with an analog signal source 124 for distributing analog communications signals. In a non-limiting example, the analog signal source 124 may be a BTS. The DAIM 120 also comprises a digital bus interface (P2) 126, which further comprises an upstream digital bus interface (P2U) 128 and a downstream digital bus interface (P2D) 130. As will be further discussed in detail below in FIGS. 5A and SB, the upstream digital bus interface 128 and the downstream digital bus interface 130 enables the DAIM 120 to be interconnected with other DAIMs to enable flexible digital signal sharing with the other DAIMs. The DAIM 120 also comprises at least one digital remote distribution interface (P3) 132 configured to be coupled with any remote HEU among the plurality of remote HEUs 84(1)-84(N) (not shown). The DAIM 120 also comprises an analog local distribution interface (P4) 134 for distributing analog RF signals to the RAU 64 (not shown). The DAIM 120 also comprises a digital communications interface (P5) 136 to be coupled to a digital signal source 138 for distributing digital communications signals. In a non-limiting example, the digital signal source 138 maybe a digital baseband unit (BBU).

With continuing reference to FIG. 3, the DAIM 120 further comprises an RF conditioning circuit 140 that is coupled to the analog communications interface 122 and the analog local distribution interface 134. In a downlink direction 142, the RF conditioning circuit 140 receives a downlink analog communications signal 144 from the analog signal source 124 via the analog communications interface 122. The RF conditioning circuit 140 converts the downlink analog communications signal 144 into a downlink analog RF signal 146, which is adapted for redistribution in the wide-area analog DAS 30. The RF conditioning circuit 140 then provides the downlink analog RF signal 146 to the analog local distribution interface 134 for distribution to the RAU 64. In addition, to provide a digitized version of the downlink analog RF signal 146 to be available for distribution, an analog-to-digital (A/D) converter 148 is provided. The A/D converter 148 converts the downlink analog RF signal 146 to generate a downlink digital RF signal ISO and provides the downlink digital RF signal 150 to a digital signal processing circuit 152. Upon receiving the downlink digital RF signal 150, the digital signal processing circuit 152 converts the downlink digital RF signal 150 into one or more first downlink digital RF signals 154 and provides the one or more first downlink digital RF signals 154 to the upstream digital bus interface 128 and the downstream digital bus interface 130.
As will be further discussed in FIGS. 5A and SB, providing the one or more first downlink digital RF signals 154 to the upstream digital bus interface 128 and the downstream digital bus interface 130 allows interconnected DAIMs to receive indirectly the one or more first downlink digital RF signals 154. Since not all of the one or more first downlink digital RF signals 154 are related to the DAIM 120, a digital signal processing controller 156 is configured to determine one or more respective first downlink digital RF signals (not shown), among the one or more first downlink digital RF signals 154, that are related to the DAIM 120. In a non-limiting example, the digital signal processing controller 156 may be provided inside or outside the DAIM 120. In a non-limiting example, the digital signal processing controller 156 is preconfigured to detect the one or more respective first downlink digital RF signals based on frequency-related information, such as channel number in a frequency-division duplex (FDD) signal or time slot number in a time-division duplex (TDD) signal, carried in the one or more first downlink digital RF signals 154. The digital signal processing controller 156 is communicatively coupled to the digital signal processing circuit 152 or embedded in the digital signal processing circuit 152. In this regard, the digital signal processing circuit 152 can combine the one or more respective first downlink digital RF signals to generate a combined downlink digital RF signal 158. Subsequently, the digital signal processing circuit 152 provides the combined downlink digital RF signal 158 to the digital remote distribution interface 132 for distribution to any remote HEU among the plurality of remote HEUs 84(1)-84(N).

With continuing reference to FIG. 3, the digital signal processing circuit 152 may receive one or more second downlink digital RF signals 160 from the upstream digital bus interface 128 and one or more third downlink digital RF signals 162 from the downstream digital bus interface 130. As will be further illustrated in FIGS. 5A and SB, the one or more second downlink digital RF signals 160 and the one or more third downlink digital RF signals 162 are provided to the digital signal processing circuit 152 by other interconnected DAIMs. The digital signal processing circuit 152 in turn forwards the one or more second downlink digital RF signals 160 to the downstream digital bus interface 130 and forward the one or more third downlink digital RF signals 162 to the upstream digital bus interface 128. As previously discussed with regard to the one or more first downlink digital RF signals 154, the one or more second downlink digital RF signals 160 and the one or more third downlink digital RF signals 162 received from the digital bus interface 126 may not be related to the DAIM 120 as well. As such, the digital signal processing controller 156 is also configured to
determine one or more respective second downlink digital RF signals (not shown) among the one or more second downlink digital RF signals 160 and one or more respective third downlink digital RF signals (not shown) among the one or more third downlink digital RF signals 162. In this regard, the digital signal processing circuit 152 can combine the one or more respective second downlink digital RF signals and the one or more respective third downlink digital RF signals into the combined downlink digital RF signal 158.

With continuing reference to FIG. 3, the digital signal processing circuit 152 may also receive a downlink digital baseband signal 164 from the digital signal source 138 that is coupled to the digital communications interface 136. In a non-limiting example, the downlink digital baseband signal 164 may be received from a BBU and is in compliance with a common public radio interface (CPRI) format. The digital signal processing circuit 152 is configured to convert the downlink digital baseband signal 164 to generate one or more fourth downlink digital RF signals 166. Accordingly, the digital signal processing circuit 152 provides the one or more fourth downlink digital RF signals 166 to the upstream digital bus interface 128 and the downstream digital bus interface 130. The digital signal processing controller 156, in turn, determines one or more respective fourth downlink digital RF signals (not shown) among the one or more fourth downlink digital RF signals 166 for combining with the combined downlink digital RF signal 158 by the digital signal processing circuit 152.

With continuing reference to FIG. 3, in an uplink direction 168, the digital signal processing circuit 152 receives a combined uplink digital RF signal 170 from any remote HEU among the plurality of remote HEUs 84(1)-84(N) (not shown) via the digital remote distribution interface 132. The digital signal processing circuit 152 splits the combined uplink digital RF signal 170 to generate one or more first uplink digital RF signals 172. The digital signal processing circuit 152 in turn provides the one or more first uplink digital RF signals 172 to the upstream digital bus interface 128 and the downstream digital bus interface 130. As previously discussed, the one or more first uplink digital RF signals 170 may or may not be related to the DAIM 120. As such, the digital signal processing controller 156 is also configured determine one or more respective first uplink digital RF signals (not shown) among the one or more first uplink digital RF signals 170. As a result, the digital signal processing circuit 152 can combine the one or more respective first uplink digital RF signals to generate an uplink digital RF signal 174.

With continuing reference to FIG. 3, the digital signal processing circuit 152 may
receive one or more second uplink digital RF signals 176 from the upstream digital bus 128. The digital signal processing circuit 152 may also receive one or more third uplink digital RF signals 178 from the downstream digital bus 130. The digital signal processing circuit 152 in turn forwards the one or more second uplink digital RF signals 176 to the downstream digital bus interface 130 and forwards the one or more third uplink digital RF signals 178 to the upstream digital bus interface 128. The digital signal processing controller 156 is configured to determine one or more respective second uplink digital RF signals (not shown) among the one or more second uplink digital RF signals 176 and one or more respective third uplink digital RF signals (not shown) among the one or more third uplink digital RF signals 178. In this regard, the digital signal processing circuit 152 can combine the one or more respective second uplink digital RF signals and the one or more respective third uplink digital RF signals into the uplink digital RF signal 174.

With continuing reference to FIG. 3, the digital signal processing circuit 152 may also receive an uplink digital baseband signal 180 from the digital signal source 138 that is coupled to the digital communications interface 136. In a non-limiting example, the uplink digital baseband signal 180 may be received from a BBU and is in compliance with the CPR format. The digital signal processing circuit 152 is configured to convert the uplink digital baseband signal 180 to generate one or more fourth uplink digital RF signals 182. Accordingly, the digital signal processing circuit 152 provides the one or more fourth uplink digital RF signals 182 to the upstream digital bus interface 128 and the downstream digital bus interface 130. The digital signal processing controller 156, in turn, determines one or more respective fourth downlink digital RF signals (not shown) among the one or more fourth downlink digital RF signals 182 for combining with the uplink digital RF signal 174 by the digital signal processing circuit 152.

With continuing reference to FIG. 3, the D/A converter 184 that is coupled to the digital signal processing circuit 152 and the RF conditioning circuit 140. The D/A converter 184 receives and converts the uplink digital RF signal 174 to generate an uplink analog RF signal 186 and provides the uplink analog RF signal 186 to the RF conditioning circuit 140. Upon receiving the uplink analog RF signal 186, the RF conditioning circuit 140 provides the uplink analog RF signal 186 to the analog local distribution interface 134 for distribution to the RAU 64 (not shown). In another aspect, the RF conditioning circuit 140 converts the uplink analog RF signal 186 into an uplink analog communications signal 188, which is adapted for communications to the
analog signal source 124. Subsequently, the RF conditioning circuit 140 provides the uplink analog communications signal 188 to the analog communications interface 122 for distribution to the analog signal source 124.

[0052] The DAIM 120 in FIG. 3 is designed and configured to be retrofitted into the chassis of the main HEU 38 of the main analog DAS 34 in the wide-area analog DAS 30 for distributing the analog and/or digital communications signals in the wide-area analog DAS 30. Although it is also possible to retrofit the DAIM 120 into the chassis of the plurality of remote HEUs 84(1)-84(N) for supporting the local-area analog DASs 32(1)-32(N), the RF conditioning circuit 140 and the analog communications interface 122 in the DAIM 120 would not be utilized if the plurality of remote HEUs 84(1)-84(N) are not directly interacting with the one or more BTSs 36(1)-36(M). In this regard, FIG. 4 is a schematic diagram of an exemplary digital interface module (DIM) 189 that provides similar functionality to the DAIM 120 in FIG. 3. However, in the DIM 189 in FIG. 4, the analog communications interface 122 and the RF conditioning circuit 140 of the DIM 120 are not included. As a result, the A/D converter 148 and the D/A converter 184 of the DIM 120 are directly coupled to the analog local distribution interface 134 in the DIM 189 for receiving the downlink analog RF signal 146 and providing the uplink analog RF signal 186, respectively. Like the DAIM 120 in FIG. 3, the DIM 189 in FIG. 4 can be configured to be retrofitted into the chassis of the plurality of remote HEUs 84(1)-84(N) as well as the main HEU 38 in the wide-area analog DAS 30 of FIG. 2 for distributing digital and/or analog communications signals in the wide-area analog DAS 30 over digital communications mediums. Common elements between FIGS. 3 and 4 are shown therein with common element numbers, thus will not be re-described herein.

[0053] In this regard, with reference to FIG. 4, the A/D converter 148 in the DIM 189 receives the downlink analog RF signal 146 from the analog local distribution interface 134 and converts the downlink analog RF signal 146 into the downlink digital RF signal 150. The D/A converter 184 converts the uplink digital RF signal 174 into the uplink analog RF signal 186 and provides the uplink analog RF signal 186 to the analog local distribution interface 134. In a non-limiting example, the digital signal processing controller 156 may be provided inside or outside the DIM 189.

[0054] As previously discussed in reference to FIG. 3, the upstream digital bus interface 128 and the downstream digital bus interface 130 enables the DAIM 120 to be interconnected with other DAIMs to support a flexible topology of the wide-area analog DAS 30. In this
regard, FIG. 5A is a schematic diagram of an exemplary main HEU 190 comprising a plurality of DAIMs 192(1)-192(3) that are interconnected to an interconnection digital bus 193 via a plurality of digital bus interfaces 194(1)-194(3) and configured to share a plurality of downlink communications signals 196(1)-196(3). The main HEU 190 may comprise any positive integer number of DAIMs 192. The plurality of DAIMs ;192(1)-192(3) are provided as a non-limiting example and for the convenience of discussion.

[0055] With reference to FIG. 5A, the DAIM 192(1) has a logically configured downstream DAIM 192(2), but has no logically configured upstream DAIM since the DAIM 192(1) is the first DAIM among the plurality of DAIMs 192(1)-192(3). The DAIM 192(2) has a logically configured upstream DAIM 192(1) and a logically configured downstream DAIM 192(3). The DAIM 192(3) has a logically configured upstream DAIM 192(2), but has no logically configured downstream DAIM since the DAIM 192(3) is the last DAIM among the plurality of DAIMs 192(1)-192(3). The plurality of DAIMs 192(1)-192(3) have a plurality of upstream digital bus interfaces 198(1)-198(3) and a plurality of downstream digital bus interfaces 200(1)-200(3), respectively. To provide the interconnections between the plurality of DAIMs 192(1)-!92(3), a downstream digital bus interface of a logically configured upstream DAIM is coupled to an upstream digital bus interface of a logically configured downstream DAIM. Hence, in the non-limiting example provided herein, the DAIM 192(1) is logically configured as an upstream DAIM to the DAIM 192(2). As such, a downstream digital bus interface 200(1) in the DAIM 192(1) is coupled to an upstream digital bus interface 198(2) in the DAIM 192(2). The DAIM 192(3) is logically configured as a downstream DAIM to the DAIM 192(3). As such, a downstream digital bus interface 200(2) in the DAIM 192(2) is coupled to an upstream digital bus interface 198(3) in the DAIM 192(3).

[0056] With continuing reference to FIG. 5A, the DAIM 192(1) receives a downlink communications signal 196(1) via an analog communications interface 202(1). The DAIM 192(1) converts the downlink communications signal 196(1) into downlink digital RF signals 196(1)(1), 196(1)(2) and provides the downlink digital RF signals 196(1)(1), 196(1)(2) to the interconnection digital bus 193 via the downstream digital bus interface 200(1). The DAIM 192(2) receives the downlink communications signal 196(2) via a digital communications interface 204(2). The DAIM 192(2) converts the downlink communications signal 196(2) into downlink digital RF signal 196(2)(1) and provides the downlink digital RF signal 196(2)(1) to the interconnection digital bus 193 via the upstream digital bus interface 198(2)
and the downstream digital bus interface 200(2). The DAIM 192(3) receives the downlink communications signal 196(3) via an analog/communications interface 202(3). The DAIM 192(3) converts the downlink communications signal 196(3) into downlink digital RF signals 196(3)(0), 196(3)(2) and provides the downlink digital RF signals 196(3)(0), 196(3)(2) to the interconnection digital bus 193 via the upstream digital bus interface 198(3). As a result, the downlink digital RF signals 196(1)(0), 196(1)(2), 196(2)(1), 196(3)(0), 196(3)(2) are made available to the DAIMs 192(1)-192(3) through the interconnection digital bus 193 in the main HEU 190. As previously discussed in FIG. 3, a respective digital signal processing controller (not shown) in each of the DAIMs 192(1)-192(3) can programmably determine which downlink digital RF signal(s) among the downlink digital RF signals 196(1)(0), 196(1)(2), 196(2)(1), 196(3)(0), 196(3)(2) is related to the respective DAIM and included in a plurality of combined downlink digital RF signals 206(1)-206(3), respectively.

FIG. SB is a schematic diagram of an exemplary main HEU 190(1) comprising the plurality of DAIMs 192(1)-192(3) in FIG. 5A that are interconnected to the interconnection digital bus 193 via the plurality of digital bus interfaces 194(1)-194(3) in FIG. 5A and configured to share a plurality of combined uplink communications signals 2080(0)-208(3). Common elements between FIGS. 5A and SB are shown therein with common element numbers, thus will not be re-described herein.

With reference to FIG. SB, the DAIM 192(1) receives the combined uplink communications signal 208(1) via at least one digital remote distribution interface 210(1). The DAIM 192(1) converts the combined uplink communications signal 208(1) into uplink digital RF signals 208(1)(1), 208(1)(2) and provides the uplink digital RF signals 208(1)(0), 208(1)(2) to the interconnection digital bus 193 via the downstream digital bus interface 200(1). The DAIM 192(2) receives the combined uplink communications signal 208(2) via at least one digital remote distribution interface 210(2). The DAIM 192(2) converts the combined uplink communications signal 208(2) into uplink digital RF signal 208(2)(0) and provides the uplink digital RF signal 208(2)(0) to the interconnection digital bus 193 via the upstream digital bus interface 198(2) and the downstream digital bus interface 200(2). The DAIM 192(3) receives the combined uplink communications signal 208(3) via at least one digital remote distribution interface 210(3). The DAIM 192(3) converts the combined uplink communications signal 208(3) into uplink digital RF signals 208(3)(0), 208(3)(2) and provides the uplink digital RF signals 208(3)(0), 208(3)(2) to the interconnection digital bus 193 via the upstream digital bus interface 198(3). As a result, the uplink digital RF signals
208(1)(1), 208(1)(2), 208(2)(1), 208(3)(0), 208(3X2) are made available to the plurality of DAIMs 192(1)-192(3) through the interconnection digital bus 193 in the main HEU 190(1). As previously discussed in FIG. SA, the respective digital signal processing controller (not shown) in each of the DAIMs 192(1)-192(3) can programmably determine which uplink digital RF signal(s) among the uplink digital RF signals 208(1)(1), 208(1)(2), 208(2)(1), 208(3)(0), 208(3)(2) is related to the respective DAIM and included in a plurality of combined uplink communications signals 212(1)-212(3), respectively.

As previously discussed in FIGS. 3 and 4 above, the DAIM 120 and the DIM 189 are designed to retrofit into the chassis of the main HEU 38 and the plurality of remote HEUs 84(1)-84(N) in the wide-area analog DAS 30 of FIG. 2 for distributing the analog and/or digital communications signals in the wide-area in the wide-area analog DAS 30. By reconfiguring the main HEU 38 and the plurality of remote HEUs 84(1)-84(N) with the DAIM 120 and/or the DIM 189, it is possible to flexibly reconfigure the wide-area analog DAS 30 to distribute digital and/or analog communications signals over digital communications mediums.

In this regard, FIG. 6 is a schematic diagram of an exemplary optical fiber-based wide-area DAS 220 configured to distribute digital and analog communications signals from a main HEU 222 to one or more remote HEUs 224(1)-224(N) over optical fiber-based digital communications mediums 226(1)-226(N). The main HEU 222 is reconfigured by retrofitting one or more of the DAIMs 120 illustrated FIG. 3 into the existing chassis of the main HEU 38 in FIG. 2. Elements in FIG. 2 are referenced in connection with FIG. 6 and will not be re-described herein. Common elements between FIGS. 3, 4, and 6 are shown therein with common element numbers, thus will not be re-described herein.

With reference to FIG. 6, the optical fiber-based wide-area DAS 220 comprises a main DAS 228 that comprises the main HEU 222. The optical fiber-based wide-area DAS 220 further comprises one or more remote DASs 230(1)-230(N) that comprise the one or more remote HEUs 224(1)-224(N), respectively. The main HEU 222 comprises one or more DAIMs 232(1)-232(N), wherein each of the one or more DAIMs 232(1)-232(N) is same as the DAIM 120. The one or more DAIMs 232(1)-232(N) are configured to distribute digital and analog communications signals to the one or more remote HEUs 224(1)-224(N) over the optical fiber-based digital communications mediums 226(1)-226(N), respectively. The optical fiber-based digital communications mediums 226(1)-226(N) comprise optical fiber-based downlink digital communications mediums 234(1)-234(N) and optical fiber-based
uplink digital communications mediums 236(1)-236(N), respectively. Hence, the one or more DAIMs 232(1)-232(N) are configured to distribute digital and analog communications signals to the one or more remote HEUs 224(1)-224(N) over the optical fiber-based downlink digital communications mediums 234(1)-234(N) and the optical fiber-based uplink digital communications mediums 236(1)-236(N), respectively. Further, the one or more DAIMs 232(1)-232(N) are coupled to one or more BTSs 238(1)-238(N) and to one or more BBUs 240(1)-240(N), respectively. In addition, the one or more DAIMs 232(1)-232(N) may also be coupled to one or more RAUs 242(1)-242(N), respectively. For the convenience of discussion, the DAIM 232(1) in the main HEU 222 and the remote HEU 224(1) are described hereinafter as a non-limiting example. Nonetheless, the configuration and operating principles for distributing digital and analog communications signals in the optical fiber-based wide-area DAS 220 are applicable to any of the one or more DAIMs 232(1)-232(N) and any of the one or more remote HEUs 224(1)-224(TV).

[0062] With continuing reference to FIG. 6, like the DAIM 120, the DAIM 232(1) comprises the analog communications interface 122, the upstream digital bus interface 128, the downstream digital bus interface 130, the at least one digital remote distribution interface 132, the analog local distribution interface 134, and the digital communications interface 136. In a non-limiting example, the analog communications interface 122 and the digital communications interface 136 are coupled to the BTS 238(1) and the BBU 240(1), respectively. The analog local distribution interface 134 may be coupled with the RAU 242(1). The digital remote distribution interface 132 is coupled to the respective optical fiber-based downlink digital communications medium 234(1) via a respective E/Q converter 244(1) and is coupled to the respective optical fiber-based uplink digital communications medium 236(1) via a respective O/E converter 246(1). The upstream digital bus interface 128 is coupled to a downstream digital bus interface (a second downstream digital bus interface) (not shown) in a second DAIM (not shown) among the one or more DAIMs 232(1)-232(N) that is logically configured as an upstream: DAIM to the DAIM 232(1). The downstream digital bus interface 130 is coupled to an upstream digital bus interface (a third upstream digital bus interface) (not shown) in a third DAIM among the one or more DAIMs 232(1)-232(N) that is logically configured as a downstream DAIM to the DAIM 232(1). The DAIM 232(1) generates a combined downlink digital RF signal 248(1), which is subsequently converted into a combined downlink optical RF signal 250(1) and distributed to the remote HEU 224(1) over the optical fiber-based downlink digital communications
With continuing reference to FIG. 6, the remote HEU 224(1) comprises one or more remote-HEU DIMs 252(i)(l)-252(i)(M) corresponding to one or more RF bands (not shown), respectively. Each of the one or more remote-HEU DIMs 252(i)(l)-252(i)(M) is the same as the DIM 189. In this regard, each of the one or more remote-HEU DIMs 252(1)(1)-252(1)(M) comprises the upstream digital bus interface (remote-DIM upstream digital bus interface) 128, the downstream digital bus interface (remote-DIM downstream digital bus interface) 130, the at least one digital remote distribution interface (at least one remote-DIM digital remote distribution interface) 132, the analog local distribution interface (remote-DIM analog local distribution interface) 134, and the digital communications interface (remote-DIM digital communications interface) 136. At least one remote-HEU DIM among the one or more remote-HEU DIMs 252(1)(1)-252(1)(M) in the remote HEU 224(1) is configured to interface with the DAIM 232(1) in the main HEU 222. For the convenience of discussion, the remote-HEU DIM 252(1)(M) is referenced herein as the at least one remote-HEU DIM configured to interface with the DAIM 232(1) in the main HEU 222 in a non-limiting example.

With continuing reference to FIG. 6, the remote-DIM digital remote distribution interface 132 in the remote-HEU DIM 252(1)(M) is coupled to the optical fiber-based downlink digital communications medium 234(1) via a remote-HEU O/E converter 254(1) and to the optical fiber-based uplink digital communications medium 236(1) via a remote-HEU E/O converter 256(1). The remote-HEU O/E converter 254(1) receives and converts the combined downlink optical RF signal 250(1) back to the combined downlink digital RF signal 248(1). The remote-HEU DIM 252(1)(M) receives the combined downlink digital RF signal 248(1) from the remote-DIM digital remote distribution interface 132 in the remote-HEU DIM 252(1)(M). Subsequently, remote-HEU DIM 252(1)(M) converts the combined downlink digital RF signal 248(1) into one or more first remote-DIM downlink digital RF signals 258 that correspond to the one or more RF bands. The remote-HEU DIM 252(1)(M) then provides the one or more first remote-DIM downlink digital RF signals 258 to the remote-DIM upstream digital bus interface 128 and the remote-DIM downstream digital bus interface 130. The remote-HEU DIM 252(1)(M) may receive one or more second remote-DIM downlink digital RF signals 260 corresponding to the one or more RF bands from the remote-DIM upstream digital bus interface 128. The remote-HEU DIM 252(1)(M) may also receive one or more third remote-DIM downlink digital RF signals 262 corresponding to the
one or more RF bands from the remote-DIM downstream digital bus interface 130. The remote-HEU DIM 252(1)(M) is configured to provide the one or more second remote-DIM downlink digital RF signals 260 to the remote-DIM downstream digital bus interface 130. The remote-HEU DIM 252(1)(M) is also configured to provide the one or more third remote-DIM downlink digital RF signals 262 to the remote-DIM upstream digital bus interface 128. The remote-HEU DIM 252(1)(M) may also receive a remote-DAS downlink digital baseband signal 264(M) from a remote-DAS digital signal source 266(1)(M). In a non-limiting example, the remote-DAS digital signal source 266(1)(M) is a BBU. The remote-HEU DIM 252(1)(M) converts the remote-DAS downlink digital baseband signal 264(M) to generate one or more fourth remote-DIM downlink digital RF signals 268 corresponding to the one or more RF bands. The remote-HEU DIM 252(1)(M) provides the one or more fourth remote-DIM downlink digital RF signals 268 to the remote-DIM upstream digital bus interface 128 and the remote-DIM downstream digital bus interface 130.

With continuing reference to FIG. 6, the remote-HEU DIM 252(i)(M) is further configured to combine one or more remote-DIM downlink digital signals (not shown) to generate a remote-DIM combined downlink digital RF signal (not shown), which is then converted into a remote-DIM combined downlink analog RF signal 270(M) by a remote-DIM D/A converter (not shown) in the remote-HEU DIM 252(J)(M). The remote-DIM combined downlink digital RF signal and the remote-DIM combined downlink analog RF signal 270(M) correspond to an RF band associated with the remote-HEU DIM 252(1)(M) among the one or more RF bands supported by the remote HEU 224(1). The remote-DIM combined downlink analog RF signal 270(M) is provided to the remote-DIM analog local distribution interface 134. The one or more remote-DIM downlink digital signals are programmably determined by a remote-DIM digital signal processing controller (not shown) in the remote-HEU DIM 252(1)(M).

With continuing reference to FIG. 6, a remote-HEU RF combiner/splitter 272(1) in the remote HEU 224(1) converts and combines one or more remote-DIM combined downlink analog RF signals 270(1)-270(M) to generate a remote-HEU combined downlink analog RF signal 274(1). An remote-HEU optical splitter/combiner 276(1) then splits the remote-HEU combined downlink analog RF signal 274(1) to generate one or more remote-OIM downlink analog RF signals 278(1)-278(P), which are subsequently received by one or more remote-HEU OIMs 280(1)(1)-280(J)(P). The one or more remote-HEU OIMs 280(1)(1)-280(J)(P) then convert the one or more remote-OIM downlink analog RF signals
278(1)-278 (P) into one or more remote-OIM downlink optical RF signals 282(1)-282(P) and provide to the one or more remote-DAS RAUs 284(1)(1)-284(1)(P), respectively.

[0067] With continuing reference to FIG. 6, the one or more remote-HEU OIMs 280(1)(1)-280(1)(P) receive one or more remote-OIM uplink optical RF signals 286(1)-286(P). The one or more remote-HEU OIMs 280(1)(1)-280(1)(P) then convert the one or more remote-OIM: uplink optical RF signals 286(1)-286(P) into one or more remote-OIM uplink analog RF signals 288(1)-288(P). The remote-HEU optical splitter/combiner 276(1) combines the one or more remote-OIM uplink analog RF signals 288(1)-288(P) to generate a remote-HEU combined uplink analog RF signal 290(1). The remote-HEU RF combiner/splitter 272(1) then splits the remote-HEU combined uplink analog RF signal 290(1) into one or more remote-DIM combined uplink analog RF signals 292(1)-292(M) corresponding to the one or more RF bands, respectively. The one or more remote-DIM combined uplink analog RF signals 292(1)-292(M) are received by the one or more remote-HEU DIMs 252(1)(1)-252(1)(M), respectively. The remote-HEU DIM 252(1)(M) receives the remote-DIM combined uplink analog RF signal 292(M) among the one or more remote-DIM combined uplink analog RF signals 292(1)-292(M). A remote-DIM A/D converter (not shown) inside the remote-HEU DIM 252(1)(M) receives the remote-DIM combined uplink analog RF signal 292(M) from the remote-DIM analog local distribution interface 134 and converts the remote-DIM combined uplink analog RF signal 292(M) into a remote-DIM combined uplink digital RF signal (not shown). The digital signal processing circuit 152 (not shown) in the remote-HEU DIM 252(1)(M) (the remote-DIM digital signal processing circuit) splits the remote-DIM combined uplink digital RF signal into one or more first remote-DIM uplink digital RF signals 294 and provides the one or more first remote-DIM uplink digital RF signals 294 to the remote-DIM upstream digital bus interface 128 and the remote-DIM downstream digital bus interface 130.

[0068] With continuing reference to FIG. 6, the remote-HEU DIM 252(1)(M) may receive one or more second remote-DIM uplink digital RF signals 296 and one or more third remote-DIM uplink digital RF signals 298 from the remote-DIM upstream digital bus interface 128 and the remote-DIM downstream digital bus interface 130, respectively. The remote-HEU DIM 252(1)(M) is configured to provide the one or more second remote-DIM uplink digital RF signals 296 to the remote-DIM downstream digital bus interface 130. The remote-HEU DIM 252(1)(M) is also configured to provide the one or more third remote-DIM uplink digital RF signals 298 to the remote-DIM upstream digital bus interface 128. The
remote-HEU DIM 252(1)(M) may also receive a remote-DAS uplink digital baseband signal 300(M) from the remote-DIM digital communications interface 136 that is coupled to the remote-DAS digital signal source 266(1)(M). The remote-HEU DIM 252(1)(M) converts the remote-DAS uplink digital baseband signal 300(M) to generate one or more fourth remote-DIM uplink digital RF signals 302. The remote-HEU DIM 252(1)(M) provides the one or more fourth remote-DIM uplink digital RF signals 302 to the remote-DIM upstream digital bus interface 128 and the remote-DIM downstream digital bus interface 130.

With continuing reference to Fig. 6, the remote-HEU DIM 252(1)(M) combines one or more remote-DIM uplink digital RF signals (not shown) to generate a combined uplink digital RF signal 304(1). The one or more remote-DIM uplink digital RF signals are programmably determined by the remote-DIM digital signal processing controller 156 (not shown) from the one or more first remote-DIM uplink digital RF signals, the one or more second remote-DIM uplink digital signals, the one or more third remote-DIM uplink digital signals, and the one or more fourth remote-DIM uplink digital signals. The combined uplink digital RF signal 304(1) is subsequently converted into a combined uplink optical RF signal 306(1) by the remote-HEU E/O converter 256(1) and distributed to the respective O/E converter 246(1) via the respective optical fiber-based uplink digital communications medium 236(1). The respective O/E converter 246(1) converts the combined uplink optical RF signal 306(1) back to the combined uplink digital RF signal 304(1) and provides to the at least one digital remote distribution interface 132 in the DAIM 232(1).

FIG. 7 is a flowchart of an exemplary HEU configuration process 310 for reconfiguring the main HEU 38 in FIG. 2 with the one or more DAIMs 231(1)-232(N) in FIG. 6. Elements in FIGS. 2, 3, and 6 are referenced in connection to FIG. 7 and will not be re-described herein.

According to the HEU configuration process 310, the one or more main-HEU RIMs 44(1)-44(M) in the main HEU 38 are replaced with the one or more DAIMs 232(1)-232(N) (block 312). Next, the HEU configuration process 310 configures each of the one or more DAIMs 232(1)-232(N) (block 314). For a DAIM among the one or more DAIMs 232(1)-232(N), an analog communications interface (122) is coupled to a respective BTS among the one or more BTSs 238(1)-238(N) (block 316). Next, a digital communications interface 136 in the DAIM is coupled to a respective BBU among the one or more BBUs 240(1)-240(N) (block 318). Subsequently, at least one digital remote distribution interface 132 in the DAIM is coupled to a respective optical fiber-based downlink digital
communications medium 234 and a respective optical fiber-based uplink digital communications medium 236 (block 320). Then, an analog local distribution interface 134 in the DAIM is coupled to a respective RAU among the one or more RAUs 242(1)-242(N) (block 322). To enable interconnections between the one or more DAIMs 232(i)-232(N), a logical upstream DAIM and a logical downstream DAIM are identified for each of the one or more DAIMs 232(J)-232(N). Subsequently for each of the DAIM among the one or more DAIMs 232(1)-232(N), the upstream digital bus interface 128 of the DAIM is coupled to a downstream digital bus 130 of the logical upstream DAIM. Also, the downstream digital bus interface 130 of the DAIM is coupled to an upstream digital bus interface 128 of the logical downstream DAIM.

(0072) Alternative to retrofitting the one or more DAIMs 120 of FIG. 3 into the existing chassis of the main HEU 38 in FIG. 2, it is also possible to retrofit one or more DIMs 189 of FIG. 4 into the existing chassis of the main-HEU DAS-OIU 42 in FIG. 2 for distributing digital and analog communications signals over optical fiber-based digital communications mediums. In this regard, FIG. 8 is a schematic diagram of an exemplary optical fiber-based wide-area DAS 220(1) configured to distribute digital and analog communications signals from a main HEU 222(1) to the one or more remote HEUs 224(1)-224(N) in FIG. 6 over the optical fiber-based digital communications mediums 226(1)-226(N) in FIG. 6, wherein the main HEU 222(1) is reconfigured by retrofitting one or more of the DIMs 189 illustrated in FIG. 4 into the existing chassis of the main HEU 38 in FIG. 2. Common elements between FIGS. 2, 4, 6, and 8 are shown therein with common element numbers, thus will not be re-described herein.

10073] With reference to FIG. 8, the optical fiber-based wide-area DAS 220(1) comprises a main DAS 228(1) that comprises the main HEU 222(1). The optical fiber-based wide-area DAS 220(1) further comprises the one or more remote DASs 230(1)-230(N) that comprise the one or more remote HEUs 224(1)-224(N), respectively. In the main HEU 222(1), one or more DIMs (main-HEU DIMs) 330(1)-330(N) are retrofit into the chassis of a main-HEU DAS-OIU 42(1). The one or more DIMs 330(1)-330(N) are configured to distribute digital and analog communications signals to the one or more remote HEUs 224(1)-224(N) over the optical fiber-based digital communications mediums 226(1)-226(N), respectively. The optical fiber-based digital communications mediums 226(1)-226(N) comprise the optical fiber-based downlink digital communications mediums -234(1)-234(N) and the optical fiber-based uplink digital communications mediums 236(1)-236(N).
respectively. Hence, the one or more main-HEU DIMs 330(1)-330(M) are configured to distribute digital and analog communications signals to the one or more remote HEUs 224(1)-224(N) over the optical fiber-based downlink digital communications mediums 234(1)-234(N) and the optical fiber-based uplink digital communications mediums 236(1)-236(N), respectively. For the convenience of discussion, the main-HEU DIM 330(1) in the main HEU 222(1) and the remote HEU 224(1) are described hereinafter as a non-limiting example. Nonetheless, the configuration and operating principles for distributing digital and analog communications signals in the optical fiber-based wide-area DAS 220(1) are applicable to any of the one or more main-HEU DIMs 330(1)-330(N) and any of the one or more remote HEUs 224(1)-224(N).

[0074] With continuing reference to FIG. 8, the main-HEU DIM 330(1) among the one or more main-HEU DIMs 330(1)-330(N) receives the second downlink analog RF signal 60(1) among the plurality of second downlink analog RF signals 60(1)-60(N) from the optical splitter/combiner 58. The second downlink analog RF signal (downlink analog RF signal) 60(1) is received by the main-HEU DIM 330(1) via the analog local distribution interface 134. The A/D converter 148 (not shown) in the main-HEU DIM 330(1) converts the second downlink analog RF signal 60(1) to generate a downlink digital RF signal 150 (not shown). The digital signal processing circuit 152 (not shown) in the main-HEU DIM 330(1) receives and converts the downlink digital RF signal 150 to generate one or more first downlink digital RF signals 332. The main-HEU DIM 330(1) then provides the one or more first downlink digital RF signals 332 to the upstream digital bus interface 128 and the downstream digital bus interface 130 for sharing the one or more first downlink digital RF signals 332 with the rest of main-HEU DIMs 330(1)-330(N) in the main HEU 222(1). The digital signal processing circuit 152 in the main-HEU DIM 330(1) may also receive one or more second downlink digital RF signals 334 from the upstream digital bus interface 128 and one or more third downlink digital RF signals 336 from the downstream digital bus interface 130. In turn, the digital signal processing circuit 152 in the main-HEU DIM 330(1) provides the one or more second downlink digital RF signals 334 to the downstream digital bus interface 130 and provides the one or more third downlink digital RF signals 336 to the upstream digital bus interface 128. The one or more main-HEU DIMs 330(1)-330(N) may be coupled to one or more BBUs 340(1)-340(N), respectively. In this regard, the digital signal processing circuit 152 in the main-HEU DIM 330(1) may also receive a downlink digital baseband signal 338 from the digital communications interface 136, which is coupled to the BBU 340(1).
non-limiting example, the downlink digital baseband signal 338 is in conformance with the CPRI format. The digital signal processing circuit 152 in the main-HEU DIM 330(1) converts the downlink digital baseband signal 338 to generate one or more fourth downlink digital RF signals 342. Again, the digital signal processing circuit 152 in the main-HEU DIM 330(1) provides the one or more fourth downlink digital RF signals 342 to the upstream digital bus interface 128 and the downstream digital bus interface 130.

[0075] With continuing reference to FIG. 8, the digital signal processing circuit 152 in the main-HEU DIM 330(1) combines one or more respective first downlink digital RF signals (not shown), one or more respective second downlink digital RF signals (not shown), one or more respective third downlink digital RF signals (not shown), and one or more respective fourth downlink digital RF signals (not shown) into the combined downlink digital RF signal 248(1). The one or more respective first downlink digital RF signals are programmably determined by the digital signal processing controller 156 (not shown) among the one or more first downlink digital RF signals 332. The one or more respective second downlink digital RF signals are programmably determined by the digital signal processing controller 156 among the one or more second downlink digital RF signals 334. The one or more respective third downlink digital RF signals are programmably determined by the digital signal processing controller 156 among the one or more third downlink digital RF signals 336. The one or more respective fourth downlink digital RF signals are programmably determined by the digital signal processing controller 156 among the one or more fourth downlink digital RF signals 342. The combined downlink digital RF signal 248(1) is then provided to the respective E/O converter 244(1) for distribution to the remote HEU 224(1). The signal processing performed by the remote HEU 224(1) has been described previously in reference to FIG. 6 and will not be re-described herein.

[0076] With continuing reference to FIG. 8, the digital signal processing circuit 152 in the main-HEU DIM 330(1) receives the combined uplink digital RF signal 304(1) from the remote HEU 224(1) via the respective 0/1: converter 246(1) that is coupled to the at least one digital remote distribution interface 136. The digital signal processing circuit 152 in the main-HEU DIM 330(1) splits the combined uplink digital RF signal 304(1) to generate one or more first uplink digital RF signals 344. The main-HEU DIM 330(1) then provides the one or more first uplink digital RF signals 344 to the upstream digital bus interface 128 and the downstream digital bus interface 130 for sharing the one or more first uplink digital RF signals 344 with the rest of main-HEU DIMs 330(1)-330(N) in the main HEU 222(1). The
digital signal processing circuit 152 in the main-HEU DIM 330(1) may also receive one or more second uplink digital RF signals 346 from the upstream digital bus interface 128 and one or more third uplink digital RF signals 348 from the downstream digital bus interface 130. In turn, the digital signal processing circuit 152 in the main-HEU DIM 330(1) provides the one or more second uplink digital RF signals 346 to the downstream digital bus interface 130 and provides the one or more third uplink digital RF signals 348 to the upstream digital bus interface 128. The digital signal processing circuit 152 in the main-HEU DIM 330(1) may also receive an uplink digital baseband signal 350 from the digital communications interface 136, which is coupled to the BBU 340(1). In a non-limiting example, the uplink digital baseband signal 350 is in conformance with the CPRI format. The digital signal processing circuit 152 in the main-HEU DIM 330(1) converts the uplink digital baseband signal 350 to generate one or more fourth uplink digital RF signals 352. Again, the digital signal processing circuit 152 in the main-HEU DIM 330(1) provides the one or more fourth uplink digital RF signals 352 to the upstream digital bus interface 128 and the downstream digital bus interface 130.

With continuing reference to FIG. 8, the digital signal processing circuit 152 in the main-HEU DIM 330(1) combines one or more respective first uplink digital RF signals (not shown), one or more respective second uplink digital RF signals (not shown), one or more respective third uplink digital RF signals (not shown), and one or more respective fourth uplink digital RF signals (not shown) into the second uplink digital RF signal (the uplink digital RF signal) 72(1). The one or more respective first uplink digital RF signals are progTammably determined by the digital signal processing controller 156 among the one or more first uplink digital RF signals 344. The one or more respective second uplink digital RF signals are programmable determined by the digital signal processing controller 156 among the one or more second uplink digital RF signals 346. The one or more respective third uplink digital RF signals are programmably determined by the digital signal processing controller 156 among the one or more third uplink digital RF signals 348. The one or more respective fourth uplink digital RF signals are programmably determined by the digital signal processing controller 156 among the one or more fourth uplink digital RF signals 352. The second uplink digital RF signal 74 is then provided to the optical splitter/combiner 58.

FIG. 9 is a flowchart of an exemplary HEU configuration process 360 for reconfiguring the main HBU 38 in FIG. 2 with the one or more main-HEU DIMs 330(1)-330(N) in FIG. 8. Elements in FIGS. 2, 3, 6, and 8 are referenced in connection to FIG. 9
and will not be re-described herein.

[0079] According to the HEU configuration process 360, the plurality of OIMs 62(1)-62(N) in the main HEU 38 are replaced with the one or more main-HEU DIMs 330(1)-330(N) (block 362). Next, the HEU configuration process 310 configures each of the one or more main-HEU DIMs 330(1)-330(N) (block 364). For a main-HEU DIM among the one or more main-HEU DIMs 330(1)-330(N), a digital communications interface 136 in the main-HEU DIM is coupled to a respective BBU among the one or more BBUs 340(1)-340(N) (block 366). Subsequently, at least one digital remote distribution interface 132 in the main-HEU DIM is coupled to a respective optical fiber-based downlink digital communications medium 234 and a respective optical fiber-based uplink digital communications medium 236 (block 368). Then, an analog local distribution interface 134 in the main-HEU DIM is coupled to a respective RIM among the one or more main-HEU RIMs 44(1)-44(N) (block 370). To enable interconnections between the one or more main-HEU DIMs 330(1)-330(N), a logical upstream main-HEU DIM and a logical downstream main-HEU DIM are identified for each of the one or more main-HEU DIMs 330(1)-330(N). Subsequently for each of the main-HEU DIM among the one or more main-HEU DIMs 330(1)-330(N), the upstream digital bus interface 128 of the main-HEU DIM is coupled to a downstream digital bus 130 of the logical upstream main-HEU DIM. Also, the downstream digital bus interface 130 of the main-HEU DIM is coupled to an upstream digital bus interface 128 of the logical downstream main-HEU DIM.

[0080] As previously discussed in references to FIGS. 6 and 8, the combined downlink digital RF signal 248(1) comprises the one or more respective first downlink digital RF signals, the one or more respective second downlink digital RF signals, the one or more respective third downlink digital RF signals, and the one or more respective fourth downlink digital RF signals. Likewise, the combined uplink digital RF signal 304(1) comprises the one or more respective first uplink digital RF signals, the one or more respective second uplink digital RF signals, the one or more respective third uplink digital RF signals, and the one or more respective fourth uplink digital RF signals. As such, the optical fiber-based downlink digital communications mediums 234(1) and the optical fiber-based uplink digital communications mediums 236(1) are required to provide larger bandwidth, thus increasing complexities and costs of the respective E/O converters 244(1), the respective O/E converters 246(1), the remote-HEU O/E converter 254(1), and the remote-HEU E/O converter 256(1). In this regard, FIG. 10 is a schematic diagram of an exemplary DAS 380 comprising a main
HEU 382 coupled to a remote HEU 384 over a plurality of respective optical fiber-based downlink communications mediums 386(1)-386(Q) and a plurality of respective optical fiber-based uplink communications mediums 387(1)-387(Q).

[0081] With reference to FIG. 10, the main HEU 382 comprises a DAIM 388 or a DIM 390. The DAIM 388 or the DIM 390 comprises a plurality of digital remote distribution interfaces 3-92(I)-392(Q) that are coupled to a plurality of main-HEU E/O converters 394(1)-394(Q) and a plurality of main-HEU O/E converters 396(1)-396(Q), respectively. The remote HEU 384 comprises a remote-HEU DIM 398. The remote-HEU DIM 398 comprises a plurality of remote-DIM digital remote distribution interfaces 400(1)-400(Q). The plurality of remote-DIM digital remote distribution interfaces 400(1)-400(Q) are coupled to a plurality of remote-HEU O/E converters 402(1)-402(Q) and a plurality of remote-HEU E/O converters 404(1)-404(Q), respectively. The plurality of main-HEU E/O converters 394(1)-394(Q) is coupled to the plurality of remote-HEU O/E converters 402(1)-402(Q) over the plurality of respective optical fiber-based downlink communications mediums 386(1)-386(Q), respectively. The plurality of main-HEU O/E converters 396(1)-396(Q) is coupled to the plurality of remote-HEU E/O converters 404(1)-404(Q) over the plurality of respective optical fiber-based uplink communications mediums 387(1)-387(Q), respectively.

[0082] With continuing reference to FIG. 10, a digital signal processing circuit (not shown) in the DAIM 388 or the DIM 390 splits a combined downlink digital RF signal (not shown) into a plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q). The plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q) is distributed to the remote HEU 384 via the plurality of digital remote distribution interfaces 392(1)-392(Q). Similarly, a digital signal processing circuit (not shown) in the remote-HEU DIM 398 splits a combined uplink digital RF signal (not shown) into a plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q). The plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q) is distributed to the main HEU 382 via the plurality of remote-DIM digital remote distribution interfaces 400(1)-400(Q).

[0083] By providing the plurality of digital remote distribution interfaces 392(1)-392(Q) in the main HEU 382 and the plurality of remote-DIM digital remote distribution interfaces 400(1)-400(Q) in the remote HEU 384, it is possible to provide the plurality of main-HEU E/O converters 394(1)-394(Q), the plurality of main-HEU O/E converters 396(1)-396(Q), the plurality of remote-HEU O/E converters 402(1)-402(Q), and the plurality of remote-HEU
E/O converters 404(1)-404(Q) with reduced complexities and costs. However, it may be desirable to combine the plurality of optical fiber-based communications mediums 386(1)-386(Q) into a single optical fiber-based communications medium to achieve further cost savings. In this regard, FIG. 11 is a schematic diagram of an exemplary DAS 380(1) comprising a main HEU 382(1) coupled to a remote HEU 384(1) using wavelength-division multiplexing (WDM). Common elements between FIGS. 10 and 11 are shown therein with common element numbers, thus will not be re-described herein.

With reference to FIG. 11, the main HEU 382(1) comprises a main-HEU WDM circuit 410 that is coupled to a remote-HEU WDM circuit 412 comprised in the remote HEU 384(1) over an optical fiber-based digital communications medium 414. In the main HEU 382(1), the plurality of main-HEU E/O converters 394(1)-394(Q) converts the plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q) into a plurality of bandwidth-reduced combined downlink optical RF signals 416(1)-416(Q). The main-HEU WDM circuit 410 wavelength multiplexes the plurality of bandwidth-reduced combined downlink optical RF signals 416(1)-416(Q) to generate a combined downlink optical RF signal 418. The remote-HEU WDM circuit 412 in turn wavelength de-multiplexes the combined downlink optical RF signal 418 back into the plurality of bandwidth-reduced combined downlink optical RF signals 416(1)-416(Q). The plurality of remote-HEU O/E converters 402(1)-402(Q) subsequently convert the plurality of bandwidth-reduced combined downlink optical RF signals 416(1)-416(Q) into the plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q).

With continuing reference to FIG. 11, in the remote HEU 384(1), the plurality of remote-HEU E/O converters 404(1)-404(Q) converts the plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q) into a plurality of bandwidth-reduced combined uplink optical RF signals 420(1)-420(Q). The remote-HEU WDM circuit 412 wavelength multiplexes the plurality of bandwidth-reduced combined uplink optical RF signals 420(1)-420(Q) to generate a combined uplink optical RF signal 422. The main-HEU WDM circuit 410 in turn wavelength de-multiplexes the combined uplink optical RF signal 422 back into the plurality of bandwidth-reduced combined uplink optical RF signals 420(1)-420(Q). The plurality of main-HEU O/E converters 396(1)-396(Q) subsequently converts the plurality of bandwidth-reduced combined uplink optical RF signals 420(1)-420(Q) into the plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q).

Alternative to adding the plurality of digital remote distribution interfaces 392(1)-
392(Q) in the DAIM 388 or the DIM 390 and the plurality of remote-DIM digital remote distribution interfaces 400(1)-400(Q) in the remote-HEU DIM 398 in FIG. 10, it is also possible to utilize multiple DAIMs and/or DIMs for digital and/or analog communications signals distribution between a main HEU and a remote HEU. In this regard, FIG. 12 is a schematic diagram of an exemplary DAS 430 wherein a main HEU 432 and a remote HEU 434 are configured to concurrently distribute digital and/or analog communications signals multiple using a plurality of DAIMs 436(1)-436(Q) and a plurality of DIMs 438<1)-438(Q). Common elements between FIGS. 10 and 12 are shown therein with common element numbers, thus will not be re-described herein.

With reference to FIG. 12, a main-HEU load-sharing bus 440 interconnects the plurality of DAIMs 436(1)-436(Q). A main-HEU load-sharing controller 442, which may be incorporated into the plurality of DAIMs 436(1)-436(Q) for example, is configured to implement load sharing among the plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q). In the remote HEU 434, a remote-HEU load-sharing bus 444 interconnects the plurality of DIMs 438(1)-438(Q). A remote-HEU load-sharing controller 446, which may be incorporated into the plurality of DIMs 438<1)-438(Q), for example, is configured to implement load sharing among the plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q).

Alternative to employing the plurality of optical fiber-based communications mediums 386(1)-386(Q) between the main HEU 432 and the remote HEU 434, it may be desirable to combine the plurality of optical fiber-based communications mediums 386(1)-386(0) into a single optical fiber-based communications medium to achieve further cost savings. In this regard, FIG. 13 is a schematic diagram of an exemplary DAS 430(1) wherein a main HEU 432(1) and a remote HEU 434(1) are configured to concurrently distribute digital and/or analog communications signals multiple using WDM. Common elements between FIGS. 12 and 13 are shown therein with common element numbers, thus will not be re-described herein.

With reference to FIG. 13, the main HEU 432(1) comprises a main-HEU WDM circuit 448 that is coupled to a remote-HEU WDM circuit 450 comprised in the remote HEU 384(1) over an optical fiber-based digital communications medium 452. In the main HEU 432(1), the plurality of main-HEU E/O converters 394(1)-394(Q) converts the plurality of bandwidth-reduced combined downlink digital RF signals 406(S)-406(Q) into a plurality of bandwidth-reduced combined downlink optical RF signals 454(3)-454(Q). The main-HEU
WDM circuit 448 wavelength multiplexes the plurality of bandwidth-reduced combined downlink optical RF signals 454(J)-4S4(Q) to generate a combined downlink optical RF signal 456. The remote-HEU WDM circuit 450 in turn wavelength de-multiplexes the combined downlink optical RF signal 456 back into the plurality of bandwidth-reduced combined downlink optical RF signals 454(1)-454(Q). The plurality of remote-HEU O/E converters 402(1)-402(Q) subsequently converts the plurality of bandwidth-reduced combined downlink optical RF signals 454(1)-454(Q) into the plurality of bandwidth-reduced combined downlink digital RF signals 406(1)-406(Q).

[0090] With continuing reference to FIG. 11, in the remote HEU 434(1), the plurality of remote-HEU E/O converters 404(1)-404(Q) converts the plurality of bandwidth-reduced combined uplink digital RF signals 408(1)-408(Q) into a plurality of bandwidth-reduced combined uplink optical RF signals 458(I)-458(Q). The remote-HEU WDM circuit 450 wavelength multiplexes the plurality of bandwidth-reduced combined uplink optical RF signals 458(I)-458(Q) to generate a combined uplink optical RF signal 460. The main-HEU WDM circuit 448 in turn wavelength de-multiplexes the combined uplink optical RF signal 460 back into the plurality of bandwidth-reduced combined uplink optical RF signals 458(I)-458(Q). The plurality of main-HEU O/E converters 396(1)-396(Q) subsequently converts the plurality of bandwidth-reduced combined uplink optical RF signals 458(I)-458(Q) into the plurality of bandwidth-reduced combined uplink digital RF signals 408(I)-408(Q).

[0091] The DAIM 120 in FIG. 3 or the DIM 189 in FIG. 4 may be provided in an analog DAS 470 in an indoor environment, as illustrated in FIG. 14. FIG. 14 is a partially schematic cut-away diagram of an exemplary building infrastructure in which the analog DAS 470, which can include the DAIM 120 in FIG. 3 or the DIM 189 in FIG. 4 to support the distribution of digital and/or communications signals, can be employed. The building infrastructure 472 in this embodiment includes a first (ground) floor 474(1), a second floor 474(2), and a third floor 474(3). The floors 474(1)-474(3) are serviced by a central unit 476, which may include the DAIM 120 in FIG. 3 or the DIM 189 in FIG. 4, to provide antenna coverage areas 478 in the building infrastructure 470. The central unit 476 is communicatively coupled to a base station 480 to receive downlink communications signals 482D from the base station 480. The central unit 476 is communicatively coupled to remote antenna units 484 to receive uplink communications signals 482U from the remote antenna units 484, as previously discussed above. The downlink and uplink communications signals 482D, 482U communicated between the central unit 476 and the remote antenna units 484.
are carried over a riser cable 486. The riser cable 486 may be routed through interconnect units (ICUs) 488(1)-488(3) dedicated to each of the floors 474(J)-474(3) that route the downlink and uplink communications signals 482D, 482U to the remote antenna units 484 and also provide power to the remote antenna units 484 via array cables 490.

[0092] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[0093] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit or scope of the invention. Since modifications, combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and their equivalents.
What is claimed is:

1. A digital-analog interface module (DAIM) in a main distributed antenna system (DAS) to support a wide-area DAS, comprising:
   - an analog communications interface configured to receive a downlink analog communications signal from at least one of an analog signal source and a baseband signal source;
   - at least one digital remote distribution interface to be coupled with a remote DAS component in a remote DAS in the wide-area DAS;
   - an analog local distribution interface configured to distribute a downlink analog radio frequency (RF) signal to a remote antenna unit (RAU) in the main DAS;
   - an RF conditioning circuit coupled to the analog communications interface and the analog local distribution interface, the RF conditioning circuit is configured to:
     - receive the downlink analog communications signal from the analog signal source;
     - convert the downlink analog communications signal into the downlink analog RF signal adapted for distribution in the wide-area DAS;
     - provide the downlink analog RF signal to the analog local distribution interface; and
     - provide the downlink analog RF signal to an analog-to-digital (A/D) converter;
   - the A/D converter coupled to the RF conditioning circuit, wherein the A/D converter is configured to convert the downlink analog RF signal to generate a downlink digital RF signal;
   - a digital signal processing circuit coupled to the A/D converter and the at least one digital remote distribution interface; and
   - wherein the digital signal processing circuit is configured to:
     - receive the downlink digital RF signal from the A/D converter;
     - convert the downlink digital RF signal to generate one or more first downlink digital RF signals;
     - combine one or more respective first downlink digital RF signals to generate a combined downlink digital RF signal; and
     - provide the combined downlink digital RF signal to the at least one digital remote distribution interface to be distributed to the remote DAS
2. The DAIM of claim 1, further comprising:
   a digital communications interface coupled to the digital signal processing circuit, the
digital communications interface is configured to receive a downlink digital baseband signal from a digital signal source; and
   a digital signal processing controller communicatively coupled to the digital signal processing circuit, the digital signal processing controller is configured to programmably determine the one or more respective first downlink digital RF signals among the one or more first downlink digital RF signals to be combined into the combined downlink digital RF signal.

3. The DAIM of claim 2, wherein the downlink digital baseband signal is configured to be in compliance with a common public radio interface (CPRI) format.

4. The DAIM according to any of claims 2-3, further comprising:
   a digital bus interface comprising:
      an upstream digital bus interface coupled to the digital signal processing circuit and is configured to be coupled with a second downstream digital bus interface comprised in a second DAIM that is logically configured as an upstream DAIM to the DAIM; and
      a downstream digital bus interface coupled to the digital signal processing circuit and is configured to be coupled with a third upstream digital bus interface comprised in a third DAIM that is logically configured as a downstream DAIM to the DAIM.

5. The DAIM of claim 4, wherein the digital signal processing circuit is further configured to:
   provide the one or more first downlink digital RF signals to the downstream digital bus interface;
   provide the one or more first downlink digital RF signals to the upstream digital bus interface;
   receive one or more second downlink digital RF signals from the upstream digital bus interface;
provide the one or more second downlink digital RF signals to the downstream digital bus interface;
receive one or more third downlink digital RF signals from the downstream digital bus interface;
provide the one or more third downlink digital RF signals to the upstream digital bus interface; and
combine one or more respective second downlink digital RF signals and one or more respective third downlink digital RF signals to the combined downlink digital RF signal, wherein the one or more respective second downlink digital RF signals and the one or more respective third downlink digital RF signals are programmable determined by the digital signal processing controller among the one or more second downlink digital RF signals and the one or more third downlink digital RF signals, respectively.

6. The DAJM according to any of claims 4-5, wherein the digital signal processing circuit is further configured to:
   convert the downlink digital baseband signal to generate one or more fourth downlink digital RF signals;
   provide the one or more fourth downlink digital RF signals to the downstream digital bus interface;
   provide the one or more fourth downlink digital RF signals to the upstream digital bus interface; and
   combine one or more respective fourth downlink digital RF signals to generate the combined downlink digital RF signal, wherein the one or more respective fourth downlink digital RF signals are programmable determined by the digital signal processing controller among the one or more fourth downlink digital RF signals.

7. The DAJM according to any of claims 4-6, wherein the digital signal processing circuit is further configured to:
   receive a combined uplink digital RF signal from the remote DAS component via the at least one digital remote distribution interface;
   split the combined uplink digital RF signal to generate one or more first uplink digital
RF signals;
provide the one or more first uplink digital RF signals to the downstream digital bus interface;
provide the one or more first uplink digital RF signals to the upstream digital bus interface; and
combine one or more respective first uplink digital RF signals to generate an uplink digital RF signal, wherein the one or more respective first uplink digital RF signals are programmably determined by the digital signal processing controller among the one or more first uplink digital RF signals.

8. The DAIM of claim 7, wherein the digital signal processing circuit is further configured to:
receive one or more second uplink digital RF signals from the upstream digital bus interface;
provide the one or more second uplink digital RF signals to the downstream digital bus interface;
receive one or more third uplink digital RF signals from the downstream digital bus interface;
provide the one or more third uplink digital RF signals to the upstream digital bus interface; and
combine one or more respective second uplink digital RF signals and one or more respective third uplink digital RF signals to generate an uplink digital RF signal, wherein the one or more respective second uplink digital RF signals and the one or more respective third uplink digital RF signals are programmably determined by the digital signal processing controller among the one or more second uplink digital RF signals and the one or more third uplink digital RF signals, respectively.

9. The DAIM according to any of claims 7-8, wherein the digital signal processing circuit is further configured to:
receive an uplink digital baseband signal from the digital signal source via the digital communications interface;
convert the uplink digital baseband signal to generate one or more fourth uplink
digital RF signals;
provide the one or more fourth uplink digital RF signals to the downstream digital bus interface;
provide the one or more fourth uplink digital RF signals to the upstream digital bus interface; and
combine one or more respective fourth uplink digital RF signals to generate the uplink digital RF signal wherein the one or more respective fourth uplink digital RF signals are programmably determined by the digital signal processing controller among the one or more fourth uplink digital RF signals.

10. The DAIM of claim 9, wherein the uplink digital baseband signal is configured to be in compliance with a common public radio interface (CPRI) format.

11. The DAIM according to any of claims 7-10, further comprising a digital-to-analog (D/A) converter coupled to the RF conditioning circuit and the digital signal processing circuit, wherein the D/A converter is configured to convert the uplink digital RF signal to generate an uplink analog RF signal.

12. The DAIM of claim 11, wherein the RF conditioning circuit is further configured to:
provide the uplink analog RF signal to the analog local distribution interface;
convert the uplink analog RF signal into an uplink analog communications signal adapted for communications to the analog signal source; and
provide the uplink analog communications signal to the analog communications interface,

13. The DAIM according to any of claims 1-12, wherein the remote DAS component in the remote DAS in the wide-area DAS is a remote head-end unit (HEU).

14. The DAIM according any of claims 1-13, wherein the RAU in the main DAS is a main DAS component.

15. An optical fiber-based wide-area distributed antenna system (DAS), comprising:
a main DAS comprising a main head-end unit (HEU), wherein the main HEU comprises one or more digital-analog interface modules (DAIMs);
wherein each of the one or more DAlMs is coupled to a respective optical fiber-based downlink digital communications medium via a respective electrical-to-optical (E/O) converter and is coupled to a respective optical fiber-based uplink digital communications medium via a respective optical-to-electrical (O/E) converter; and

one or more remote DAsSs comprising one or more remote HEUs, respectively, wherein a remote HEU among the one or more remote HEUs comprises:

one or more remote-HEU digital interface modules (DiMs) corresponding to one or more radio frequency (RF) bands, respectively, wherein at least one remote-HEU DiM among the one or more remote-HEU DiMs comprised in the remote HF.U is configured to interface with a respective DAIM in the main HEU;

wherein the at least one remote-HEU DiM configured to interface with the respective DAIM in the main HEU is coupled to the respective optical fiber-based downlink digital communications medium via a respective remote-HEU O/E converter and is coupled to the respective optical fiber-based uplink digital communications medium via a respective remote-HEU E/O converter;

a remote-HEU RF combiner/splitter coupled to the one or more remote-HEU DiMs;

a remote-HEU optical splitter/combiner coupled to the remote-HEU RF combiner/splitter; and

one or more remote-HEU optical interface modules (OIMs) coupled to the remote-HEU optical splitter/combiner, wherein the one or more remote-HEU OIMs is coupled with one or more remote-DAS remote antenna units (RAUs).

16. The optical fiber-based wide-area DAS of claim 15, wherein a DAIM among the one or more DAIMs in the main HEU comprises:

an analog communications interface to be coupled with an analog signal source associated with the main HEU;

da digital bus interface, comprising:

an upstream digital bus interface coupled to a second downstream digital bus interface comprised in a second DAIM among the one or more
DAIMs, wherein the second DAIM is logically configured as an upstream DAIM to the DAIM; and

a downstream digital bus interface coupled to a third upstream digital bus interface comprised in a third DAIM among the one or more DAIMs, wherein the third DAIM is logically configured as a downstream DAIM to the DAIM;

at least one digital remote distribution interface coupled to a respective downlink communications medium and a respective uplink communications medium;

an analog local distribution interface to be coupled with a RAU associated with the main HEU;

a digital communications interface to be coupled with a digital signal source associated with the main HEU;

an RF conditioning circuit coupled to the analog communications interface and the analog local distribution interface;

an analog-to-digital (A/D) converter coupled to the RF conditioning circuit;

a digital-to-analog (D/A) converter coupled to the RF conditioning circuit;

a digital signal processing circuit coupled to the A/D converter, the D/A converter, the upstream digital bus interface, the downstream digital bus interface, the at least one digital remote distribution interface, and the digital communications interface; and

a digital signal processing controller communicatively coupled to the digital signal processing circuit;

wherein the digital signal processing circuit is configured to generate a combined downlink digital RF signal and provide the combined downlink digital RF signal to the at least one digital remote distribution interface.

17. The optical fiber-based wide-area DAS of claim 16, wherein the analog signal source is configured to be a base transceiver station (BTS) and the digital signal source is configured to be a baseband unit (BBU).

18. The optical fiber-based wide-area DAS according to any of claims 15-17, wherein a remote-HEU DIM among the one or more remote-HEU DJMs comprised in the remote HEU among the one or more remote HEUs comprises:

   a remote-DIM upstream digital bus interface;
a remote-DIM downstream digital bus interface;
at least one remote-DIM digital remote distribution interface;
wherein the at least one remote-DIM digital remote distribution interface is coupled to
the respective remote-HEU E/O converter and the respective remote-HEU O/E
converter if the remote-HEU DIM is the at least one remote-HEU DIM
configured to interface with the respective DAIM in the main HEU;
a remote-DIM analog local distribution interface coupled to the remote-HEU RF
combiner/splitter;
a remote-DIM digital communications interface to be coupled with a remote-DAS
digital signal source associated with the remote HEU;
a remote-DIM analog-to-digital- (A/D) converter coupled to the remote-DIM analog
local distribution interface;
a remote-DIM digital-to-analog (D/A) converter coupled to the remote-DIM analog
local distribution interface;
a remote-DIM digital signal processing circuit coupled to the remote-DIM A/D
converter, the remote-DIM D/A converter, the remote-DIM upstream digital
bus interface, the remote-DIM downstream digital bus interface, the at least
one remote-DIM digital remote distribution interface, and the remote-DIM
digital communications interface; and
a remote-DIM: digital signal processing controller communicatively coupled to the
remote-DIM digital signal processing circuit.

19. The optical fiber-based wide-area DAS of claim 18, wherein the remote-DIM digital
signal processing circuit in the remote-HEU DIM is configured to:
if the remote-HEU DIM is the at least one remote-HEU DIM configured to interface
with the respective DAIM in the main HEU:
receive a combined downlink digital RF signal from the respective DAIM in
the main HEU through the at least one remote-DIM digital remote
distribution interface;
convert the combined downlink digital RF signal into one or more first
remote-DIM downlink digital RF signals corresponding to the one or
more RF bands, respectively;
provide the one or more first remote-DIM downlink digital RF signals to the
remote-DIM upstream digital bus interface; and
provide the one or more first remote-DIM downlink digital RF signals to the remote-DIM downstream digital bus interface.

20. The optical fiber-based wide-area DAS of claim 19, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is further configured to:
   receive one or more second remote-DIM downlink digital RF signals from the remote-DIM upstream digital bus interface, wherein the one or more second remote-DIM downlink digital RF signals correspond to the one or more RF bands;
   provide the one or more second remote-DIM downlink digital RF signals to the remote-DIM downstream digital bus interface;
   receive one or more third remote-DIM downlink digital RF signals from the remote-DIM downstream digital bus interface, wherein the one or more third remote-DIM downlink digital RF signals correspond to the one or more RF bands; and
   provide the one or more third remote-DIM downlink digital RF signals to the remote-DIM upstream digital bus interface.

21. The optical fiber-based wide-area DAS of claim 20, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is further configured to:
   receive a remote-DAS downlink digital baseband signal from the remote-DIM digital communications interface;
   convert the remote-DAS downlink digital baseband signal to generate one or more fourth remote-DIM downlink digital RF signals corresponding to the one or more RF bands, respectively;
   provide the one or more fourth remote-DIM downlink digital RF signals to the remote-DIM downstream digital bus interface; and
   provide the one or more fourth remote-DIM downlink digital RF signals to the remote-DIM upstream digital bus interface.

22. The optical fiber-based wide-area DAS of claim 21, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is further configured to:
   combine one or more remote-DIM downlink digital RF signals to generate a remote-DIM combined downlink digital RF signal corresponding to an RF band associated with the remote-HEU DIM among the one or more RF bands
supported by the remote HEU, wherein the one or more remote-DIM downlink digital RF signals are programmably determined by the remote-DIM digital signal processing controller from the one or more first remote-DIM downlink digital RF signals, the one or more second remote-DIM downlink digital RF signals, the one or more third remote-DIM downlink digital RF signals, and the one or more fourth remote-DIM downlink digital RF signals based on the RF band associated with the remote-HEU DIM; and provide the remote-DIM combined downlink digital RF signal to the remote-DIM D/A converter.

23. The optical fiber-based wide-area DAS of claim 22, wherein the remote-DIM D/A converter in the remote-HEU DIM is configured to:
   convert the remote-DIM combined downlink digital RF signal into a remote-DIM combined downlink analog RF signal; and provide the remote-DIM combined downlink analog RF signal to the remote-DIM analog local distribution interface.

24. The optical fiber-based wide-area DAS of claim 23, wherein the remote-HEU RF combiner/splitter comprised in the remote HEU is configured to:
   receive one or more remote-DIM combined downlink analog RF signals from the one or more remote-HEU DIMs comprised in the remote HEU;
   convert and combine the one or more remote-DIM combined downlink analog RF signals to generate a remote-HEU combined downlink analog RF signal; and provide the remote-HEU combined downlink analog RF signal to the remote-HEU optical splitter/combiner comprised in the remote HEU.

25. The optical fiber-based wide-area DAS of claim 24, wherein the remote-HEU optical splitter/combiner comprised in the remote HEU among the one or more remote HEUs is configured to:
   receive the remote-HEU combined downlink analog RF signal from the remote-HEU RF combiner/splitter comprised in the remote HEU;
   split the remote-HEU combined downlink analog RF signal to generate one or more remote-OIM downlink analog RF signals; and
provide the one or more remote-OIM downlink analog RF signals to the one or more remote-HEU OIMs comprised in the remote HEU.

26. The optical fiber-based wide-area DAS of claim 25, wherein the one or more remote-HEU OIMs comprised in the remote HEU among the one or more remote HEUs are configured to:

- receive the one or more remote-OIM downlink analog RF signals from the one or more remote-HEU OIMs comprised in the remote HEU;
- convert the one or more remote-OIM downlink analog RF signals into one or more remote-OIM downlink optical RF signals; and
- provide the one or more remote-OEVi downlink optical RF signals to the one or more remote-DAS RAUs.

27. The optical fiber-based wide-area DAS according to any of claims 18-26, wherein the one or more remote-HEU OIMs comprised in the remote HEU among the one or more remote HEUs are configured to:

- receive one or more remote-OIM uplink optical RF signals from the one or more remote-DAS RAUs;
- convert the one or more remote-OIM uplink optical RF signals into one or more remote-OIM uplink analog RF signals; and
- provide the one or more remote-OIM uplink analog RF signals to the remote-HEU optical splitter/combiner.

28. The optical fiber-based wide-area DAS of claim 27, wherein the remote-HEU optical splitter/combiner comprised in the remote HEU among the one or more remote HEUs is configured to:

- receive the one or more remote-OIM uplink analog RF signals from the one or more remote-HEU OIMs comprised in the remote HEU;
- combine the one or more remote-OIM uplink analog RF signals to generate a remote-HEU combined uplink analog RF signal; and
- provide the remote-HEU combined uplink analog RF signal to the remote-HEU RF combiner/splitter in the remote HEU.

29. The optical fiber-based wide-area DAS of claim 28, wherein the remote-HEU RF
combiner/splitter comprised in the remote HEU antong the one or more remote HEUs is configured to;

- receive the remote-HEU combined uplink analog RF signal from the remote-HEU optical splitter/combiner;
- split the remote-HEU combined uplink analog RF signal into one or more remote-DIM combined uplink analog RF signals corresponding to the one or more RF bands, respectively; and
- provide the one or more remote-DIM combined uplink analog RF signals to the one or more remote-HEU DIMs comprised in the remote HEU based on the one or more RF bands, respectively.

30. The optical fiber-based wide-area DAS of claim 29, wherein the remote-DIM A/D converter in the remote-HEU DIM is configured to:

- receive a remote-DIM combined uplink analog RF signal from the remote-DIM analog local distribution interface;
- convert the remote-DIM combined uplink analog RF signal into a remote-DIM combined uplink digital RF signal; and
- provide the remote-DIM combined uplink digital RF signal to the remote-DIM digital signal processing circuit.

31. The optical fiber-based wide-area DAS of claim 30, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is further configured to:

- split the remote-DIM combined uplink digital RF signal to generate one or more first remote-DIM uplink digital RF signals;
- provide the one or more first remote-DIM uplink digital RF signals to the remote-DIM upstream digital bus interface; and
- provide the one or more first remote-DIM uplink digital RF signals to the remote-DIM downstream digital bus interface.

32. The optical fiber-based wide-area DAS of claim 31, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is further configured to:

- receive one or more second remote-DIM uplink digital RF signals from the remote-DIM upstream digital bus interface;
provide the one or more second remote-DIM uplink digital RF signals to the remote-DIM downstream digital bus interface;
receive one or more third remote-DIM uplink digital RF signals from the remote-DIM downstream digital bus interface; and
provide the one or more third remote-DIM uplink digital RF signals to the remote-DIM upstream digital bus interface.

33. The optical fiber-based wide-area DAS of claim 32, wherein the remote-DiM digital signal processing circuit in the remote-HEU DIM is further configured to:
receive a remote-DAS uplink digital baseband signal from the remote-DIM digital communications interface;
convert the remote-DAS uplink digital baseband signal to generate one or more fourth remote-DIM uplink digital RF signals;
provide the one or more fourth remote-DIM uplink digital RF signals to the remote-DIM downstream digital bus interface; and
provide the one or more fourth remote-DIM uplink digital RF signals to the remote-DIM upstream digital bus interface,

34. The optical fiber-based wide-area DAS of claim 33, wherein the remote-DIM digital signal processing circuit in the remote-HEU DIM is configured to:
if the remote-HEU DIM is the at least one remote-HEU DIM configured to interface with the respective DAIM in the main HEU:
combine one or more remote-DIM uplink digital RF signals to generate a combined uplink digital RF signal corresponding to the respective DAIM in the main HEU, wherein the one or more remote-DIM uplink digital RF signals are programmably determined by the remote-DIM digital signal processing controller from the one or more first remote-DIM uplink digital RF signals, the one or more second remote-DIM uplink digital RF signals, the one or more third remote-DIM uplink digital RF signals, and the one or more fourth remote-DIM uplink digital RF signals; and
provide the combined uplink digital RF signal to the respective DAIM in the main HEU through the at least one remote-DIM digital remote
distribution interface.

35. The optical fiber-based wide-area DAS of claim 15, wherein a DAM among the one or more DAiMs comprised in the main HEU comprises a plurality of digital remote distribution interfaces.

36. The optical fiber-based wide-area DAS of claim 35, wherein:
the plurality of digital remote distribution interfaces comprised in the DAM is coupled to a main-HEU wavelength-division multiplexer (WDM); and
the main-HEU WDM is coupled to a respective optical fiber-based downlink digital communications medium and a respective optical Fiber-based uplink digital communications medium.

37. The optical fiber-based wide-area DAS according to any of claims 35-36, wherein the plurality of digital remote distribution interfaces comprised in the DAIM is coupled to a plurality of respective optical fiber-based downlink digital communications mediums and a plurality of respective optical fiber-based uplink digital communications mediums, respectively.

38. The optical fiber-based wide-area DAS of claim 37, wherein a remote-HEU DIM comprised in the remote HEU in the one or more remote DASs comprises a plurality of remote-DIM digital remote distribution interfaces.

39. The optical fiber-based wide-area DAS of claim 38 wherein the plurality of remote-DIM digital remote distribution interfaces in the remote-HEU DIM is coupled to:
the plurality of respective optical fiber-based downlink digital communications mediums that are coupled to the respective DAIM in the main HEU; and
the plurality of respective optical fiber-based uplink digital communications mediums that are coupled to the respective DAIM in the main HEU.

40. The optical fiber-based wide-area DAS according to any of claims 38-39, wherein:
the plurality of remote-DIM digital remote distribution interfaces comprised in the remote-HEU DIM is coupled to a remote-HEU wavelength-division multiplexer (WDM); and
the reraote-HEU WDM is coupled to a respective optical fiber-based downlink digital communications medium and a respective optical fiber-based uplink digital communications medium.

41. A method for reconfiguring an existing head-end unit (HEU) in a distributed antenna system (DAS) with digital-analog interface modules (DAIMs), comprising:
   replacing one or more radio interface modules (RIMs) in an existing HEU with one or more DAIMs;
   for each of the one or more DAIMs:
      coupling an analog communications interface comprised in the DAIM to a respective analog signal source;
      coupling a digital communications interface comprised in the DAIM to a respective digital signal source;
      coupling at least one digital remote distribution interface comprised in the DAIM to a respective downlink digital communications medium and a respective uplink digital communications medium; and
      coupling an analog local distribution interface comprised in the DAIM to a respective remote antenna unit (RAU).

42. The method of claim 41, further comprising:
   for each of the one or more DAIMs:
      identifying a logical upstream DAIM to the DAIM among the one or more DAIMs;
      identifying a logical downstream DAIM to the DAIM among the one or more DAIMs, wherein the logical downstream DAIM is different from the logical upstream DAIM;
      coupling an upstream digital bus interface comprised in the DAIM to a downstream digital bus interface comprised in the logical upstream DAIM; and
      coupling a downstream digital bus interface comprised in the DAIM to an upstream digital bus interface comprised in the logical downstream DAIM,
Replace one or more radio interface modules (RIMs) (44(1)-44(M)) in a main head-end unit (HEU) (38) with one or more digital-analog interface modules (DAIMs) (232(1)-232(N))

Configure each of the one or more DAIMs (232(1)-232(N))

For a DAIM among the one or more DAIMs (232(1)-232(N)), couple an analog communications signal interface (122) in the DAIM to a respective base transceiver station (BTS) among one or more BTSs (238(1)-238(N))

Couple a digital communications signal interface (136) in the DAIM to a respective baseband unit (BBU) among one or more BBUs (240(1)-240(N))

Couple at least one remote distribution interface (132) in the DAIM to a respective optical fiber-based downlink digital communications medium (234) and a respective optical fiber-based uplink digital communications medium (236)

Couple a local distribution interface (134) in the DAIM to a respective remote antenna unit (RAU) among one or more RAUs (242(1)-242(N))

FIG. 7
Replace a plurality of optical interface modules (OIMs) (62(1)-62(N)) in a main head-end unit (HEU) (38) with one or more main-HEU digital interface modules (DIMs) (330(1)-330(N))

Configure each of the one or more main-HEU DIMs (330(1)-330(N))

For a main-HEU DIM among the one or more main-HEU DIMs (330(1)-330(N)), couple a digital communications signal interface (136) in the main-HEU DIM to respective BBU among the one or more BBUs (340(1)-340(N))

Couple at least one remote distribution interface (132) in the main-HEU DIM to a respective optical fiber-based downlink digital communications medium (234) and a respective optical fiber-based uplink digital communications medium (236)

Couple a local distribution interface (134) in the main-HEU DIM to a respective radio interface module (RIM) among one or more RIMs (44(1)-44(N))

FIG. 9
A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W88/08
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)
H04W

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>paragraphs [0041] - [0053], [0069], [0070]; figures 1,2,6,7</td>
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<td>paragraphs [0071] - [0079]; figures 2, 5A, 5B</td>
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Date of the actual completion of the international search: 8 March 2016
Date of mailing of the international search report: 17/03/2016

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<table>
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<tr>
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<tr>
<td>US 2013017863 Al 17-01-2013</td>
<td>CN 103733664 A 16-04-2014</td>
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<td>US 2013017863 Al 17-01-2013</td>
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<td></td>
<td>US 2013272441 Al 17-10-2013</td>
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<tr>
<td>US 2012314797 Al 13-12-2012</td>
<td>CN 103621035 A 05-03-2014</td>
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<td>EP 2719138 A2 16-04-2014</td>
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