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Pustovalov

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(45) **Date of Patent: Aug. 19, 2025**

(54) **SIGNAL COMPRESSION AND NOISE SHAPING IN A WIRELESS COMMUNICATIONS SYSTEM (WCS)**

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H04W 72/0453 (2023.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 5/0044*** (2013.01); ***H04W 72/0453*** (2013.01); ***H04W 72/21*** (2023.01); ***H04W 72/23*** (2023.01)

(58) **Field of Classification Search**
CPC H04L 5/0044; H04L 67/025; H04L 69/04; H04W 72/0453; H04W 72/21; H04W 72/23
See application file for complete search history.

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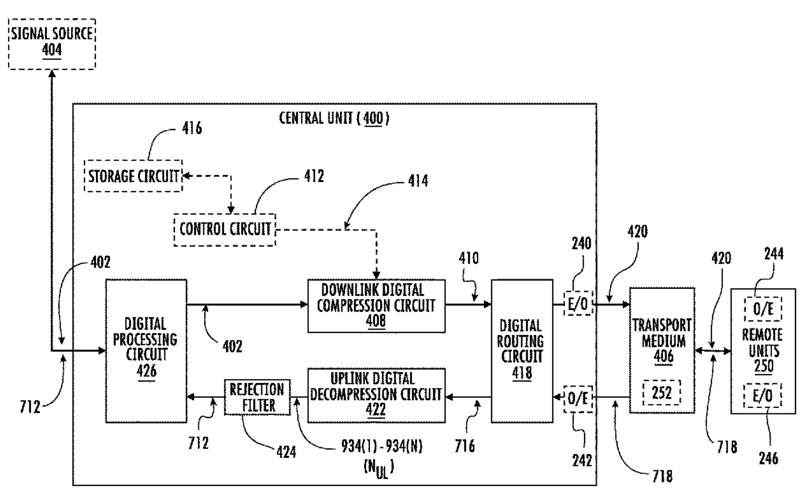
(57) **ABSTRACT**

Signal compression and noise shaping in a wireless communications system (WCS) is provided. Herein, a block compression circuit is integrated with a noise shaping circuit to concurrently perform downlink/uplink signal compression and noise shaping in the WCS. The block compression circuit performs block scaling compression on the downlink/uplink signal, which can cause a compression noise being distributed across an entire sampling bandwidth of the downlink/uplink signal. As such, the noise shaping circuit is configured to redistribute the compression noise from the entire sampling bandwidth to a selected portion of the sampling bandwidth. Accordingly, the redistributed compression noise can be effectively suppressed and/or filtered out when the downlink/uplink signal is received and decompressed. By concurrently performing block compression and noise shaping on the downlink/uplink signal, it is possible to achieve a good trade-off between compression ratio and
(Continued)



latency, without compromising quality metrics of the down-link/uplink signal.

25 Claims, 13 Drawing Sheets

(51) **Int. Cl.**
H04W 72/21 (2023.01)
H04W 72/23 (2023.01)

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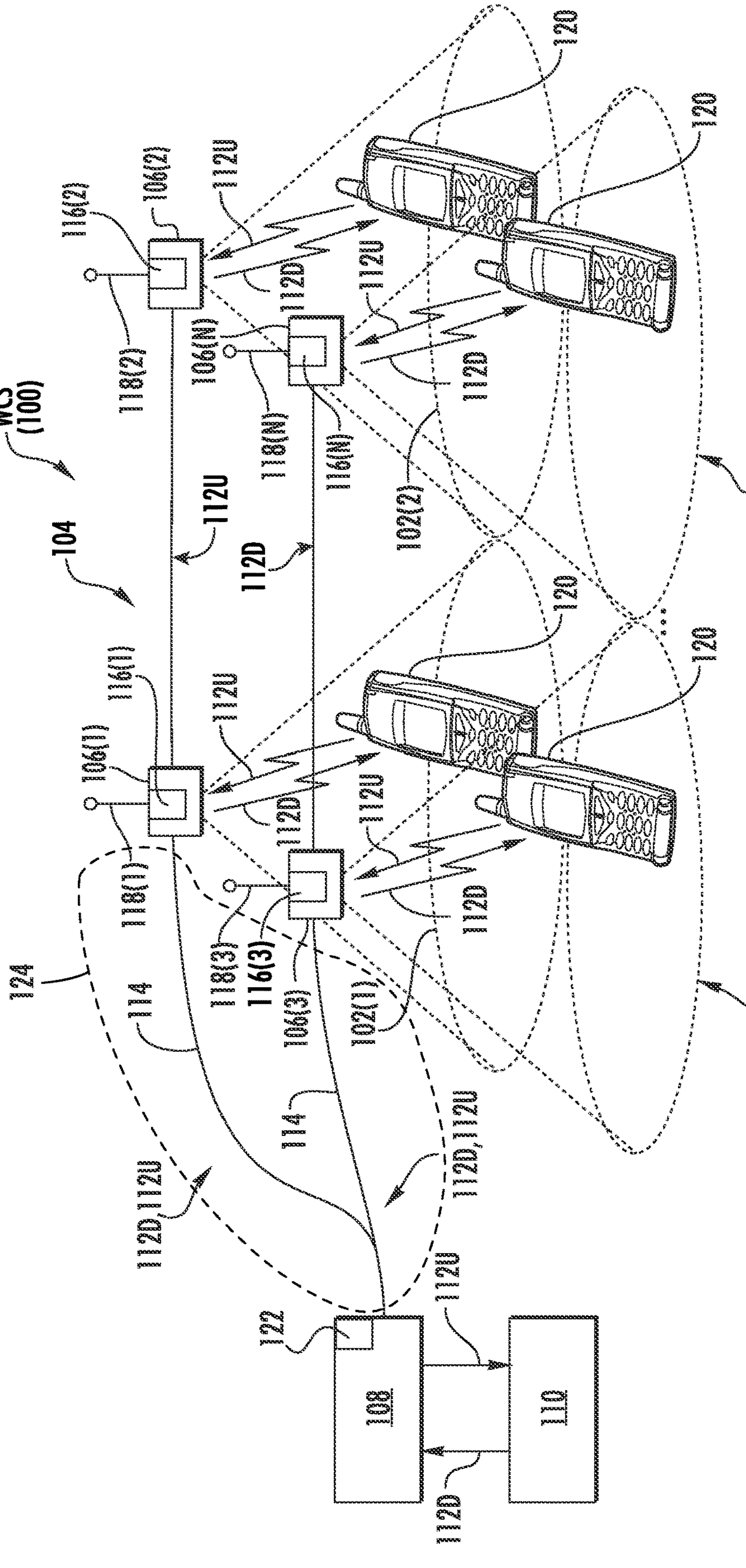

WCS (100)
104
106(1)
106(2)
106(3)
106(N)
116(1)
116(2)
116(3)
116(N)
118(1)
118(2)
118(3)
118(N)
112U
112D
112D,112U
114
102(1)
102(2)
102(3)
102(N)
120
122
124
108
110

FIG. 1

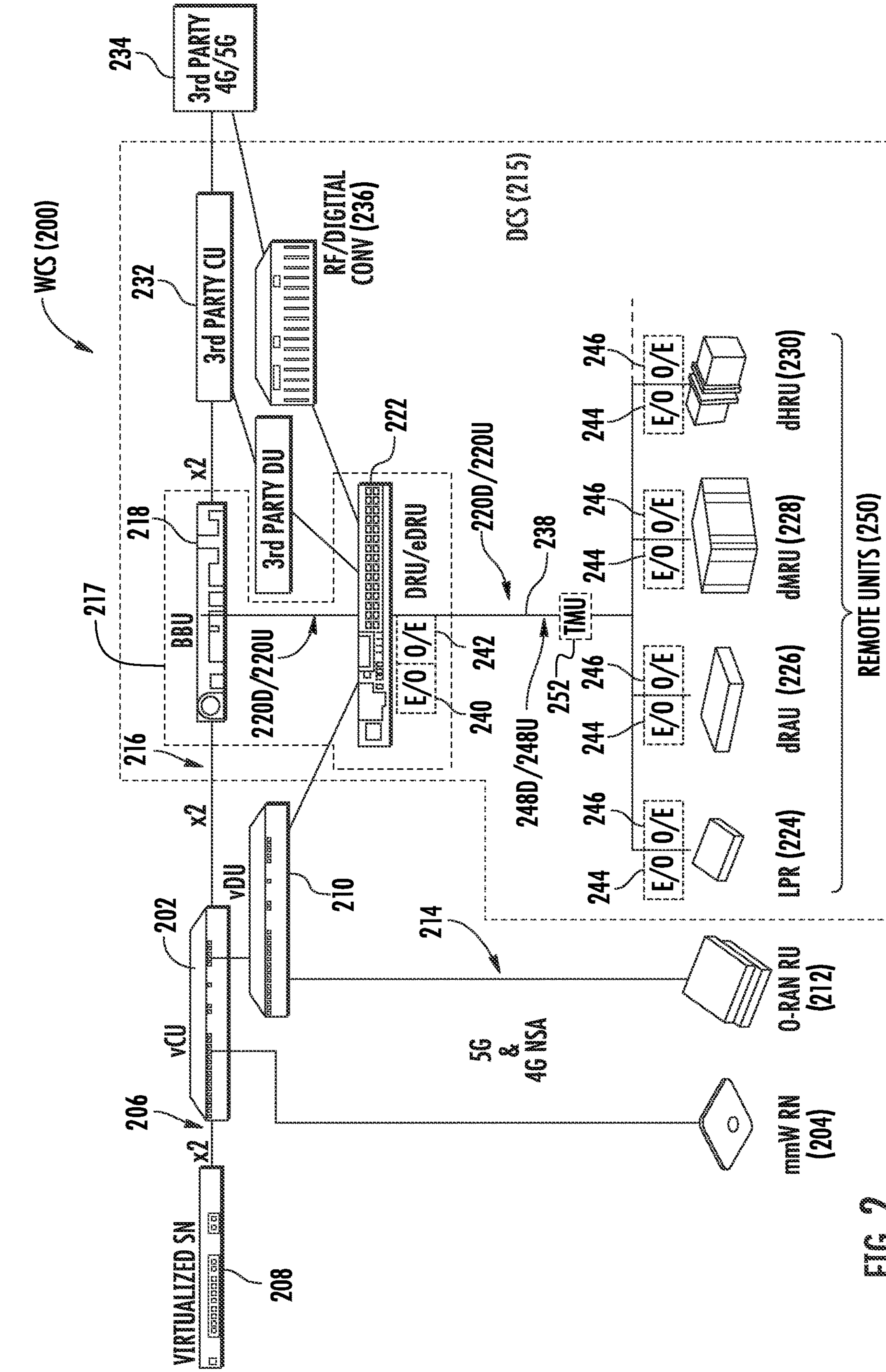

WCS (200)
234
3rd PARTY 4G/5G
DCS (215)
RF/DIGITAL CONV (236)
232
3rd PARTY CU
3rd PARTY DU
222
DRU/eDRU
220D/220U
238
TMU
252
248D/248U
217
216
218
BBU
x2
220D/220U
240
E/O
O/E
242
244
246
E/O
O/E
LPR (224)
dRAU (226)
dMRU (228)
dHRU (230)
REMOTE UNITS (250)
202
vCU
vDU
210
214
5G & 4G NSA
O-RAN RU (212)
mmW RN (204)
206
x2
VIRTUALIZED SN
208

FIG. 2

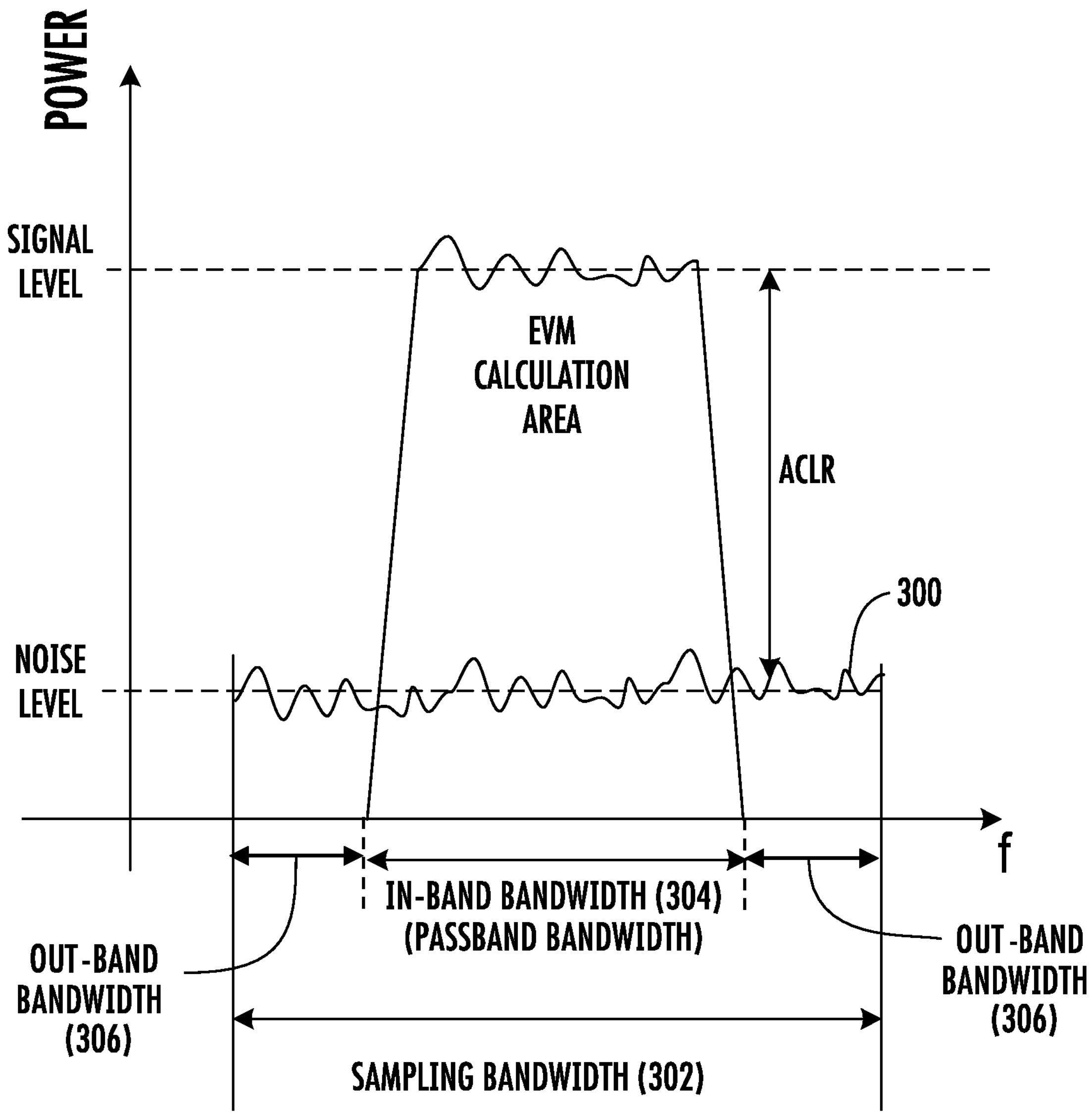

POWER
SIGNAL LEVEL
EVM CALCULATION AREA
ACLR
300
NOISE LEVEL
f
IN-BAND BANDWIDTH (304)
(PASSBAND BANDWIDTH)
OUT-BAND BANDWIDTH (306)
OUT-BAND BANDWIDTH (306)
SAMPLING BANDWIDTH (302)

FIG. 3

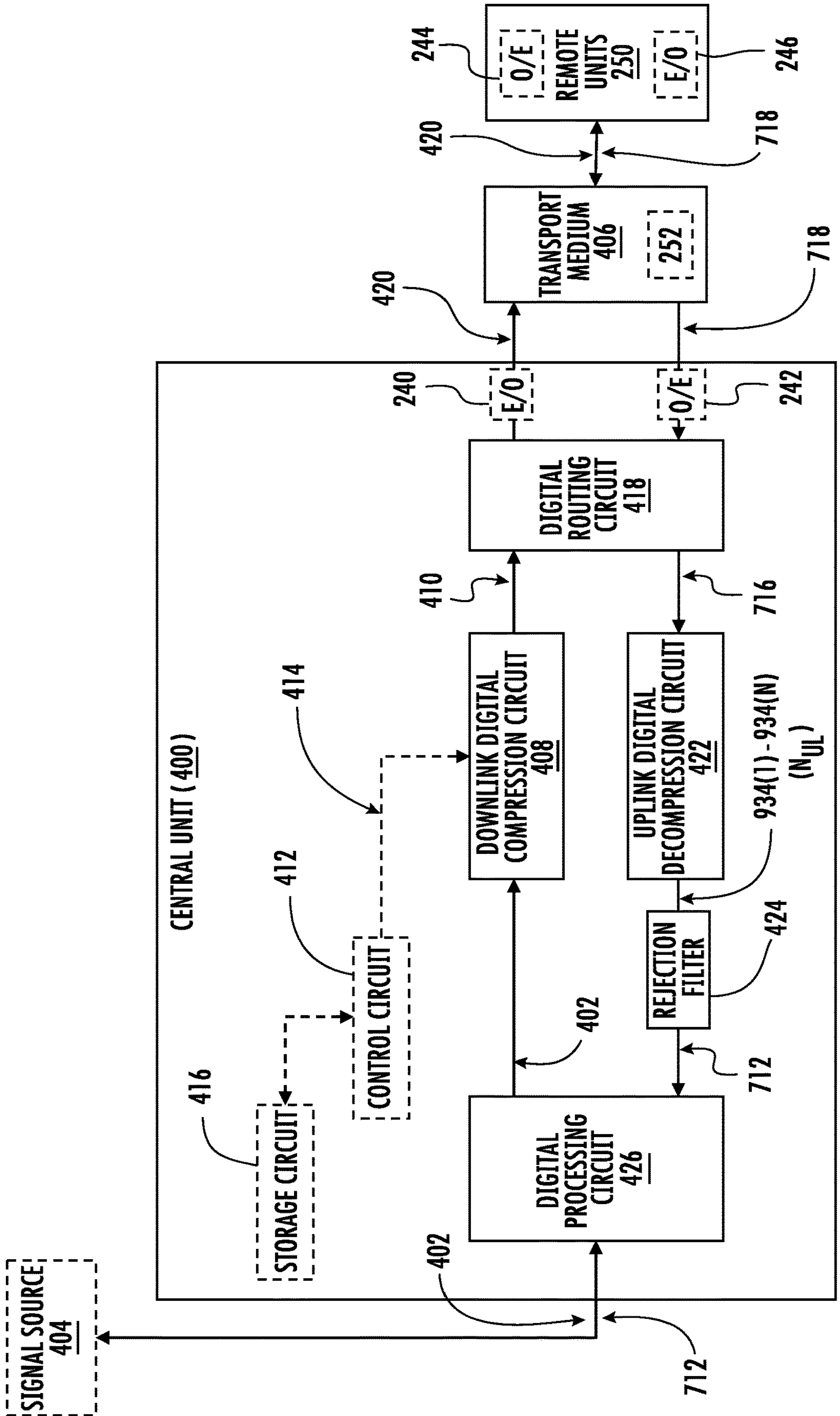

CENTRAL UNIT (400)
SIGNAL SOURCE 404
DIGITAL PROCESSING CIRCUIT 426
STORAGE CIRCUIT
CONTROL CIRCUIT
DOWNLINK DIGITAL COMPRESSION CIRCUIT 408
UPLINK DIGITAL DECOMPRESSION CIRCUIT 422
REJECTION FILTER
DIGITAL ROUTING CIRCUIT 418
E/O
O/E
TRANSPORT MEDIUM 406
252
REMOTE UNITS 250
O/E
E/O
934(1) - 934(N) (N_{UL})
402
402
410
412
414
416
420
420
424
712
712
716
718
718
240
242
244
246

FIG. 4

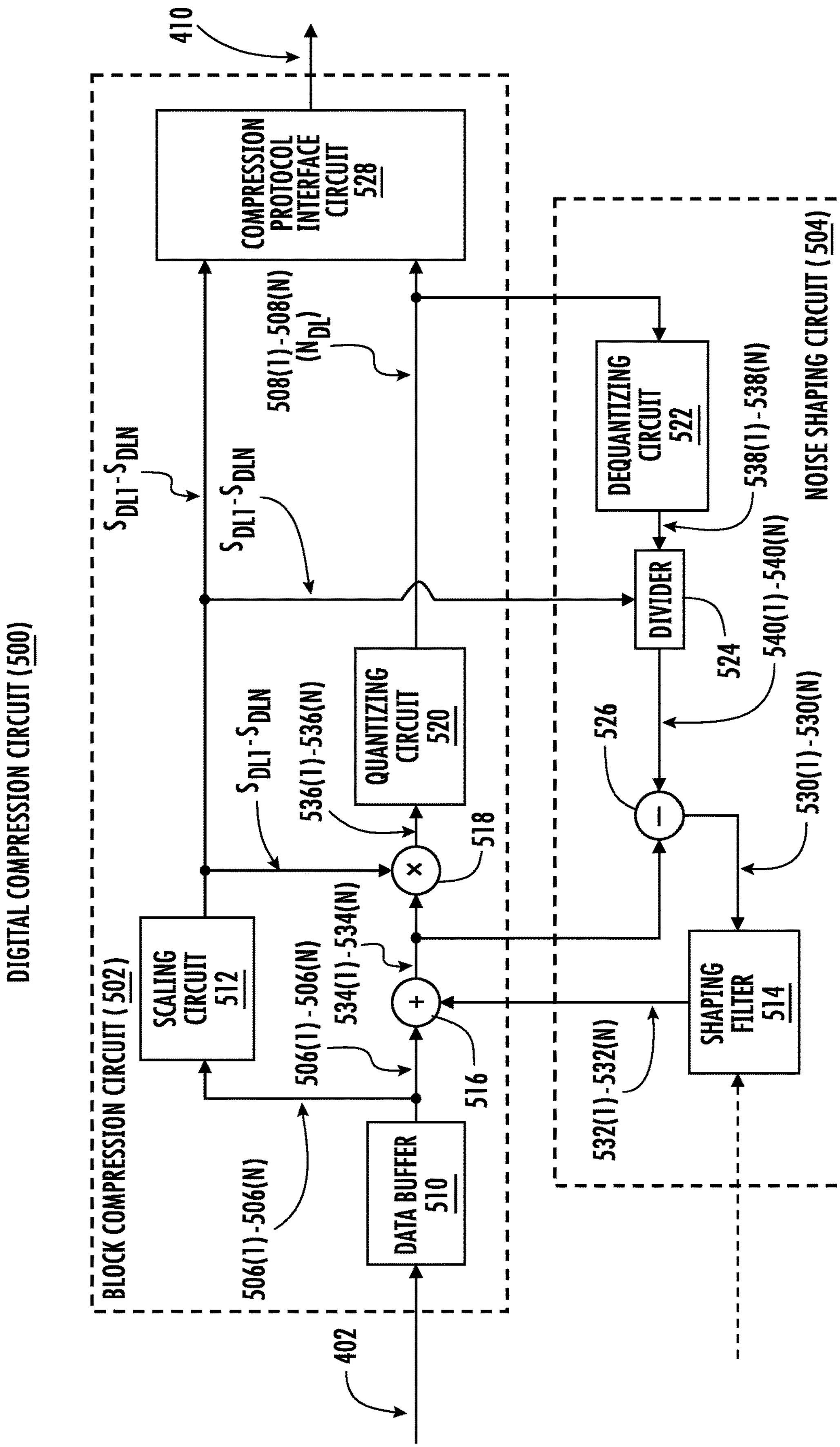

DIGITAL COMPRESSION CIRCUIT (500)
BLOCK COMPRESSION CIRCUIT (502)
NOISE SHAPING CIRCUIT (504)
402
410
DATA BUFFER 510
SCALING CIRCUIT 512
SHAPING FILTER 514
516
518
QUANTIZING CIRCUIT 520
DEQUANTIZING CIRCUIT 522
DIVIDER
524
526
COMPRESSION PROTOCOL INTERFACE CIRCUIT 528
506(1)-506(N)
506(1)-506(N)
508(1)-508(N) (N_DL)
530(1)-530(N)
532(1)-532(N)
534(1)-534(N)
536(1)-536(N)
538(1)-538(N)
540(1)-540(N)
S_DL1-S_DLN
S_DL1-S_DLN
S_DL1-S_DLN

FIG. 5

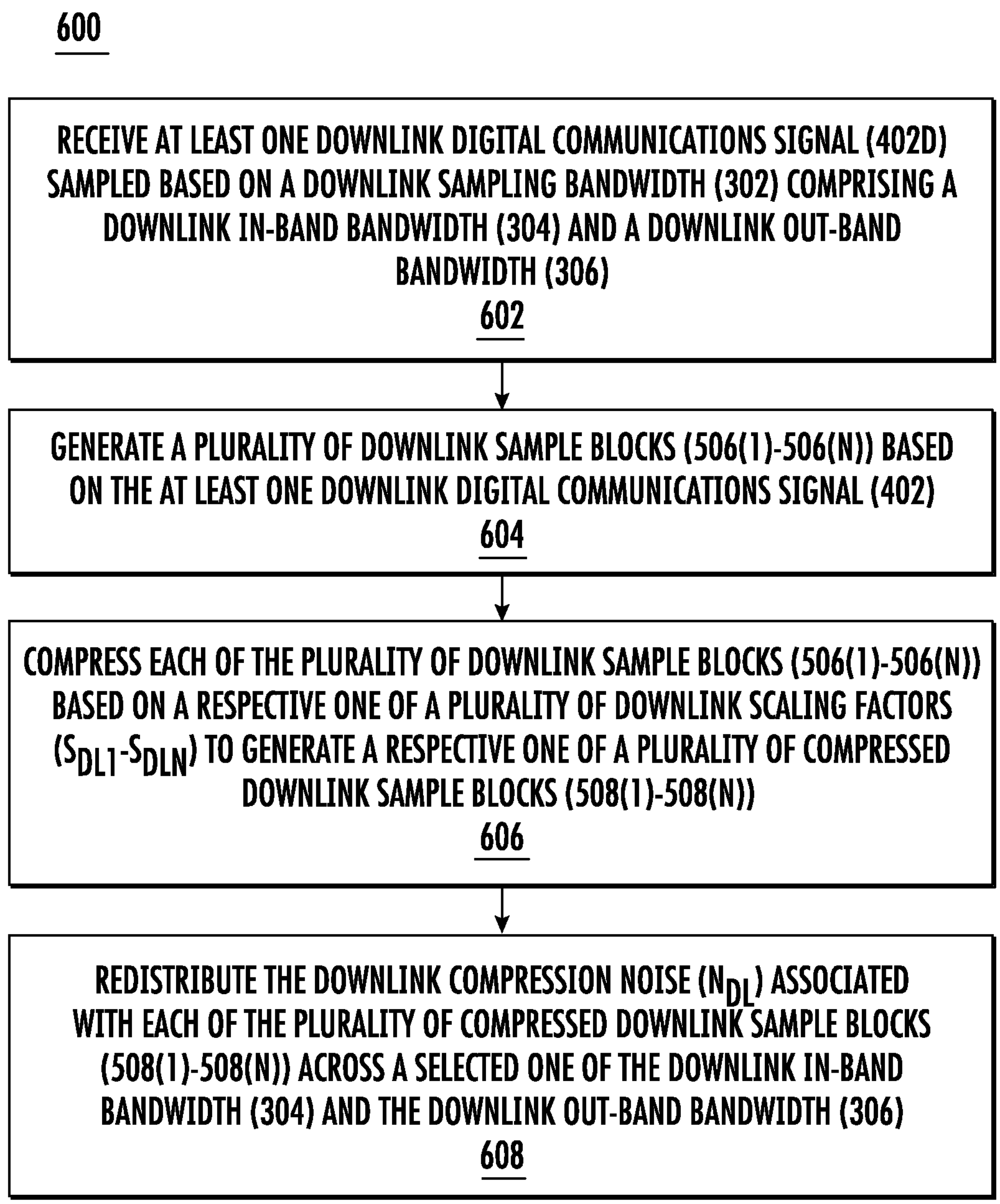

600
RECEIVE AT LEAST ONE DOWNLINK DIGITAL COMMUNICATIONS SIGNAL (402D) SAMPLED BASED ON A DOWNLINK SAMPLING BANDWIDTH (302) COMPRISING A DOWNLINK IN-BAND BANDWIDTH (304) AND A DOWNLINK OUT-BAND BANDWIDTH (306)
602
GENERATE A PLURALITY OF DOWNLINK SAMPLE BLOCKS (506(1)-506(N)) BASED ON THE AT LEAST ONE DOWNLINK DIGITAL COMMUNICATIONS SIGNAL (402)
604
COMPRESS EACH OF THE PLURALITY OF DOWNLINK SAMPLE BLOCKS (506(1)-506(N)) BASED ON A RESPECTIVE ONE OF A PLURALITY OF DOWNLINK SCALING FACTORS (S_{DL1}-S_{DLN}) TO GENERATE A RESPECTIVE ONE OF A PLURALITY OF COMPRESSED DOWNLINK SAMPLE BLOCKS (508(1)-508(N))
606
REDISTRIBUTE THE DOWNLINK COMPRESSION NOISE (N_{DL}) ASSOCIATED WITH EACH OF THE PLURALITY OF COMPRESSED DOWNLINK SAMPLE BLOCKS (508(1)-508(N)) ACROSS A SELECTED ONE OF THE DOWNLINK IN-BAND BANDWIDTH (304) AND THE DOWNLINK OUT-BAND BANDWIDTH (306)
608

FIG. 6

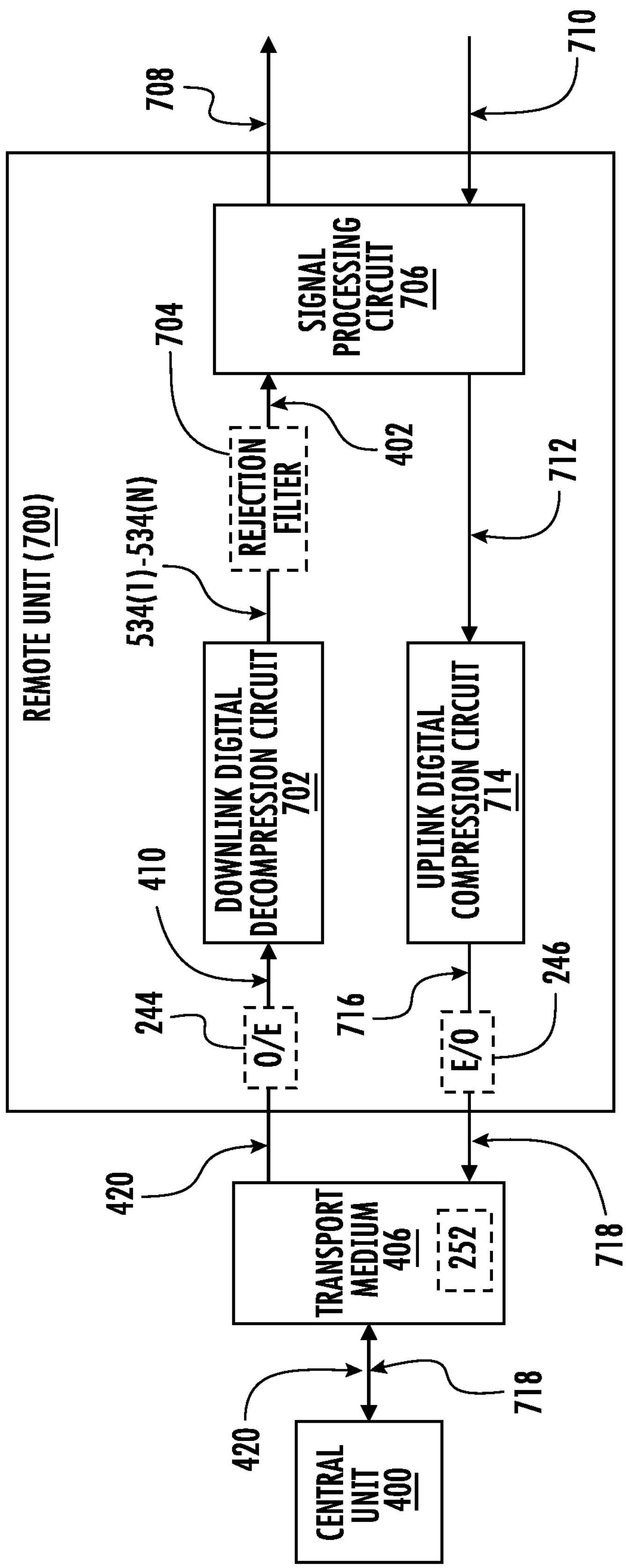

REMOTE UNIT (700)
DOWNLINK DIGITAL DECOMPRESSION CIRCUIT 702
UPLINK DIGITAL COMPRESSION CIRCUIT 714
REJECTION FILTER
SIGNAL PROCESSING CIRCUIT 706
TRANSPORT MEDIUM 406
252
CENTRAL UNIT 400
O/E
E/O
708
710
704
402
712
534(1)-534(N)
410
244
716
246
420
718
420
718

FIG. 7

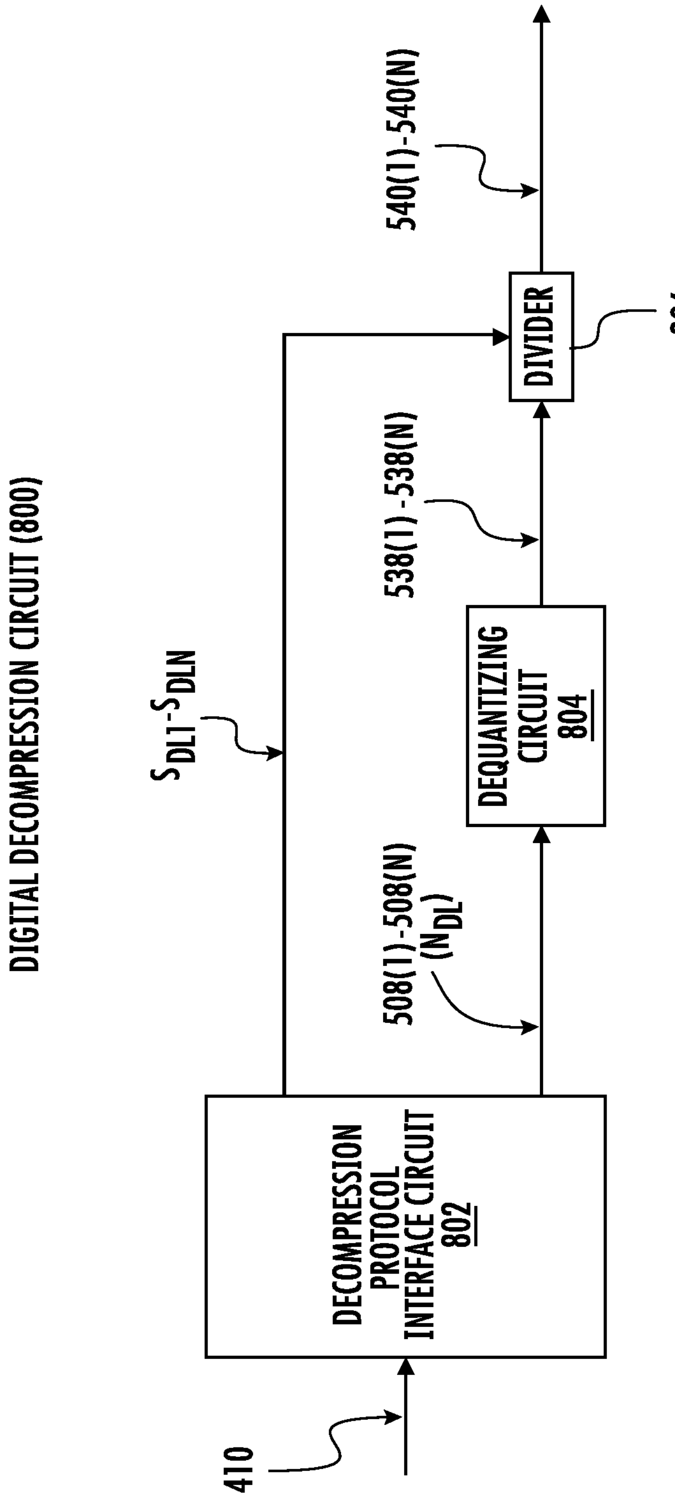

DIGITAL DECOMPRESSION CIRCUIT (800)
410
DECOMPRESSION PROTOCOL INTERFACE CIRCUIT 802
S_{DL1}-S_{DLN}
508(1)-508(N) (N_{DL})
DEQUANTIZING CIRCUIT 804
538(1)-538(N)
DIVIDER
806
540(1)-540(N)

FIG. 8

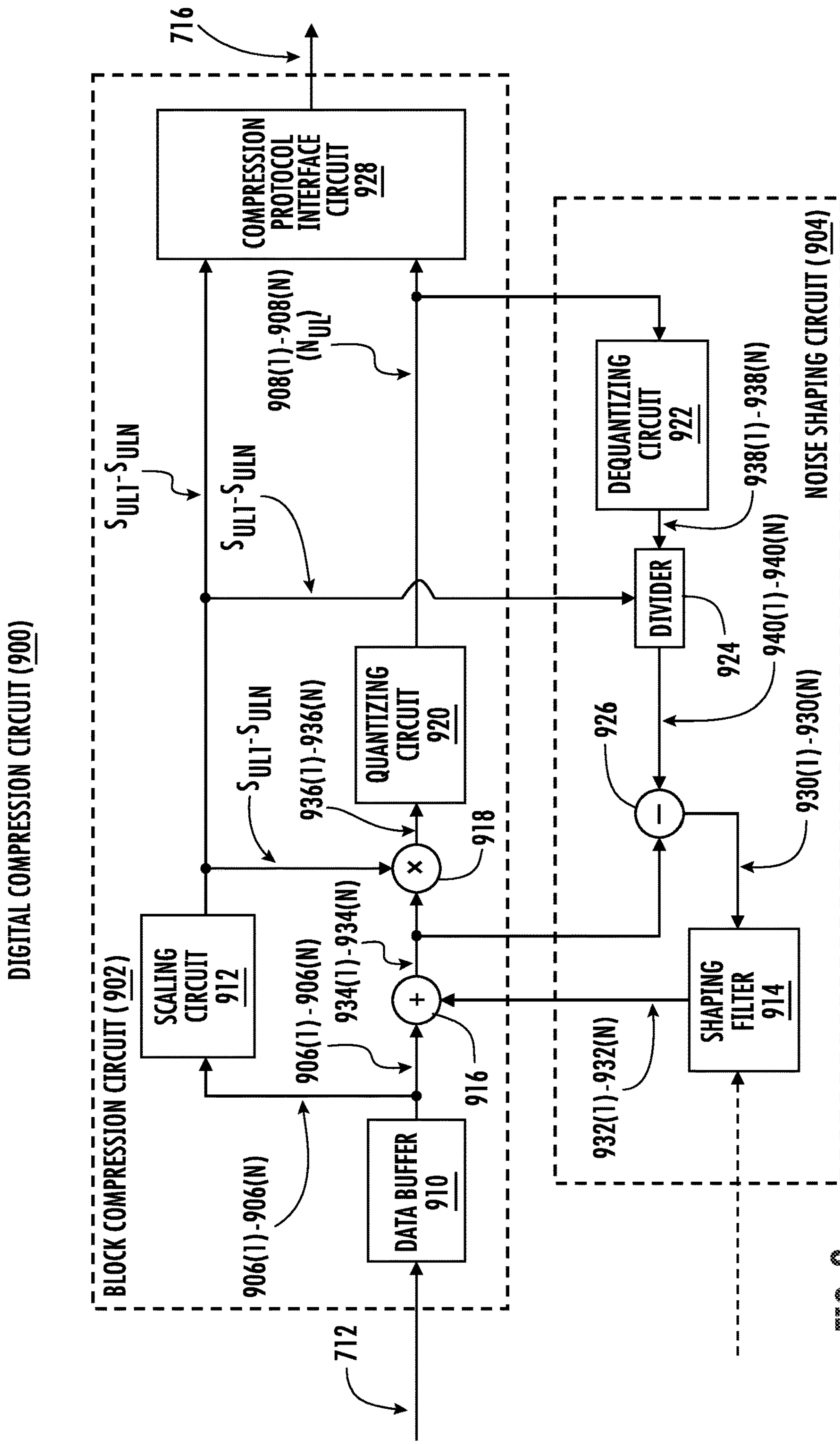
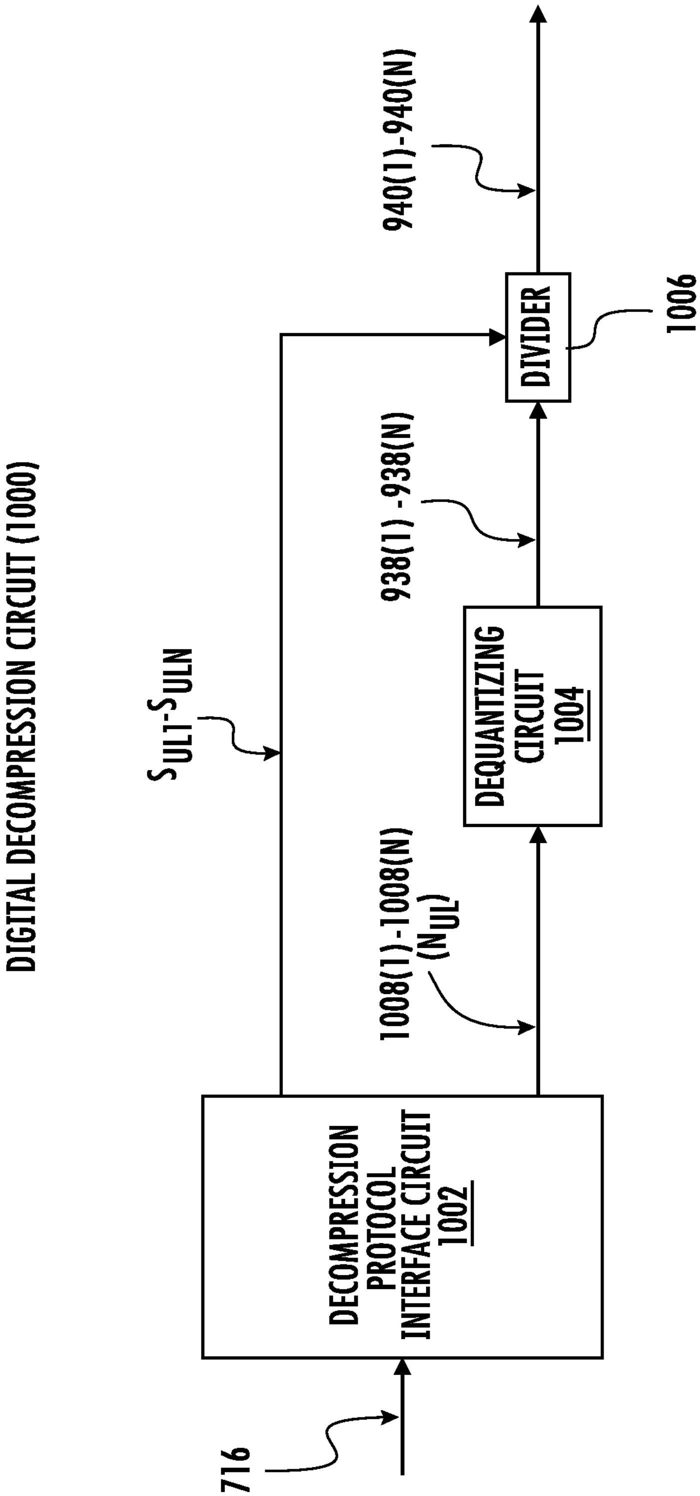

DIGITAL COMPRESSION CIRCUIT (900)
BLOCK COMPRESSION CIRCUIT (902)
NOISE SHAPING CIRCUIT (904)
COMPRESSION PROTOCOL INTERFACE CIRCUIT 928
716
908(1)-908(N) (N_{UL})
S_{ULT}-S_{ULN}
S_{ULT}-S_{ULN}
DEQUANTIZING CIRCUIT 922
938(1)-938(N)
DIVIDER
924
940(1)-940(N)
QUANTIZING CIRCUIT 920
S_{ULT}-S_{ULN}
936(1)-936(N)
918
926
930(1)-930(N)
SCALING CIRCUIT 912
906(1)-906(N)
934(1)-934(N)
916
SHAPING FILTER 914
932(1)-932(N)
906(1)-906(N)
DATA BUFFER 910
712

FIG. 9



DIGITAL DECOMPRESSION CIRCUIT (1000)
716
DECOMPRESSION PROTOCOL INTERFACE CIRCUIT 1002
S_{ULT}-S_{ULN}
1008(1)-1008(N) (N_{UL})
DEQUANTIZING CIRCUIT 1004
938(1) -938(N)
DIVIDER
1006
940(1)-940(N)

FIG. 10

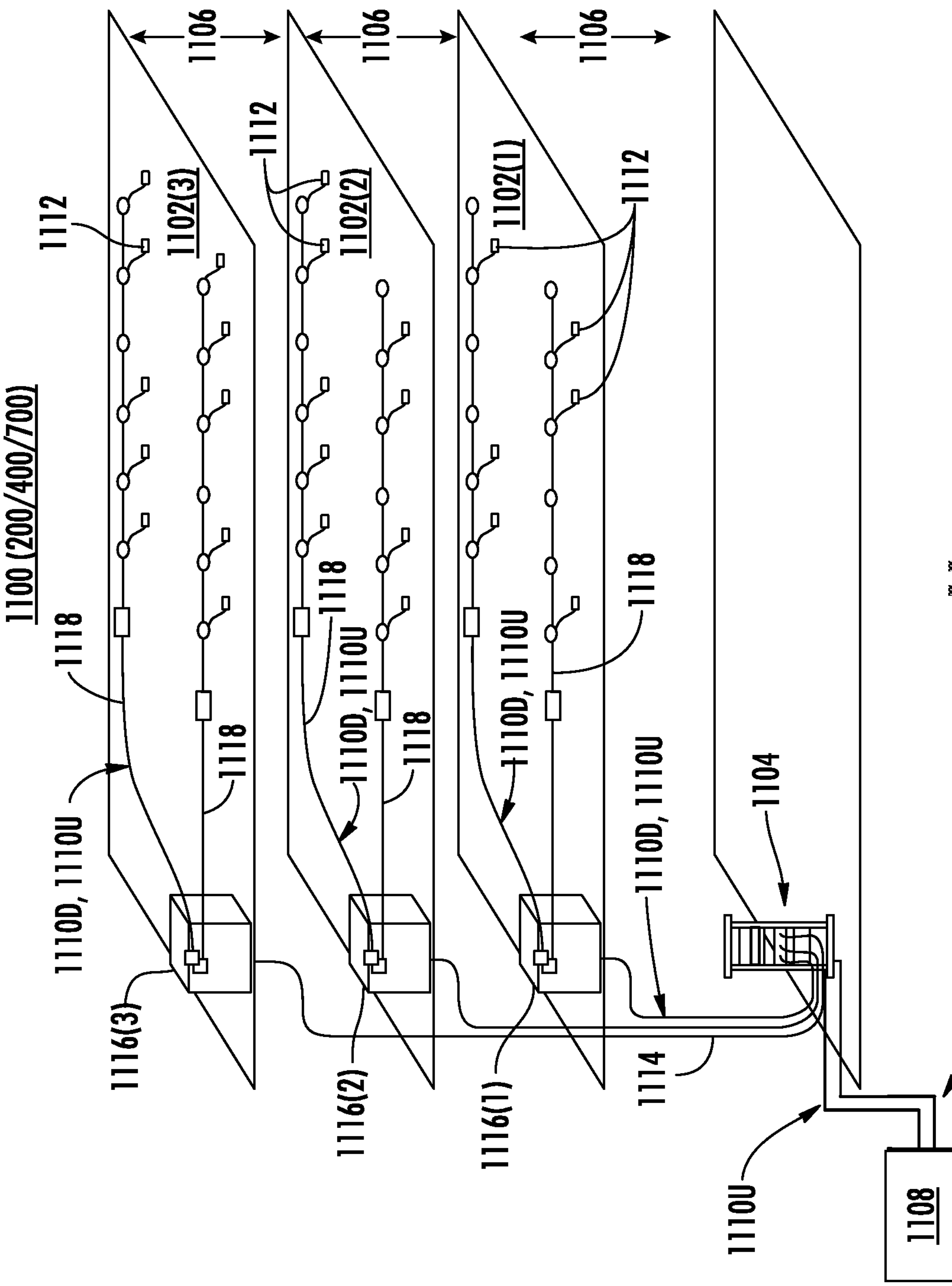

1100 (200/400/700)
1106
1106
1106
1112
1112
1112
1102(3)
1102(2)
1102(1)
1118
1118
1118
1118
1118
1118
1110D, 1110U
1110D, 1110U
1110D, 1110U
1110D, 1110U
1116(3)
1116(2)
1116(1)
1114
1104
1110D
1110U
1108

FIG. 11

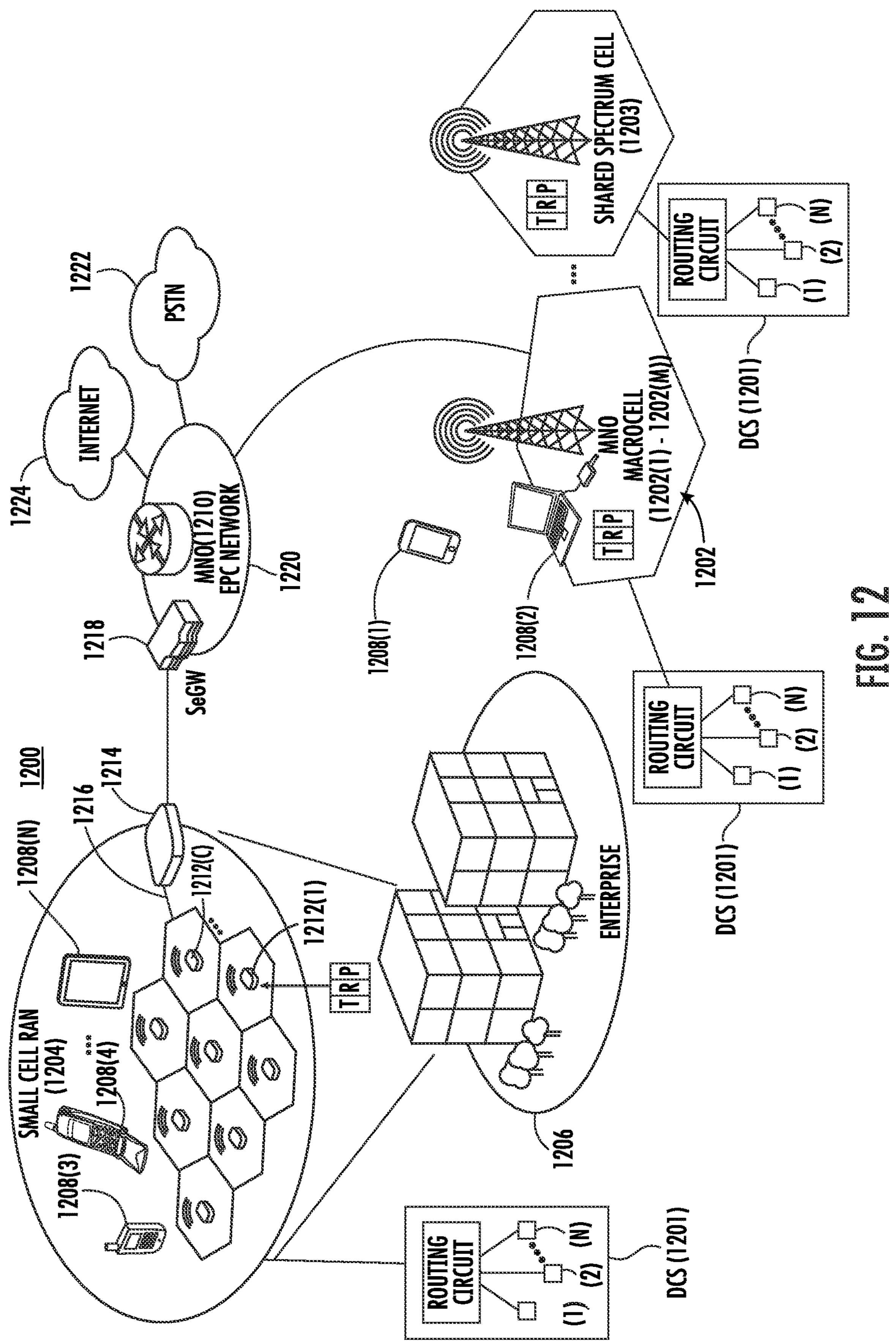

1200
SMALL CELL RAN
(1204)
1208(N)
1208(3)
1208(4)
1216
1214
1212(C)
1212(1)
TRP
ENTERPRISE
1206
ROUTING CIRCUIT
(1)
(2)
(N)
DCS (1201)
SeGW
1218
MNO(1210)
EPC NETWORK
1220
INTERNET
1224
PSTN
1222
1208(1)
1208(2)
MNO
MACROCELL
(1202(1) - 1202(M))
1202
SHARED SPECTRUM CELL
(1203)

FIG. 12

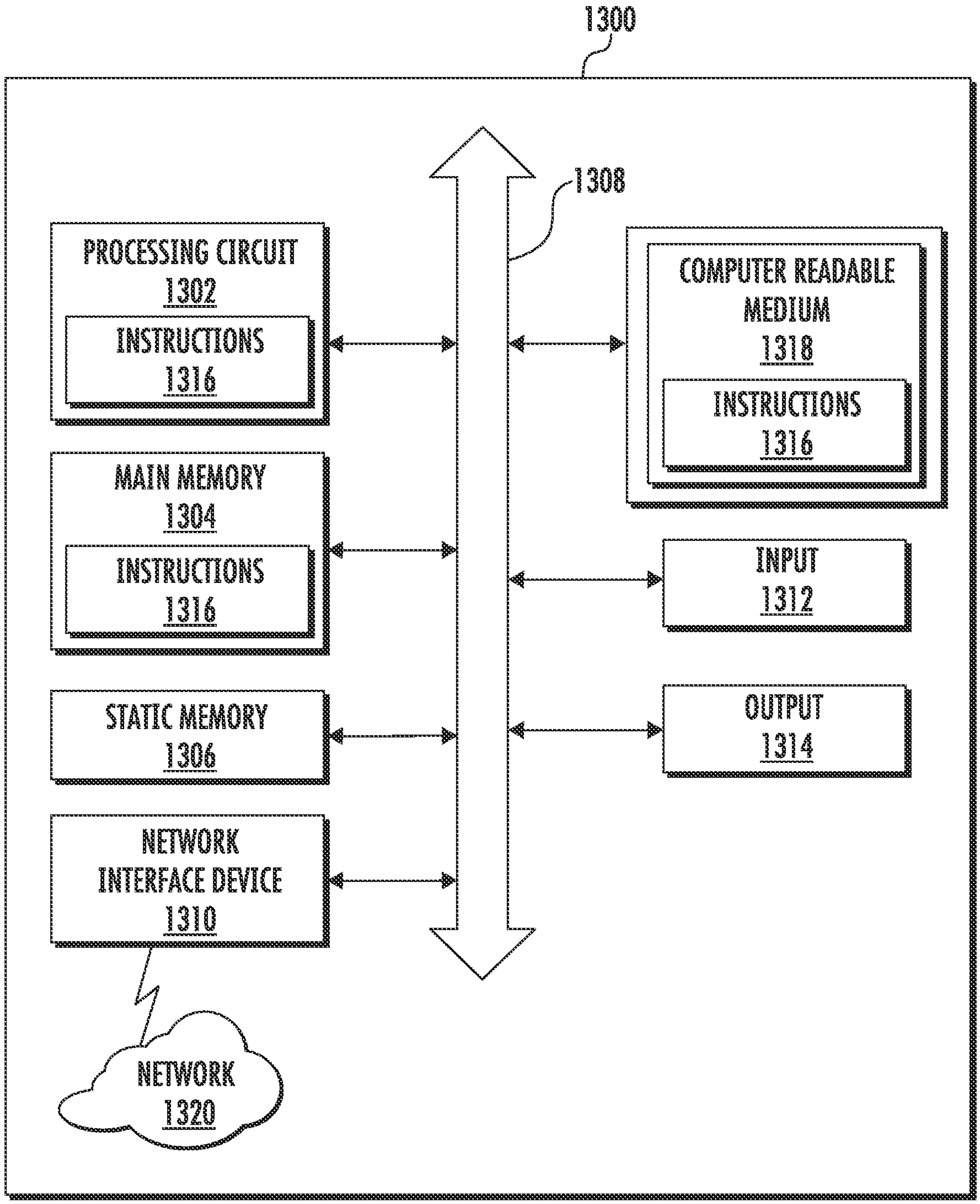

1300
1308
PROCESSING CIRCUIT
1302
INSTRUCTIONS
1316
MAIN MEMORY
1304
INSTRUCTIONS
1316
STATIC MEMORY
1306
NETWORK
INTERFACE DEVICE
1310
NETWORK
1320
COMPUTER READABLE
MEDIUM
1318
INSTRUCTIONS
1316
INPUT
1312
OUTPUT
1314

FIG. 13

SIGNAL COMPRESSION AND NOISE SHAPING IN A WIRELESS COMMUNICATIONS SYSTEM (WCS)

RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application Ser. No. 63/284,032, filed on Nov. 30, 2021, and entitled "SIGNAL COMPRESSION AND NOISE SHAPING IN A WIRELESS COMMUNICATIONS SYSTEM (WCS)," which is incorporated herein by reference in its entirety.

BACKGROUND

The disclosure relates generally to signal compression and noise shaping in a wireless communications system (WCS), which can include a fifth-generation (5G) or a 5G new-radio (5G-NR) system and/or a distributed communications system (DCS).

Wireless communication is rapidly growing, with ever-increasing demands for high-speed mobile data communication. As an example, local area wireless services (e.g., so-called "wireless fidelity" or "WiFi" systems) and wide area wireless services are being deployed in many different types of areas (e.g., coffee shops, airports, libraries, etc.). Communications systems have been provided to transmit and/or distribute communications signals to wireless devices called "clients," "client devices," or "wireless client devices," which must reside within the wireless range or "cell coverage area" in order to communicate with an access point device. Example applications where communications systems can be used to provide or enhance coverage for wireless services include public safety, cellular telephony, wireless local access networks (LANs), location tracking, and medical telemetry inside buildings and over campuses. One approach to deploying a communications system involves the use of radio nodes/base stations that transmit communications signals distributed over physical communications medium remote units forming radio frequency (RF) antenna coverage areas, also referred to as "antenna coverage areas." The remote units each contain or are configured to couple to one or more antennas configured to support the desired frequency(ies) of the radio nodes to provide the antenna coverage areas. Antenna coverage areas can have a radius in a range from a few meters up to twenty meters, as an example. Another example of a communications system includes radio nodes, such as base stations, that form cell radio access networks, wherein the radio nodes are configured to transmit communications signals wirelessly directly to client devices without being distributed through intermediate remote units.

For example, FIG. **1** illustrates a WCS **100**, such as a DCS, that is configured to distribute communications services to remote coverage areas **102**(**1**)-**102**(N), where 'N' is the number of remote coverage areas. The WCS **100** in FIG. **1** is provided in the form of a wireless DCS, such as a DAS **104**. The DAS **104** can be configured to support a variety of communications services that can include cellular communications services, such as fourth generation (4G) and/or fifth generation (5G) radio access network (RAN), wireless communications services, such as RF identification (RFID) tracking, Wi-Fi, local area network (LAN), and wireless LAN (WLAN), wireless solutions (Bluetooth, Wi-Fi, Global Positioning System (GPS) signal-based, and others) for location-based services, and combinations thereof, as examples. The remote coverage areas **102**(**1**)-**102**(N) are created by and centered on remote units **106**(**1**)-**106**(N) connected to a central unit **108** (e.g., a head-end controller, a central unit, or a head-end unit). The central unit **108** may be communicatively coupled to a signal source **110**, such as for example, a mobile service provider(s) and/or a network operator(s). In this regard, the central unit **108** receives downlink communications signals **112**D from the signal source **110** to be distributed to the remote units **106**(**1**)-**106**(N). The downlink communications signals **112**D can include data communications signals and/or communication signaling signals, as examples. The central unit **108** is configured with filtering circuits and/or other signal processing circuits that are configured to support a specific number of communications services in a particular frequency bandwidth (i.e., frequency communications bands). The downlink communications signals **112**D are communicated by the central unit **108** over a communications link **114** over their frequency to the remote units **106**(**1**)-**106**(N).

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

Because the remote units **106**(**1**)-**106**(N) include components that require power to operate, such as the RF transmitters/receivers **116**(**1**)-**116**(N) for example, it is necessary to provide power to the remote units **106**(**1**)-**106**(N). In one example, each remote unit **106**(**1**)-**106**(N) may receive power from a local power source. In another example, the remote units **106**(**1**)-**106**(N) may be powered remotely from a remote power source(s). For example, the central unit **108** in the WCS **100** in FIG. **1** includes a power source **122** that is configured to remotely supply power over the communications links **114** to the remote units **106**(**1**)-**106**(N). For example, the communications links **114** may be cable that includes electrical conductors for carrying current (e.g., direct current (DC)) to the remote units **106**(**1**)-**106**(N).

If the WCS **100** is an optical fiber-based DCS, the central unit **108** can be coupled to the remote units **106**(**1**)-**106**(N) via an optical communications network **124**, such as a passive optical network (PON). In this regard, the communications links **114** may by a "hybrid" cable that includes optical fibers for carrying the downlink and uplink communications signals **112**D, **112**U and separate electrical conductors for carrying current to the remote units **106**(**1**)-**106**(N).

As mentioned earlier, the DAS **104** can be configured to support 4G and/or 5G RAN services in the remote coverage areas **102**(**1**)-**102**(N). In this regard, the remote units **106**(**1**)-**106**(N) can each function as a 4G base station (a.k.a. eNodeB) and/or a 5G base station (a.k.a. gNodeB). The whole spectrum available for 4G and/or 5G networks is divided to multiple wireless channels each assigned to one or more of the remote coverage areas **102**(**1**)-**102**(N). In this regard, the remote units **106**(**1**)-**106**(N) are each configured to communicate with the UE **120** in a respective one of the remote coverage areas **102**(**1**)-**102**(N) in a passband of a respective wireless channel(s) assigned by the signal source **110**. For example, a 5G wireless channel can be associated with a bandwidth from 5 MHz to 100 MHz in frequency range one (FR1).

Each of the remote units **106**(**1**)-**106**(N) is required to meet stringent signal quality requirements as stipulated by standard bodies and/or regulatory authorities. Specifically, signal quality in a 4G/5G system can be measured by such performance metrics as error vector magnitude (EVM) and/or adjacent channel leakage ratio (ACLR).

The EVM, which is typically expressed in decibel (dB), measures a difference between an ideally transmitted constellation point(s) and a constellation point(s) actually received at an antenna port. In the 4G/5G system, the EVM is measured in frequency domain and only valid for a specific wireless channel bandwidth. Understandably, the lower the EVM is, the better the signal quality can be achieved in the passband of the respective wireless channel(s) to thereby support better performance in the remote coverage areas **102**(**1**)-**102**(N). The ACLR represents a ratio (typically in dB) between signal power in the passband of a wireless channel and signal/noise power in an adjacent wireless channel (e.g., assigned to a neighboring wireless coverage area). In this regard, the lower the ACLR is, the lower the interference can be in the adjacent wireless channel and therefore a better overall network performance can be achieved in the DAS **104**.

SUMMARY

Embodiments disclosed herein include signal compression and noise shaping in a wireless communications system (WCS). In embodiments disclosed herein, a block compression circuit is integrated with a noise shaping circuit to concurrently perform downlink/uplink signal compression and noise shaping in a central unit and/or a remote unit(s) in the WCS. More specifically, the block compression circuit is configured to perform block scaling compression on the downlink/uplink signal, which can cause a compression noise being distributed across an entire sampling bandwidth of the downlink/uplink signal. In this regard, the noise shaping circuit is configured to redistribute the compression noise from the entire sampling bandwidth to a selected portion of the sampling bandwidth (e.g., in-band bandwidth or out-band bandwidth). Accordingly, the redistributed compression noise can be effectively suppressed and/or filtered out when the downlink/uplink signal is received and decompressed. By concurrently performing block compression and noise shaping on the downlink/uplink signal, it is possible to achieve a good trade-off between compression ratio and latency, without compromising such quality metrics as error vector magnitude (EVM) and adjacent channel leakage ratio (ACLR) of the downlink/uplink signal.

One exemplary embodiment of the disclosure relates to a central unit in a WCS. The central unit includes a downlink digital compression circuit. The downlink digital compression circuit includes a downlink block compression circuit. The downlink block compression circuit is configured to receive at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth. The downlink block compression circuit is also configured to generate a plurality of downlink sample blocks based on the at least one downlink digital communications signal. The downlink block compression circuit is also configured to compress each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks. The downlink digital compression circuit also includes a downlink noise shaping circuit. The downlink noise shaping circuit is configured to cause a downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

An additional exemplary embodiment of the disclosure relates to a method for supporting signal compression and noise shaping in a WCS. The method includes receiving at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth. The method also includes generating a plurality of downlink sample blocks based on the at least one downlink digital communications signal. The method also includes compressing each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks. The method also includes redistributing a downlink compression noise associated with each of the plurality of compressed downlink sample blocks across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

An additional exemplary embodiment of the disclosure relates to a WCS. The WCS includes a plurality of remote units. The WCS also includes a central unit coupled to the plurality of remote units via a transport medium. The central unit is configured to distribute at least one compressed downlink digital communications signal to a respective one or more of the plurality of remote units. The central unit is also configured to receive at least one compressed uplink digital communications signal from the respective one or more of the plurality of remote units. The central unit includes a downlink digital compression circuit. The downlink digital compression circuit includes a downlink block compression circuit. The downlink block compression circuit is configured to receive at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth. The downlink block compression circuit is also configured to generate a plurality of downlink sample blocks based on the at least one downlink digital communications signal. The downlink block compression circuit is also configured to compress each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks. The downlink digital compression circuit also includes a downlink noise shaping circuit. The downlink noise shaping circuit is configured to cause a downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

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.

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

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

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an exemplary wireless communications system (WCS), such as a distributed communications system (DCS), configured to distribute communications services to remote coverage areas;

FIG. **2** is a schematic diagram of an exemplary WCS, which can be configured according to any of the embodiments disclosed herein to support signal compression and noise shaping;

FIG. **3** is a graphic diagram providing an exemplary illustration of a compression noise caused by block scaling compression and distributed across a sampling bandwidth;

FIG. **4** is a schematic diagram of an exemplary central unit, which can be provided in the WCS of FIG. **2**, to perform compression and noise shaping on at least one downlink digital communications signal;

FIG. **5** is a schematic diagram of an exemplary digital compression circuit, which can be provided in the central unit of FIG. **4** to function as a downlink digital compression circuit to perform compression and noise shaping on the downlink digital communications signal;

FIG. **6** is a flowchart of an exemplary process for supporting signal compression and noise shaping in the WCS of FIG. **2**;

FIG. **7** is a schematic diagram of an exemplary remote unit, which can be coupled to the central unit of FIG. **4** to perform compression and noise shaping on the at least one uplink digital communications signal;

FIG. **8** is a schematic diagram of an exemplary digital decompression circuit, which can be provided in the remote unit in FIG. **7** to function as a downlink digital decompression circuit;

FIG. **9** is a schematic diagram of an exemplary digital compression circuit, which can be provided in the remote unit of FIG. **7** to function as an uplink digital compression circuit to perform compression and noise shaping on the uplink digital communications signal;

FIG. **10** is a schematic diagram of an exemplary digital decompression circuit, which can be provided in the central unit in FIG. **4** to function as an uplink digital decompression circuit;

FIG. **11** is a partial schematic cut-away diagram of an exemplary building infrastructure in a WCS, such as the WCS of FIG. **2** that includes the central unit of FIG. **4** and the remote unit of FIG. **7** for supporting downlink and uplink signal compression and noise shaping;

FIG. **12** is a schematic diagram of an exemplary mobile telecommunications environment that can includes the WCS of FIG. **2** that includes the central unit of FIG. **4** and the remote unit of FIG. **7** for supporting downlink and uplink signal compression and noise shaping; and

FIG. **13** is a schematic diagram of a representation of an exemplary computer system that can be included in or interfaced with any of the components in the WCS of FIG. **2**, the central unit in FIG. **4**, and the remote unit in FIG. **7** for supporting downlink and uplink signal compression and noise shaping, wherein the exemplary computer system is configured to execute instructions from an exemplary computer-readable medium.

DETAILED DESCRIPTION

Embodiments disclosed herein include signal compression and noise shaping in a wireless communications system (WCS). In embodiments disclosed herein, a block compression circuit is integrated with a noise shaping circuit to concurrently perform downlink/uplink signal compression and noise shaping in a central unit and/or a remote unit(s) in the WCS. More specifically, the block compression circuit is configured to perform block scaling compression on the downlink/uplink signal, which can cause a compression noise being distributed across an entire sampling bandwidth of the downlink/uplink signal. In this regard, the noise shaping circuit is configured to redistribute the compression noise from the entire sampling bandwidth to a selected portion of the sampling bandwidth (e.g., in-band bandwidth or out-band bandwidth). Accordingly, the redistributed compression noise can be effectively suppressed and/or filtered out when the downlink/uplink signal is received and decompressed. By concurrently performing block compression and noise shaping on the downlink/uplink signal, it is possible to achieve a good trade-off between compression ratio and latency, without compromising such quality metrics as error vector magnitude (EVM) and adjacent channel leakage ratio (ACLR) of the downlink/uplink signal.

In this regard, FIG. **2** is a schematic diagram of an exemplary WCS **200**, which can be configured according to any of the embodiments disclosed herein to support signal compression and noise shaping. The WCS **200** supports both legacy 4G LTE, 4G/5G non-standalone (NSA), and 5G standalone communications systems. As shown in FIG. **2**, a centralized services node **202** is provided that is configured to interface with a core network to exchange communications data and distribute the communications data as radio signals to remote units. In this example, the centralized services node **202** is configured to support distributed communications services to an mmWave radio node **204**. Despite that only one mmWave radio node **204** is shown in FIG. **2**, it should be appreciated that the WCS **200** can be configured to include additional numbers of the mmWave radio node **204**, as needed. The functions of the centralized services node **202** can be virtualized through an x2 interface **206** to another services node **208**. The centralized services node **202** can also include one or more internal radio nodes that are configured to be interfaced with a distribution unit (DU) **210** to distribute communications signals to one or more open radio access network (O-RAN) remote units (RUs) **212** that are configured to be communicatively coupled through an O-RAN interface **214**. The O-RAN RUs **212** are each configured to communicate downlink and uplink communications signals in a respective coverage cell.

The centralized services node **202** can also be interfaced with a distributed communications system (DCS) **215** through an x2 interface **216**. Specifically, the centralized services node **202** can be interfaced with a central unit **217**.

The central unit **217** includes a digital baseband unit (BBU) **218** that can provide a digital signal source to the centralized services node **202**. The digital BBU **218** may be configured to provide a signal source to the centralized services node **202** to provide downlink communications signals **220**D to a digital routing unit (DRU) **222**, which is also included in the central unit **217**, as part of a digital distributed antenna system (DAS). The DRU **222** is configured to split and distribute the downlink communications signals **220**D to different types of remote units, including a low-power remote unit (LPR) **224**, a radio antenna unit (dRAU) **226**, a mid-power remote unit (dMRU) **228**, and a high-power remote unit (dHRU) **230**. The DRU **222** is also configured to combine uplink communications signals **220**U received from the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** and provide the combined uplink communications signals to the digital BBU **218**. The digital BBU **218** is also configured to interface with a third-party central unit **232** and/or an analog source **234** through a radio frequency (RF)/digital converter **236**.

The DRU **222** may be coupled to the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** via an optical fiber-based communications medium **238**. In this regard, the DRU **222** can include a respective electrical-to-optical (E/O) converter **240** and a respective optical-to-electrical (O/E) converter **242**. Likewise, each of the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** can include a respective E/O converter **244** and a respective O/E converter **246**.

The E/O converter **240** at the DRU **222** is configured to convert the downlink communications signals **220**D into downlink optical communications signals **248**D for distribution to the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** via the optical fiber-based communications medium **238**. The O/E converter **246** at each of the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** is configured to convert the downlink optical communications signals **248**D back to the downlink communications signals **220**D. The E/O converter **244** at each of the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** is configured to convert the uplink communications signals **220**U into uplink optical communications signals **248**U. The O/E converter **242** at the DRU **222** is configured to convert the uplink optical communications signals **248**U back to the uplink communications signals **220**U.

In an embodiment, the services node **208** can serve a signal source that generates the downlink communications signals **220**D and receives the uplink communications signals **220**U. The LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230**, which can be collectively referred to as remote units **250**, are each coupled to the services node **208** based on non-cooperative connectivity. Herein, non-cooperative connectivity means that the LPR **224**, the dRAU **226**, the dMRU **228**, and the dHRU **230** are not time-synchronized with the services node **208** and do not receive any control signaling and/or real time trigger from the services node **208**.

The central unit **217** may be coupled to the remote units **250** via a transport medium unit(s) (TMU) **252** as part of the optical fiber-based communications medium **238** to perform signal aggregation, summation, and distribution. In this regard, the downlink communications signals **220**D and/or the uplink communications signals **220**U are sampled in the form of digital samples characterized by sampling frequency and sampling bit width (a.k.a. number of bits per sample). Given that the downlink communications signals **220**D and/or the uplink communications signals **220**U can be related to multiple mobile service providers and communicated in multiple signal channels, the TMU **252** may become a bottleneck that can hinder the ability of the WCS **200** to handle an increasing demand for higher data throughput. As such, it is often necessary to compress the downlink communications signals **220**D and/or the uplink communications signals **220**U to help ease the throughput demand and cost pressure on the TMU **252**.

In this regard, the WCS **200** can be configured according to embodiments disclosed in the present disclosure to concurrently perform signal compression and noise shaping on the downlink communications signals **220**D and/or the uplink communications signals **220**U. Specifically, the central unit **217** can be configured to compress the downlink communications signals **220**D, and the remote units **250** can be configured to compress the uplink communications signals **220**U. In an embodiment, the central unit **217** and the remote units **250** can be configured to compress the downlink communications signals **220**D and/or the uplink communications signals **220**U, respectively, based on any block scaling compression algorithm (e.g., block scaling, block floating point, block scaling with mu-law quantization, etc.). Understandably, by compressing the downlink communications signals **220**D and/or the uplink communications signals **220**U, it is possible to mitigate the throughput bottleneck caused by the TMU **252**, thus helping to avoid or reduce upgrading cost of the TMU **252**.

However, as illustrated in FIG. **3**, the block scaling compression algorithm can typically produce a frequency flat quantization error (a.k.a. compression noise) in an entire sampling bandwidth, which may not be desirable from a practical point of view. FIG. **3** is a graphic diagram providing an exemplary illustration of a compression noise **300** caused by block scaling compression and distributed across a sampling bandwidth **302**.

The downlink communications signals **220**D and/or the uplink communications signals **220**U in FIG. **2** are typically sampled at the sampling bandwidth **302** that is wider than an in-band bandwidth **304** (a.k.a. passband bandwidth) of the downlink communications signals **220**D and/or the uplink communications signals **220**U. For example, the sampling bandwidth and the in-band bandwidth as specified by common public radio interface (CPRI) standard are 7.68 MHz and 5 MHz, respectively. In this regard, the difference between the sampling bandwidth **302** and the in-band bandwidth **304** can be referred to as an out-band bandwidth **306**.

According to earlier discussions in FIG. **1**, the WCS **200** is required to satisfy both error vector magnitude (EVM) requirements in the in-band bandwidth **304** and adjacent channel leakage ratio (ACLR) requirements in the out-band bandwidth **306**. However, as shown in FIG. **3**, the compression noise **300** caused by block scaling compression is distributed across both the in-band bandwidth **304** and the out-band bandwidth **306**. If the compression noise **300** is not adequately suppressed, the compression noise **300** may negatively impact the EVM in the in-band bandwidth **304** and the ACLR in the out-band bandwidth **306**. Thus, it is desirable to effectively compress the downlink communications signals **220**D and/or the uplink communications signals **220**U without negatively impacting EVM and ACLR performance.

With reference back to FIG. **2**, to help improve the EVM and the ACLR, the central unit **217** and the remote units **250** are further configured to perform noise shaping concurrent to performing block scaling compression. In an embodiment, the central unit **217** can perform noise shaping on the downlink communications signals **220**D based on whether the remote units **250** are equipped with out-band noise filtering capability to effectively suppress the compression noise **300** in the out-band bandwidth **306**. More specifically, the central unit **217** can redistribute the compression noise **300** across the out-band bandwidth **306** if the remote units **250** are equipped with out-band noise filtering capability. Alternatively, the central unit **217** can redistribute the compression noise **300** across the in-band bandwidth **304** if the remote units **250** are not equipped with out-band noise filtering capability. The remote units **250**, on the other hand, can always assume that the central unit **217** has the out-band noise filtering capability. Accordingly, the remote units **250** can perform noise shaping on the uplink communications signals **220**U to redistribute the compression noise **300** across the in-band bandwidth **304**. By performing noise shaping concurrent to signal compression, it is possible to achieve a good trade-off between compression ratio and latency, without compromising such quality metrics as EVM and ACLR, thus helping to improve throughput and performance of the WCS **200**.

FIG. **4** is a schematic diagram of an exemplary central unit **400**, which can be provided in the WCS **200** of FIG. **2**, to perform compression and noise shaping on at least one downlink digital communications signal **402**. Common elements between FIGS. **2** and **4** are shown therein with common element numbers and will not be re-described herein.

In a non-limiting example, the central unit **400** can replace or be functionally equivalent to the central unit **217** in the WCS **200**. In this regard, the central unit **400** may be coupled between a signal source **404** (e.g., mobile service provider) and a transport medium **406**. The transport medium **406**, which may include the TMU **252**, is further coupled to the remote units **250**.

The central unit **400** includes a downlink digital compression circuit **408**. The downlink digital compression circuit **408** is configured to perform compression and noise shaping on the downlink digital communications signal **402** to thereby generate at least one compressed downlink digital communications signal **410**. A specific embodiment of the downlink digital compression circuit **408** is further illustrated in FIG. **5**.

FIG. **5** is a schematic diagram of an exemplary digital compression circuit **500**, which can be provided in the central unit **400** of FIG. **4** to function as the downlink digital compression circuit **408**. Common elements between FIGS. **4** and **5** are shown therein with common element numbers and will not be re-described herein.

In an embodiment, the digital compression circuit **500** includes a block compression circuit **502** (a.k.a. "downlink block compression circuit") and a noise shaping circuit **504** (a.k.a. "downlink noise shaping circuit"). Notably, the block compression circuit **502** and the noise shaping circuit **504** are illustrated as separate circuits merely for the convenience of reference. It should be appreciated that the block compression circuit **502** and the noise shaping circuit **504** are in fact integrated into the digital compression circuit **500** without any physical boundary and/or separation.

The block compression circuit **502** is configured to receive the downlink digital communications signal **402**, which is sampled based on a downlink sampling bandwidth, as shown in FIG. **3** as the sampling bandwidth **302**. As discussed in FIG. **3**, the downlink sampling bandwidth includes a downlink in-band bandwidth (shown in FIG. **3** as the in-band bandwidth **304**) and a downlink out-band bandwidth (as shown in FIG. **3** as the out-band bandwidth **306**). The block compression circuit **502** is also configured to generate a plurality of downlink sample blocks **506**(**1**)-**506**(N) based on the downlink digital communications signal **402**. Accordingly, the block compression circuit **502** compress each of the downlink sample blocks **506**(**1**)-**506**(N) based on a respective one of a plurality of downlink scaling factors S_{DL1}-S_{DLN} to generate a respective one of a plurality of compressed downlink sample blocks **508**(**1**)-**508**(N). Understandably from FIG. **3**, the block compression performed by the block compression circuit **502** can cause a downlink compression noise N_{DL} across the downlink sampling bandwidth (e.g., the sampling bandwidth **302** in FIG. **3**) of each of the compressed downlink sample blocks **508**(**1**)-**508**(N). The noise shaping circuit **504** is configured to cause the downlink compression noise N_{DL} associated with each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to be redistributed across a selected one of the downlink in-band bandwidth (e.g., the in-band bandwidth **304** in FIG. **3**) and the downlink out-band bandwidth (e.g., the out-band bandwidth **306** in FIG. **3**).

In an embodiment, the digital compression circuit **500** includes a data buffer **510**, a scaling circuit **512**, a shaping filter **514**, a combiner **516**, a multiplier **518**, a quantizing circuit **520**, a dequantizing circuit **522**, a divider **524**, a subtractor **526**, and a compression protocol interface circuit **528**. The data buffer **510** is configured to generate the downlink sample blocks **506**(**1**)-**506**(N) from the downlink digital communications signal **402**. The scaling circuit **512** is configured to determine a respective one of the downlink scaling factors S_{DL1}-S_{DLN} for each of the downlink sample blocks **506**(**1**)-**506**(N).

The shaping filter **514** is configured to receive a respective one of a plurality of downlink quantization error samples **530**(**1**)-**530**(N) associated with each of the compressed downlink sample blocks **508**(**1**)-**508**(N). Accordingly, the shaping filter **514** generates a respective one of a plurality of downlink noise samples **532**(**1**)-**532**(N) based on each of the downlink quantization error samples **530**(**1**)-**530**(N). In a non-limiting example, the shaping filter **514** can be a finite impulse response (FIR) or an infinite impulse response (IIR) filter. In this regard, a coefficient of the shaping filter **514** can be calculated statically or dynamically (e.g., adaptive filtering) with one of known filter design methods, such as an effective filter vector h'=[1 h], and can have a desired frequency response. Notably, the effective filter vector h' should be a minimal-phase filter that does not introduce additional sampling latency.

The combiner **516** is configured to combine samples of each of the downlink sample blocks **506**(**1**)-**506**(N) with a respective one of the downlink noise samples **532**(**1**)-**532**(N) to generate a respective one of a plurality of noise-added downlink sample blocks **534**(**1**)-**534**(N) to thereby cause the downlink compression noise N_{DL} associated with each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to be redistributed to either the downlink in-band bandwidth **304** or the downlink out-band bandwidth **306**.

The multiplier **518** is configured to multiply each of the noise-added downlink sample blocks **534**(**1**)-**534**(N) with a respective one of the downlink scaling factors S_{DL1}-S_{DLN} to generate a respective one of a plurality of scaled noise-added downlink sample blocks **536**(**1**)-**536**(N). The quantizing circuit **520** is configured to compress each of the scaled noise-added downlink sample blocks **536**(**1**)-**536**(N) to generate a respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N).

The dequantizing circuit **522** is configured to decompress each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to generate a respective one of a plurality of scaled noise-added downlink sample feedbacks **538**(**1**)-**538**(N). The divider **524** is configured to divide each of the scaled noise-added downlink sample feedbacks **538**(**1**)-**538**(N) by a respective one of the downlink scaling factors S_{DL1}-S_{DLN} to generate a respective one of a plurality of noise-added downlink sample feedbacks **540**(**1**)-**540**(N). The subtractor **526** is configured to subtract each of the noise-added downlink sample feedbacks **540**(**1**)-**540**(N) by a respective one of the noise-added downlink sample blocks **534**(**1**)-**534**(N) to generate a respective one of the downlink quantization error samples **530**(**1**)-**530**(N). Accordingly, the divider **524** provides the downlink quantization error samples **530**(**1**)-**530** (N) to the shaping filter **514**.

The compression protocol interface circuit **528** is configured to generate the compressed downlink digital communications signal **410** based on the compressed downlink sample blocks **508**(**1**)-**508**(N) and the downlink scaling factors S_{DL1}-S_{DLN}. In an embodiment, the compressed downlink digital communications signal **410** includes a plurality of downlink protocol data units (PDUs), such as CPRI PDUs. Each of the downlink PDUs includes a respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N) and a respective one of the downlink scaling factors S_{DL1}-S_{DLN}. For example, each of the PDUs can include a first number of bits for carrying the respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N) and a second number of bits for carrying the respective one of the downlink scaling factors S_{DL1}-S_{DLN}. As discussed later, the respective one of the downlink scaling factors S_{DL1}-S_{DLN} in each of the downlink PDUs can be used to decompress the respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N).

By employing the digital compression circuit **500** as the downlink digital compression circuit **408**, the central unit **400** of FIG. **4** can be configured to perform signal compression and noise shaping for the downlink digital communications signal **402** based on a process. In this regard. FIG. **6** is a flowchart of an exemplary process **600** for supporting signal compression and noise shaping in the WCS **200** of FIG. **2**.

According to the process **600**, the downlink digital compression circuit **408** is configured to receive the downlink digital communications signal **402** sampled based on the downlink sampling bandwidth **302** that includes the downlink in-band bandwidth **304** and the downlink out-band bandwidth **306** (block **602**). The downlink digital compression circuit **408** is also configured to generate the downlink sample blocks **506**(**1**)-**506**(N) based on the downlink digital communications signal **402** (block **604**). The downlink digital compression circuit **408** is configured to compress each of the downlink sample blocks **506**(**1**)-**506**(N) based on a respective one of the downlink scaling factors S_{DL1}-S_{DLN} to generate a respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N) (block **606**). The downlink digital compression circuit **408** is also configured to cause the downlink compression noise N_{DL} associated with each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to be redistributed across the selected one of the downlink in-band bandwidth **304** and the downlink out-band bandwidth **306** (block **608**).

With reference back to FIG. **4**, in an embodiment, the central unit **400** includes a control circuit **412**, which can be a field-programmable gate array (FPGA), as an example. The control circuit **412** may be configured to determine whether to redistribute the downlink compression noise N_{DL} to the downlink in-band bandwidth **304** or the downlink out-band bandwidth **306** based on the out-band noise filtering capability of a respective one or more of the remote units **250** and provides an indication **414** to the downlink digital compression circuit **408**. If the indication **414** indicates that the respective one or more of the remote units **250** do not have the out-band noise filtering capability, the downlink digital compression circuit **408** may operate to redistribute the downlink compression noise N_{DL} in each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to the downlink in-band bandwidth **304**. In contrast, if the indication **414** indicates that the respective one or more of the remote units **250** do have the out-band noise filtering capability, the downlink digital compression circuit **408** may operate to redistribute the downlink compression noise N_{DL} in each of the compressed downlink sample blocks **508**(**1**)-**508**(N) to the downlink out-band bandwidth **306**.

The central unit **400** may further include a storage circuit **416**, which can be a flash storage device or a register bank, as an example. The storage circuit **416** may be configured to store an out-band filter configuration for each of the remote units **250**. In this regard, the control circuit **412** may determine the out-band noise filtering capability of the respective one or more of the remote units **250** based on the stored out-band filter configuration.

The central unit **400** further includes a digital routing circuit **418** that couples the downlink digital compression circuit **408** with the transport medium **406**. In a non-limiting example, the transport medium **406** can be an optical fiber-based transport medium. In this regard, the central unit **400** can include the E/O converter **240** to convert the compressed downlink digital communications signal **410** into a compressed downlink optical communications signal **420** for distribution to the remote units **250**. The remote units **250** may each include the respective O/E converter **244** to convert the compressed downlink optical communications signal **420** back to the compressed downlink digital communications signal **410**.

Each of the remote units **250** is configured to decompress the compressed downlink digital communications signal **410** for transmission in a radio frequency (RF) band. In this regard, FIG. **7** is a schematic diagram of an exemplary remote unit **700**, which can be coupled to the central unit **400** of FIG. **4** as any of the remote units **250**. Common elements between FIGS. **4**, **5**, and **7** are shown therein with common element numbers and will not be re-described herein.

In one aspect, the remote unit **700** is configured to decompress the compressed downlink digital communications signal **410** to recover the downlink digital communications signal **402**. In this regard, the remote unit **700** includes a downlink digital decompression circuit **702**, as illustrated in FIG. **8**. FIG. **8** is a schematic diagram of an exemplary digital decompression circuit **800**, which can be provided in the remote unit **700** of FIG. **7** to function as the downlink digital decompression circuit **702**. Common elements between FIGS. **4**, **5**, **7**, and **8** are shown therein with common element numbers and will not be re-described herein.

In an embodiment, the digital decompression circuit **800** includes a decompression protocol interface circuit **802**, a decompression dequantizing circuit **804**, and a decompression divider **806**. The decompression protocol interface circuit **802** is configured to extract a respective one of the compressed downlink sample blocks **508**(**1**)-**508**(N) and a respective one of the downlink scaling factors S_{DL1}-S_{DLN} from each of the downlink PDUs received in the compressed downlink digital communications signal **410**. The decompression dequantizing circuit **804** is configured to decompress each of the compressed downlink sample blocks

508(1)-508(N) to generate a respective one of the scaled noise-added downlink sample feedbacks 538(1)-538(N). The decompression divider 806 is configured to divide each of the scaled noise-added downlink sample feedbacks 538 (1)-538(N) by a respective one of the downlink scaling factors S_{DL1}-S_{DLN} to generate a respective one of the noise-added downlink sample feedbacks 540(1)-540(N). As a result of the compression and noise shaping performed by the central unit 400 of FIG. 4, the downlink compression noise N_{DL} has been redistributed across the downlink in-band bandwidth 304 or the downlink out-band bandwidth 306 in each of the noise-added downlink sample feedbacks 540(1)-540(N).

With reference back to FIG. 7, the remote unit 700 may or may not include a rejection filter 704, which defines the out-band noise filtering capability of the remote unit 700. Herein, the remote unit 700 is said to have the out-band noise filtering capability when the rejection filter 704 is present in the remote unit 700. In contrast, the remote unit 700 is said to lack the out-band noise filtering capability when the rejection filter 704 is absent from the remote unit 700. As previously discussed in FIG. 4, the downlink digital compression circuit 408 in the central unit 400 would redistribute the downlink compression noise N_{DL} to the out-band bandwidth 306 when the remote unit 700 is determined to have the out-band noise filtering capability. As such, the rejection filter 704 can be configured to suppress the downlink compression noise N_{DL} associated with each of the scaled noise-added downlink sample feedbacks 538(1)-538(N) in the downlink out-band bandwidth 306 to obtain the downlink digital communications signal 402. Otherwise, the downlink digital communications signal 402 will include the scaled noise-added downlink sample feedbacks 538(1)-538(N) in the downlink in-band bandwidth 304.

The remote unit 700 includes a signal processing circuit 706. The signal processing circuit 706 is configured to convert the downlink digital communications signal 402 into at least one downlink radio frequency (RF) communications signal 708 for transmission over an RF spectrum. The signal processing circuit 706 also receives at least one uplink RF communications signal 710 via the RF spectrum and converts the uplink RF communications signal 710 into at least one uplink digital communications signal 712.

In another aspect, the remote unit 700 is configured perform compression and noise shaping on at least one uplink digital communications signal 712. In this regard, the remote unit 700 also includes an uplink digital compression circuit 714 to perform compression and noise shaping on the uplink digital communications signal 712 to thereby generate at least one compressed uplink digital communications signal 716. The respective E/O converter 246 may convert the compressed uplink digital communications signal 716 into at least one compressed uplink optical communications signal 718 for transmission to the central unit 400 via the transport medium 406.

The uplink digital compression circuit 714 may be implemented in a similar way as the downlink digital compression circuit 408 in the central unit 400. In this regard, FIG. 9 is a schematic diagram of an exemplary digital compression circuit 900, which can be provided in the remote unit 700 of FIG. 7 to function as the uplink digital compression circuit 714. Common elements between FIGS. 5, 7, and 9 are shown therein with common element numbers and will not be re-described herein.

In an embodiment, the digital compression circuit 900 includes a block compression circuit 902 (a.k.a. "uplink block compression circuit") and a noise shaping circuit 904 (a.k.a. "uplink noise shaping circuit"). Notably, the block compression circuit 902 and the noise shaping circuit 904 are illustrated as separate circuits merely for the convenience of reference. It should be appreciated that the block compression circuit 902 and the noise shaping circuit 904 are in fact integrated into the digital compression circuit 900 without any physical boundary and/or separation.

The block compression circuit 902 is configured to receive the uplink digital communications signal 712, which is sampled based on an uplink sampling bandwidth, as shown in FIG. 3 as the sampling bandwidth 302. As discussed in FIG. 3, the uplink sampling bandwidth includes an uplink in-band bandwidth (shown in FIG. 3 as the in-band bandwidth 304) and an uplink out-band bandwidth (shown in FIG. 3 as the out-band bandwidth 306). The block compression circuit 902 is also configured to generate a plurality of uplink sample blocks 906(1)-906(N) based on the uplink digital communications signal 712. Accordingly, the block compression circuit 902 compresses each of the uplink sample blocks 906(1)-906(N) based on a respective one of a plurality of uplink scaling factors S_{UL1}-S_{ULN} to generate a respective one of a plurality of compressed uplink sample blocks 908(1)-908(N). Understandably from FIG. 3, the block compression performed by the block compression circuit 902 can cause an uplink compression noise N_{UL} across the uplink sampling bandwidth (e.g., the sampling bandwidth 302 in FIG. 3) of each of the compressed uplink sample blocks 908(1)-908(N). It may be assumed that the central unit 400 will always have the out-band noise filtering capability. As such, the noise shaping circuit 904 is configured to cause the uplink compression noise N_{UL} associated with each of the compressed uplink sample blocks 908(1)-908(N) to be redistributed across the uplink out-band bandwidth (e.g., the out-band bandwidth 306 in FIG. 3).

In an embodiment, the digital compression circuit 900 includes a data buffer 910, a scaling circuit 912, a shaping filter 914, a combiner 916, a multiplier 918, a quantizing circuit 920, a dequantizing circuit 922, a divider 924, a subtractor 926, and a compression protocol interface circuit 928. The data buffer 910 is configured to generate the uplink sample blocks 906(1)-906(N) from the uplink digital communications signal 712. The scaling circuit 912 is configured to determine a respective one of the uplink scaling factors S_{UL1}-S_{ULN} for each of the uplink sample blocks 906(1)-906(N).

The shaping filter 914 is configured to receive a respective one of a plurality of uplink quantization error samples 930(1)-930(N) associated with each of the compressed uplink sample blocks 908(1)-908(N). Accordingly, the shaping filter 914 generates a respective one of a plurality of uplink noise samples 932(1)-932(N) based on each of the uplink quantization error samples 930(1)-930(N). In a non-limiting example, the shaping filter 914 can be a finite impulse response (FIR) or an infinite impulse response (IIR) filter. In this regard, a coefficient of the shaping filter 914 can be calculated statically or dynamically (e.g., adaptive filtering) with one of the known filter design methods, such as an effective filter vector h'=[1 h], and can have a desired frequency response. Notably, the effective filter vector h' should be a minimal-phase filter that does not introduce additional sampling latency.

The combiner 916 is configured to combine samples of each of the uplink sample blocks 906(1)-906(N) with a respective one of the uplink noise samples 932(1)-932(N) to generate a respective one of a plurality of noise-added uplink sample blocks 934(1)-934(N) to thereby cause the uplink compression noise N_{UL} associated with each of the compressed uplink sample blocks **908**(**1**)-**908**(N) to be redistributed to the uplink out-band bandwidth **306**.

The multiplier **918** is configured to multiply each of the noise-added uplink sample blocks **934**(**1**)-**934**(N) with a respective one of the uplink scaling factors S_{UL1}-S_{ULN} to generate a respective one of a plurality of scaled noise-added uplink sample blocks **936**(**1**)-**936**(N). The quantizing circuit **920** is configured to compress each of the scaled noise-added uplink sample blocks **936**(**1**)-**936**(N) to generate a respective one of the compressed uplink sample blocks **908**(**1**)-**908**(N).

The dequantizing circuit **922** is configured to decompress each of the compressed uplink sample blocks **908**(**1**)-**908**(N) to generate a respective one of a plurality of scaled noise-added uplink sample feedbacks **938**(**1**)-**938**(N). The divider **924** is configured to divide each of the scaled noise-added uplink sample feedbacks **938**(**1**)-**938**(N) by a respective one of the uplink scaling factors S_{UL1}-S_{ULN} to generate a respective one of a plurality of noise-added uplink sample feedbacks **940**(**1**)-**940**(N). The subtractor **926** is configured to subtract each of the noise-added uplink sample feedbacks **940**(**1**)-**940**(N) by a respective one of the noise-added uplink sample blocks **934**(**1**)-**934**(N) to generate a respective one of the uplink quantization error samples **930**(**1**)-**930**(N). Accordingly, the subtractor **926** provides the uplink quantization error samples **930**(**1**)-**930**(N) to the shaping filter **914**.

The compression protocol interface circuit **928** is configured to generate the compressed uplink digital communications signal **716** based on the compressed uplink sample blocks **908**(**1**)-**908**(N) and the uplink scaling factors S_{UL1}-S_{ULN}. In an embodiment, the compressed uplink digital communications signal **716** includes a plurality of uplink protocol data units (PDUs), such as CPRI PDUs. Each of the uplink PDUs includes a respective one of the compressed uplink sample blocks **908**(**1**)-**908**(N) and a respective one of the uplink scaling factors S_{UL1}-S_{ULN}. For example, each of the PDUs can include a first number of bits for carrying the respective one of the compressed uplink sample blocks **908**(**1**)-**908**(N) and a second number of bits for carrying the respective one of the uplink scaling factors S_{UL1}-S_{ULN}. As discussed later, the respective one of the uplink scaling factors S_{DL1}-S_{DLN} in each of the uplink PDUs can be used to decompress the respective one of the compressed uplink sample blocks **908**(**1**)-**908**(N).

With reference back to FIG. **4**, the central unit **400** receives the compressed uplink optical communications signal **718** via the transport medium **406**. Accordingly, the O/E converter **242** in the central unit **400** converts the compressed uplink optical communications signal **718** into the compressed uplink digital communications signal **716**. In an embodiment, the central unit **400** further includes an uplink digital decompression circuit **422**. The uplink digital decompression circuit **422** is configured to decompress the compressed uplink digital communications signal **716** to recover the uplink digital communications signal **712**.

The uplink digital decompression circuit **422** may be implemented in a similar way as the uplink digital decompression circuit **714** in the remote unit **700**. In this regard, FIG. **10** is a schematic diagram of an exemplary digital decompression circuit **1000**, which can be provided in the central unit **400** of FIG. **4** to function as the uplink digital decompression circuit **422**. Common elements between FIGS. **4**, **9**, and **10** are shown therein with common element numbers and will not be re-described herein.

In an embodiment, the digital decompression circuit **1000** includes a decompression protocol interface circuit **1002**, a decompression dequantizing circuit **1004**, and a decompression divider **1006**. The decompression protocol interface circuit **1002** is configured to extract a respective one of the compressed uplink sample blocks **1008**(**1**)-**1008**(N) and a respective one of the uplink scaling factors S_{UL1}-S_{ULN} from each of the uplink PDUs received in the compressed uplink digital communications signal **716**. The decompression dequantizing circuit **1004** is configured to decompress each of the compressed uplink sample blocks **1008**(**1**)-**1008**(N) to generate a respective one of the scaled noise-added uplink sample feedbacks **938**(**1**)-**938**(N). The decompression divider **1006** is configured to divide each of the scaled noise-added uplink sample feedbacks **938**(**1**)-**938**(N) by a respective one of the uplink scaling factors S_{UL1}-S_{ULN} to generate a respective one of noise-added uplink sample feedbacks **940**(**1**)-**940**(N). As a result of the compression and noise shaping performed by the remote unit **700** of FIG. **7**, the uplink compression noise N_{UL} has been redistributed across the downlink out-band bandwidth **306** in each of the noise-added uplink sample blocks **934**(**1**)-**934**(N).

With reference back to FIG. **4**, the central unit **400** includes a rejection filter circuit **424** to provide the out-band noise rejection capability in the central unit **400**. The rejection filter circuit **424** is configured to suppress the uplink compression noise N_{UL} in each of the noise-added uplink sample blocks **934**(**1**)-**934**(N) to thereby obtain the uplink digital communications signal **712**.

The central unit **400** may also include a digital processing circuit **426**, which can be functionally equivalent to the digital BBU **218** in FIG. **2**. The digital processing circuit **426** is coupled to the signal source **404**. The digital processing circuit **426** is configured to receive the downlink digital communications signal **402** from the signal source **404** and provide the uplink digital communications signal **712** to the signal source **404**.

The WCS **200** of FIG. **2**, which can include the central unit **400** of FIG. **4** and the remote unit **700** in FIG. **7**, can be provided in an indoor environment as illustrated in FIG. **11**. FIG. **11** is a partial schematic cut-away diagram of an exemplary building infrastructure **1100** in a WCS, such as the WCS **200** of FIG. **2** that includes the central unit **400** of FIG. **4** and the remote unit **700** of FIG. **7** for supporting downlink and uplink signal compression and noise shaping. The building infrastructure **1100** in this embodiment includes a first (ground) floor **1102**(**1**), a second floor **1102**(**2**), and a third floor **1102**(**3**). The floors **1102**(**1**)-**1102**(**3**) are serviced by a central unit **1104** to provide antenna coverage areas **1106** in the building infrastructure **1100**. The central unit **1104** is communicatively coupled to a base station **1108** to receive downlink communications signals **1110**D from the base station **1108**. The central unit **1104** is communicatively coupled to a plurality of remote units **1112** to distribute the downlink communications signals **1110**D to the remote units **1112** and to receive uplink communications signals **1110**U from the remote units **1112**, as previously discussed above. The downlink communications signals **1110**D and the uplink communications signals **1110**U communicated between the central unit **1104** and the remote units **1112** are carried over a riser cable **1114**. The riser cable **1114** may be routed through interconnect units (ICUs) **1116**(**1**)-**1116**(**3**) dedicated to each of the floors **1102**(**1**)-**1102**(**3**) that route the downlink communications signals **1110**D and the uplink communications signals **1110**U to the remote units **1112** and also provide power to the remote units **1112** via array cables **1118**.

The WCS **200** of FIG. **2**, the central unit **400** of FIG. **4**, and the remote unit **700** of FIG. **7**, configured to support downlink and uplink signal compression and noise shaping, can also be interfaced with different types of radio nodes of service providers and/or supporting service providers, including macrocell systems, small cell systems, and remote radio heads (RRH) systems, as examples. For example, FIG. **12** is a schematic diagram of an exemplary mobile telecommunications environment **1200** (also referred to as "environment **1200**") that includes radio nodes and cells that may support shared spectrum, such as unlicensed spectrum, and can be interfaced to shared spectrum WCSs **1201** supporting coordination of distribution of shared spectrum from multiple service providers to remote units to be distributed to subscriber devices. The shared spectrum WCSs **1201** can include the WCS **200** of FIG. **2** that includes the central unit **400** of FIG. **4** and the remote unit **700** of FIG. **7**, as an example.

The environment **1200** includes exemplary macrocell RANs **1202(1)**-**1202**(M) ("macrocells **1202(1)**-**1202**(M)") and an exemplary small cell RAN **1204** located within an enterprise environment **1206** and configured to service mobile communications between a user mobile communications device **1208(1)**-**1208**(N) to a mobile network operator (MNO) **1210**. A serving RAN for the user mobile communications devices **1208(1)**-**1208**(N) is a RAN or cell in the RAN in which the user mobile communications devices **1208(1)**-**1208**(N) have an established communications session with the exchange of mobile communications signals for mobile communications. Thus, a serving RAN may also be referred to herein as a serving cell. For example, the user mobile communications devices **1208(3)**-**1208**(N) in FIG. **12** are being serviced by the small cell RAN **1204**, whereas the user mobile communications devices **1208(1)** and **1208(2)** are being serviced by the macrocell **1202**. The macrocell **1202** is an MNO macrocell in this example. However, a shared spectrum RAN **1203** (also referred to as "shared spectrum cell **1203**") includes a macrocell in this example and supports communications on frequencies that are not solely licensed to a particular MNO, such as CBRS for example, and thus may service user mobile communications devices **1208(1)**-**1208**(N) independent of a particular MNO. For example, the shared spectrum cell **1203** may be operated by a third party that is not an MNO and wherein the shared spectrum cell **1203** supports CBRS. Also, as shown in FIG. **12**, the MNO macrocell **1202**, the shared spectrum cell **1203**, and/or the small cell RAN **1204** can interface with a shared spectrum WCS **1201** supporting coordination of distribution of shared spectrum from multiple service providers to remote units to be distributed to subscriber devices. The MNO macrocell **1202**, the shared spectrum cell **1203**, and the small cell RAN **1204** may be neighboring radio access systems to each other, meaning that some or all can be in proximity to each other such that a user mobile communications device **1208(3)**-**1208**(N) may be able to be in communications range of two or more of the MNO macrocell **1202**, the shared spectrum cell **1203**, and the small cell RAN **1204** depending on the location of the user mobile communications devices **1208(3)**-**1208**(N).

In FIG. **12**, the mobile telecommunications environment **1200** in this example is arranged as an LTE system as described by the Third Generation Partnership Project (3GPP) as an evolution of the GSM/UMTS standards (Global System for Mobile communication/Universal Mobile Telecommunications System). It is emphasized, however, that the aspects described herein may also be applicable to other network types and protocols. The mobile telecommunications environment **1200** includes the enterprise environment **1206** in which the small cell RAN **1204** is implemented. The small cell RAN **1204** includes a plurality of small cell radio nodes **1212(1)**-**1212**(C). Each small cell radio node **1212(1)**-**1212**(C) has a radio coverage area (graphically depicted in the drawings as a hexagonal shape) that is commonly termed a "small cell." A small cell may also be referred to as a femtocell or, using terminology defined by 3GPP, as a Home Evolved Node B (HeNB). In the description that follows, the term "cell" typically means the combination of a radio node and its radio coverage area unless otherwise indicated.

In FIG. **12**, the small cell RAN **1204** includes one or more services nodes (represented as a single services node **1214**) that manage and control the small cell radio nodes **1212(1)**-**1212**(C). In alternative implementations, the management and control functionality may be incorporated into a radio node, distributed among nodes, or implemented remotely (i.e., using infrastructure external to the small cell RAN **1204**). The small cell radio nodes **1212(1)**-**1212**(C) are coupled to the services node **1214** over a direct or local area network (LAN) connection **1216** as an example, typically using secure IPsec tunnels. The small cell radio nodes **1212(1)**-**1212**(C) can include multi-operator radio nodes. The services node **1214** aggregates voice and data traffic from the small cell radio nodes **1212(1)**-**1212**(C) and provides connectivity over an IPsec tunnel to a security gateway (SeGW) **1218** in a network **1220** (e.g., evolved packet core (EPC) network in a 4G network, or 5G Core in a 5G network) of the MNO **1210**. The network **1220** is typically configured to communicate with a public switched telephone network (PSTN) **1222** to carry circuit-switched traffic, as well as for communicating with an external packet-switched network such as the Internet **1224**.

The environment **1200** also generally includes a node (e.g., eNodeB or gNodeB) base station, or "macrocell" **1202**. The radio coverage area of the macrocell **1202** is typically much larger than that of a small cell where the extent of coverage often depends on the base station configuration and surrounding geography. Thus, a given user mobile communications device **1208(3)**-**1208**(N) may achieve connectivity to the network **1220** (e.g., EPC network in a 4G network, or 5G Core in a 5G network) through either a macrocell **1202** or small cell radio node **1212(1)**-**1212**(C) in the small cell RAN **1204** in the environment **1200**.

Any of the circuits in the WCS **200** of FIG. **2**, the central unit **400** of FIG. **4**, and the remote unit **700** of FIG. **7**, such as the control circuit **412**, can include a computer system **1300**, such as that shown in FIG. **13**, to carry out their functions and operations. With reference to FIG. **13**, the computer system **1300** includes a set of instructions for causing the multi-operator radio node component(s) to provide its designed functionality, and the circuits discussed above. The multi-operator radio node component(s) may be connected (e.g., networked) to other machines in a LAN, an intranet, an extranet, or the Internet. The multi-operator radio node component(s) may operate in a client-server network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. While only a single device is illustrated, the term "device" shall also be taken to include any collection of devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein. The multi-operator radio node component(s) may be a circuit or circuits included in an electronic board card, such as a printed circuit board (PCB) as an example, a server, a personal computer, a desktop computer, a laptop computer, a personal digital assistant (PDA), a computing pad, a mobile device, or any other device, and may represent, for example, a server, edge computer, or a user's computer. The exemplary computer system **1300** in this embodiment includes a processing circuit or processor **1302**, a main memory **1304** (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM) such as synchronous DRAM (SDRAM), etc.), and a static memory **1306** (e.g., flash memory, static random access memory (SRAM), etc.), which may communicate with each other via a data bus **1308**. Alternatively, the processing circuit **1302** may be connected to the main memory **1304** and/or static memory **1306** directly or via some other connectivity means. The processing circuit **1302** may be a controller, and the main memory **1304** or static memory **1306** may be any type of memory.

The processing circuit **1302** represents one or more general-purpose processing circuits such as a microprocessor, central processing unit, or the like. More particularly, the processing circuit **1302** may be a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or processors implementing a combination of instruction sets. The processing circuit **1302** is configured to execute processing logic in instructions **1316** for performing the operations and steps discussed herein.

The computer system **1300** may further include a network interface device **1310**. The computer system **1300** also may or may not include an input **1312** to receive input and selections to be communicated to the computer system **1300** when executing instructions. The computer system **1300** also may or may not include an output **1314**, including but not limited to a display, a video display unit (e.g., a liquid crystal display (LCD) or a cathode ray tube (CRT)), an alphanumeric input device (e.g., a keyboard), and/or a cursor control device (e.g., a mouse).

The computer system **1300** may or may not include a data storage device that includes instructions **1316** stored in a computer-readable medium **1318**. The instructions **1316** may also reside, completely or at least partially, within the main memory **1304** and/or within the processing circuit **1302** during execution thereof by the computer system **1300**, the main memory **1304** and the processing circuit **1302** also constituting the computer-readable medium **1318**. The instructions **1316** may further be transmitted or received over a network **1320** via the network interface device **1310**.

While the computer-readable medium **1318** is shown in an exemplary embodiment to be a single medium, the term "computer-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "computer-readable medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by the processing circuit and that cause the processing circuit to perform any one or more of the methodologies of the embodiments disclosed herein. The term "computer-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, optical and magnetic medium, and carrier wave signals.

Note that as an example, any "ports," "combiners," "splitters," and other "circuits" mentioned in this description may be implemented using Field Programmable Logic Array(s) (FPGA(s)) and/or a digital signal processor(s) (DSP(s)), and therefore, may be embedded within the FPGA or be performed by computational processes.

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

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

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

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

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.

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.

We claim:

1. A central unit in a wireless communications system (WCS), comprising:
   a downlink digital compression circuit comprising:
      a downlink block compression circuit configured to:
         receive at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth;
         generate a plurality of downlink sample blocks based on the at least one downlink digital communications signal; and
         compress each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks; and
      a downlink noise shaping circuit configured to cause a downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

2. The central unit of claim 1, wherein the downlink digital compression circuit comprises a compression protocol interface circuit configured to generate at least one compressed downlink digital communications signal comprising a plurality of downlink protocol data units, the plurality of downlink protocol data units each comprises a respective one of the plurality of compressed downlink sample blocks and a respective one of the plurality of downlink scaling factors.

3. The central unit of claim 2, wherein the downlink digital compression circuit further comprises:
   a data buffer configured to generate the plurality of downlink sample blocks from the at least one downlink digital communications signal;
   a scaling circuit configured to determine the respective one of the plurality of downlink scaling factors for each of the plurality of downlink sample blocks;
   a shaping filter configured to:
      receive a respective one of a plurality of downlink quantization error samples associated with each of the plurality of compressed downlink sample blocks; and
      generate a respective one of a plurality of downlink noise samples based on each of the plurality of downlink quantization error samples;
   a combiner configured to combine each of the plurality of downlink sample blocks with a respective one of the plurality of downlink noise samples to generate a respective one of a plurality of noise-added downlink sample blocks to thereby cause the downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed to the selected one of the downlink in-band bandwidth and the downlink out-band bandwidth;
   a multiplier configured to multiply each of the plurality of noise-added downlink sample blocks with a respective one of the plurality of downlink scaling factors to generate a respective one of a plurality of scaled noise-added downlink sample blocks;
   a quantizing circuit configured to compress each of the plurality of scaled noise-added downlink sample blocks to generate a respective one of the plurality of compressed downlink sample blocks;
   a dequantizing circuit configured to decompress each of the plurality of compressed downlink sample blocks to generate a respective one of a plurality of scaled noise-added downlink sample feedbacks;
   a divider configured to divide each of the plurality of scaled noise-added downlink sample feedbacks by a respective one of the plurality of downlink scaling factors to generate a respective one of a plurality of noise-added downlink sample feedbacks; and
   a subtractor configured to:
      subtract each of the plurality of noise-added downlink sample feedbacks by a respective one of the plurality of noise-added downlink sample blocks to generate a respective one of the plurality of downlink quantization error samples; and
      provide the plurality of downlink quantization error samples to the shaping filter.

4. The central unit of claim 2, further comprising a digital routing circuit coupled to a plurality of remote units via a transport medium, the digital routing circuit is configured to distribute the at least one compressed downlink digital communications signal to a respective one or more of the plurality of remote units via the transport medium.

5. The central unit of claim 4, further comprising a control circuit configured to:
   determine whether to redistribute the downlink compression noise to the downlink in-band bandwidth or the downlink out-band bandwidth based on out-band noise filtering capability of the respective one or more of the plurality of remote units;
   provide an indication to instruct the downlink digital compression circuit to redistribute the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink in-band bandwidth in response to determining that the respective one or more of the plurality of remote units do not have the out-band noise filtering capability; and
   provide the indication to instruct the downlink digital compression circuit to redistribute the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink out-band bandwidth in response to determining that the respective one or more of the plurality of remote units have the out-band noise filtering capability.

6. The central unit of claim 5, further comprising a storage circuit configured to store an out-band filter configuration for each of the plurality of remote units, wherein the control circuit is further configured to determine the out-band noise filtering capability of the respective one or more of the plurality of remote units based on the stored out-band filter configuration corresponding to the respective one or more of the plurality of remote units.

7. The central unit of claim 4, wherein the digital routing circuit is further configured to receive at least one compressed uplink digital communications signal from the respective one or more of the plurality of remote units via the transport medium, wherein:
   the at least one compressed uplink digital communications signal comprises a plurality of uplink protocol data units each comprising a respective one of a plurality of compressed uplink sample blocks and a respective one of a plurality of uplink scaling factors; and

the plurality of compressed uplink sample blocks each having an uplink compression noise distributed across an uplink out-band bandwidth.

8. The central unit of claim **7**, further comprising an uplink digital decompression circuit, the uplink digital decompression circuit comprises:

a decompression protocol interface circuit configured to extract the respective one of the plurality of compressed uplink sample blocks and the respective one of the plurality of uplink scaling factors from each of the plurality of uplink protocol data units;

a decompression dequantizing circuit configured to decompress each of the plurality of compressed uplink sample blocks to generate a respective one of a plurality of scaled noise-added uplink sample blocks; and

a decompression divider configured to divide each of the plurality of scaled noise-added uplink sample blocks by a respective one of the plurality of uplink scaling factors to generate a respective one of a plurality of noise-added uplink sample blocks each having the uplink compression noise distributed across the uplink out-band bandwidth.

9. The central unit of claim **8**, further comprising a rejection filter circuit configured to suppress the uplink compression noise in each of the plurality of noise-added uplink sample blocks.

10. A method for supporting signal compression and noise shaping in a WCS, comprising:

receiving at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth;

generating a plurality of downlink sample blocks based on the at least one downlink digital communications signal;

compressing each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks; and

redistributing a downlink compression noise associated with each of the plurality of compressed downlink sample blocks across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

11. The method of claim **10**, further comprising generating at least one compressed downlink digital communications signal comprising a plurality of downlink protocol data units, the plurality of downlink protocol data units each comprises a respective one of the plurality of compressed downlink sample blocks and a respective one of the plurality of downlink scaling factors.

12. The method of claim **11**, further comprising:

determining the respective one of the plurality of downlink scaling factors for each of the plurality of downlink sample blocks;

receiving a respective one of a plurality of downlink quantization error samples associated with each of the plurality of compressed downlink sample blocks;

generating a respective one of a plurality of downlink noise samples based on each of the plurality of downlink quantization error samples;

combining each of the plurality of downlink sample blocks with a respective one of the plurality of downlink noise samples to generate a respective one of a plurality of noise-added downlink sample blocks to thereby cause the downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed to the selected one of the downlink in-band bandwidth and the downlink out-band bandwidth;

multiplying each of the plurality of noise-added downlink sample blocks with a respective one of the plurality of downlink scaling factors to generate a respective one of a plurality of scaled noise-added downlink sample blocks;

compressing each of the plurality of scaled noise-added downlink sample blocks to generate a respective one of the plurality of compressed downlink sample blocks;

decompressing each of the plurality of compressed downlink sample blocks to generate a respective one of a plurality of scaled noise-added downlink sample feedbacks;

dividing each of the plurality of scaled noise-added downlink sample feedbacks by a respective one of the plurality of downlink scaling factors to generate a respective one of a plurality of noise-added downlink sample feedbacks; and

subtracting each of the plurality of noise-added downlink sample feedbacks by a respective one of the plurality of noise-added downlink sample blocks to generate a respective one of the plurality of downlink quantization error samples.

13. The method of claim **11**, further comprising distributing the at least one compressed downlink digital communications signal to a respective one or more of a plurality of remote units.

14. The method of claim **13**, further comprising:

determining whether to redistribute the downlink compression noise to the downlink in-band bandwidth or the downlink out-band bandwidth based on an out-band noise filtering capability of the respective one or more of the plurality of remote units;

redistributing the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink in-band bandwidth in response to determining that the respective one or more of the plurality of remote units do not have the out-band noise filtering capability; and

redistributing the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink out-band bandwidth in response to determining that the respective one or more of the plurality of remote units have the out-band noise filtering capability.

15. The method of claim **14**, further comprising:

storing an out-band filter configuration for each of the plurality of remote units; and

determining the out-band noise filtering capability of the respective one or more of the plurality of remote units based on the stored out-band filter configuration corresponding to the respective one or more of the plurality of remote units.

16. The method of claim **13**, further comprising receiving at least one compressed uplink digital communications signal from the respective one or more of the plurality of remote units, wherein:

the at least one compressed uplink digital communications signal comprises a plurality of uplink protocol data units each comprising a respective one of a plurality of compressed uplink sample blocks and a respective one of a plurality of uplink scaling factors; and the plurality of compressed uplink sample blocks each having an uplink compression noise distributed across an uplink out-band bandwidth.

17. The method of claim **16**, further comprising:

extracting the respective one of the plurality of compressed uplink sample blocks and the respective one of the plurality of uplink scaling factors from each of the plurality of uplink protocol data units;

decompressing each of the plurality of compressed uplink sample blocks to generate a respective one of a plurality of scaled noise-added uplink sample blocks; and

dividing each of the plurality of scaled noise-added uplink sample blocks by a respective one of the plurality of uplink scaling factors to generate a respective one of a plurality of noise-added uplink sample blocks each having the uplink compression noise distributed across the uplink out-band bandwidth.

18. The method of claim **17**, further comprising suppressing the uplink compression noise in each of the plurality of noise-added uplink sample blocks.

19. A wireless communications system (WCS), comprising a distributed communications system (DCS), the DCS comprising:

a plurality of remote units; and

a central unit coupled to the plurality of remote units via a transport medium, the central unit is configured to:

distribute at least one compressed downlink digital communications signal to a respective one or more of the plurality of remote units; and

receive at least one compressed uplink digital communications signal from the respective one or more of the plurality of remote units;

wherein the central unit comprises a downlink digital compression circuit that comprises:

a downlink block compression circuit configured to:

receive at least one downlink digital communications signal sampled based on a downlink sampling bandwidth comprising a downlink in-band bandwidth and a downlink out-band bandwidth;

generate a plurality of downlink sample blocks based on the at least one downlink digital communications signal; and

compress each of the plurality of downlink sample blocks based on a respective one of a plurality of downlink scaling factors to generate a respective one of a plurality of compressed downlink sample blocks; and

a downlink noise shaping circuit configured to cause a downlink compression noise associated with each of the plurality of compressed downlink sample blocks to be redistributed across a selected one of the downlink in-band bandwidth and the downlink out-band bandwidth.

20. The WCS of claim **19**, wherein the central unit further comprises a control circuit configured to:

determine whether to redistribute the downlink compression noise to the downlink in-band bandwidth or the downlink out-band bandwidth based on an out-band noise filtering capability of the respective one or more of the plurality of remote units;

provide an indication to instruct the downlink digital compression circuit to redistribute the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink in-band bandwidth in response to determining that the respective one or more of the plurality of remote units do not have the out-band noise filtering capability; and

provide the indication to instruct the downlink digital compression circuit to redistribute the downlink compression noise in each of the plurality of compressed downlink sample blocks to the downlink out-band bandwidth in response to determining that the respective one or more of the plurality of remote units have the out-band noise filtering capability.

21. The WCS of claim **20**, wherein the central unit further comprises a storage circuit configured to store an out-band filter configuration for each of the plurality of remote units, wherein the control circuit is further configured to determine the out-band noise filtering capability of the respective one or more of the plurality of remote units based on the stored out-band filter configuration corresponding to the respective one or more of the plurality of remote units.

22. The WCS of claim **19**, wherein the downlink digital compression circuit comprises a compression protocol interface circuit configured to generate the at least one compressed downlink digital communications signal comprising a plurality of downlink protocol data units, the plurality of downlink protocol data units each comprises a respective one of the plurality of compressed downlink sample blocks and a respective one of the plurality of downlink scaling factors.

23. The WCS of claim **22**, wherein the respective one or more of the plurality of remote units each comprising:

a downlink decompression circuit comprising:

a decompression protocol interface circuit configured to extract the respective one of the plurality of compressed downlink sample blocks and the respective one of the plurality of downlink scaling factors from each of the plurality of downlink protocol data units;

a decompression dequantizing circuit configured to decompress each of the plurality of compressed downlink sample blocks to generate a respective one of a plurality of scaled noise-added downlink sample blocks; and

a decompression divider configured to divide each of the plurality of scaled noise-added downlink sample blocks by a respective one of the plurality of downlink scaling factors to generate a respective one of a plurality of noise-added downlink sample blocks each having the downlink compression noise distributed across the selected one of the downlink in-band bandwidth and the downlink out-band bandwidth; and

an uplink compression circuit comprising:

an uplink block compression circuit configured to:

receive at least one uplink digital communications signal sampled based on an uplink sampling bandwidth comprising an uplink in-band bandwidth and an uplink out-band bandwidth;

generate a plurality of uplink sample blocks based on the at least one uplink digital communications signal; and

compress each of the plurality of uplink sample blocks based on a respective one of a plurality of uplink scaling factors to generate a respective one of a plurality of compressed uplink sample blocks; and

an uplink noise shaping circuit configured to cause an uplink compression noise associated with each of the plurality of compressed uplink sample blocks to be redistributed across the uplink out-band bandwidth.

24. The WCS of claim **23**, wherein the respective one or more of the plurality of remote units each further comprises a rejection filter to suppress the downlink compression noise associated with each of the plurality of noise-added downlink sample blocks in the downlink out-band bandwidth.

25. The WCS of claim **19**, wherein:

the central unit comprises:

an electrical-to-optical (E/O) converter configured to convert the at least one compressed downlink digital communications signal into at least one compressed downlink optical communications signal; and

an optical-to-electrical (O/E) converter configured to convert at least one compressed uplink optical communications signal into the at least one compressed uplink digital communications signal; and

the respective one or more of the plurality of remote units each comprises:

a respective O/E converter configured to convert the at least one compressed downlink optical communications signal into the at least one compressed downlink digital communications signal; and

a respective E/O converter configured to convert the at least one compressed uplink digital communications signal into the at least one compressed uplink optical communications signal.

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