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(54) **PROCEDURE FOR NON-TERRESTRIAL NETWORK COVERAGE ENHANCEMENT WITH ULTRA COMPACT DOWNLINK CONTROL INFORMATION AND SCHEDULING PHYSICAL DOWNLINK SHARED CHANNEL**

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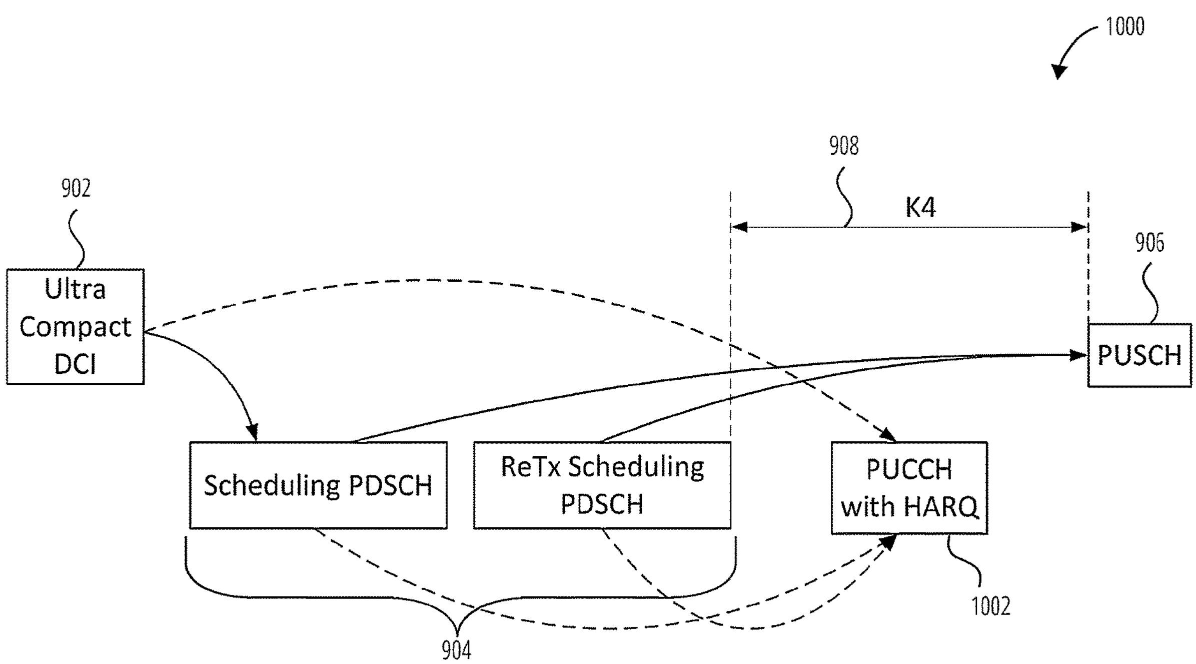
(57) **ABSTRACT**

System and methods for using ultra compact downlink control information (DCI) in conjunction with one or more scheduling physical downlink shared channels (PDSCHs) are disclosed herein. A base station may transmit, to a user equipment (UE), an ultra compact DCI that schedules the one or more scheduling PDSCHs. The one or more scheduling PDSCHs may schedule a data PDSCH or physical uplink shared channel (PUSCH) that is to be used for user/application layer data transmission. The ultra compact DCI and/or the one or more scheduling PDSCHs may be as configured by a system information block (SIB). The ultra compact DCI and/or the one or more scheduling PDSCHs may schedule a physical uplink control channel (PUCCH) used for hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling relative to the one or more scheduling PDSCHs. Aspects regarding the use of these systems and methods in non-terrestrial network (NTN) contexts are considered.



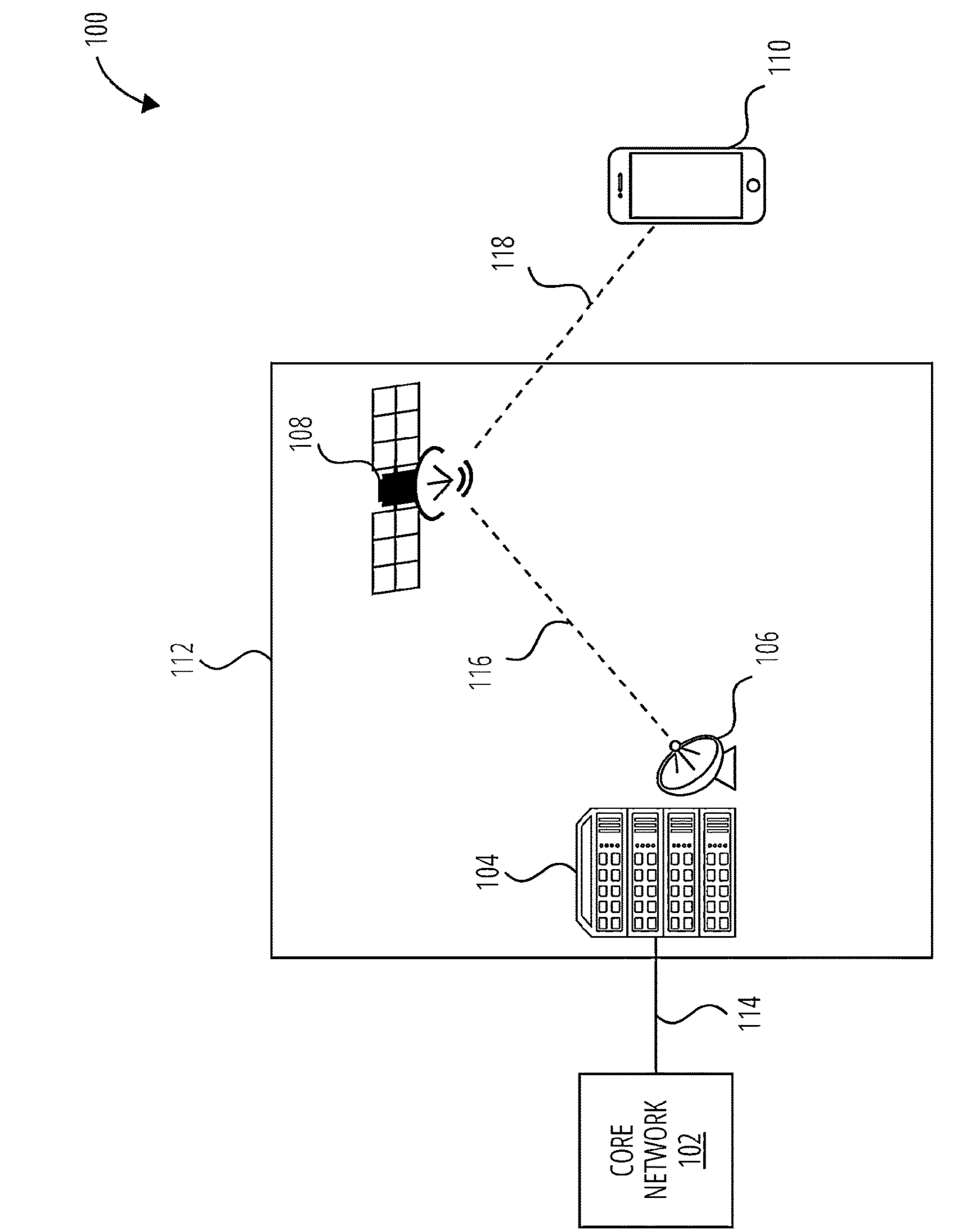


FIG. 1

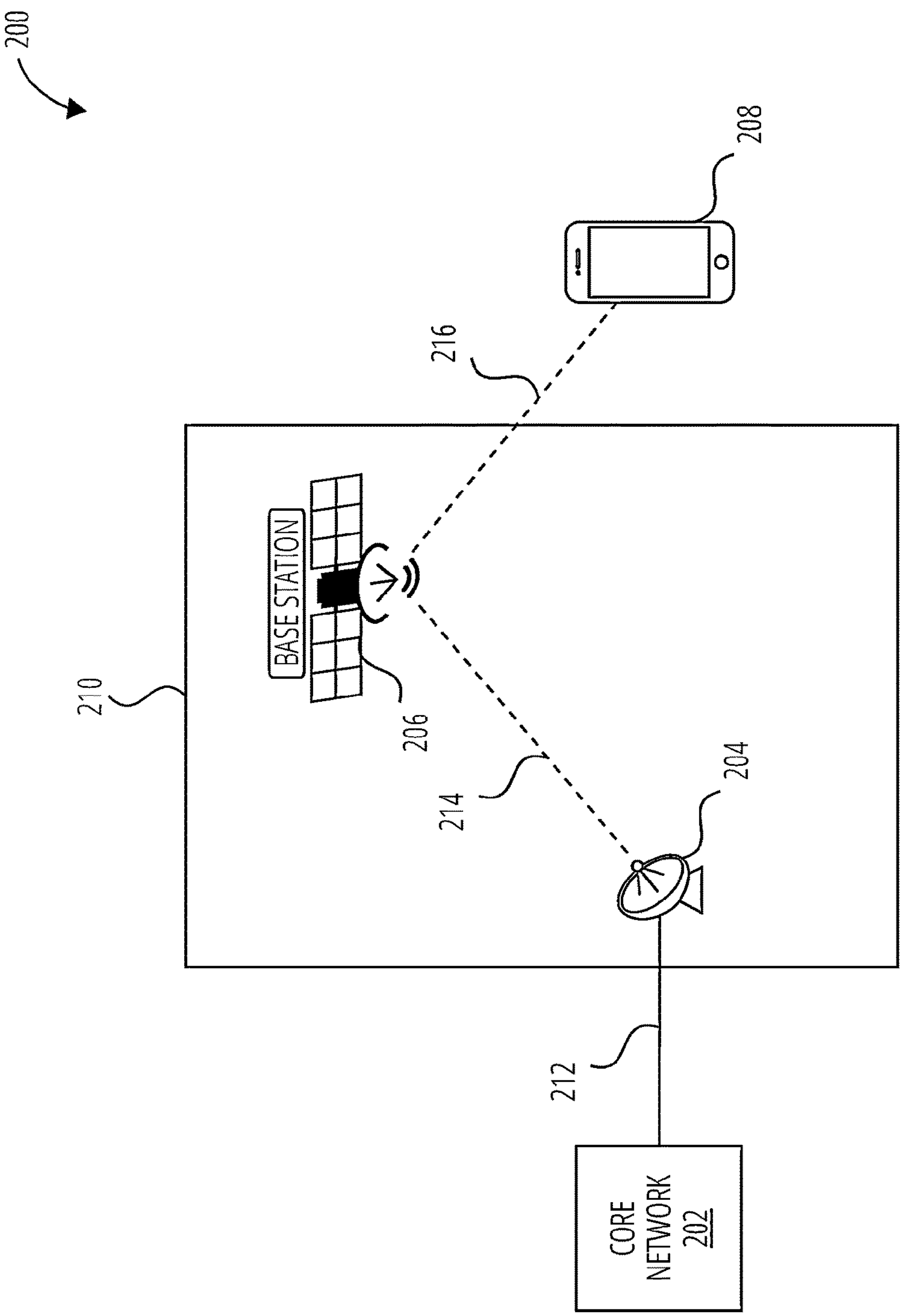


FIG. 2

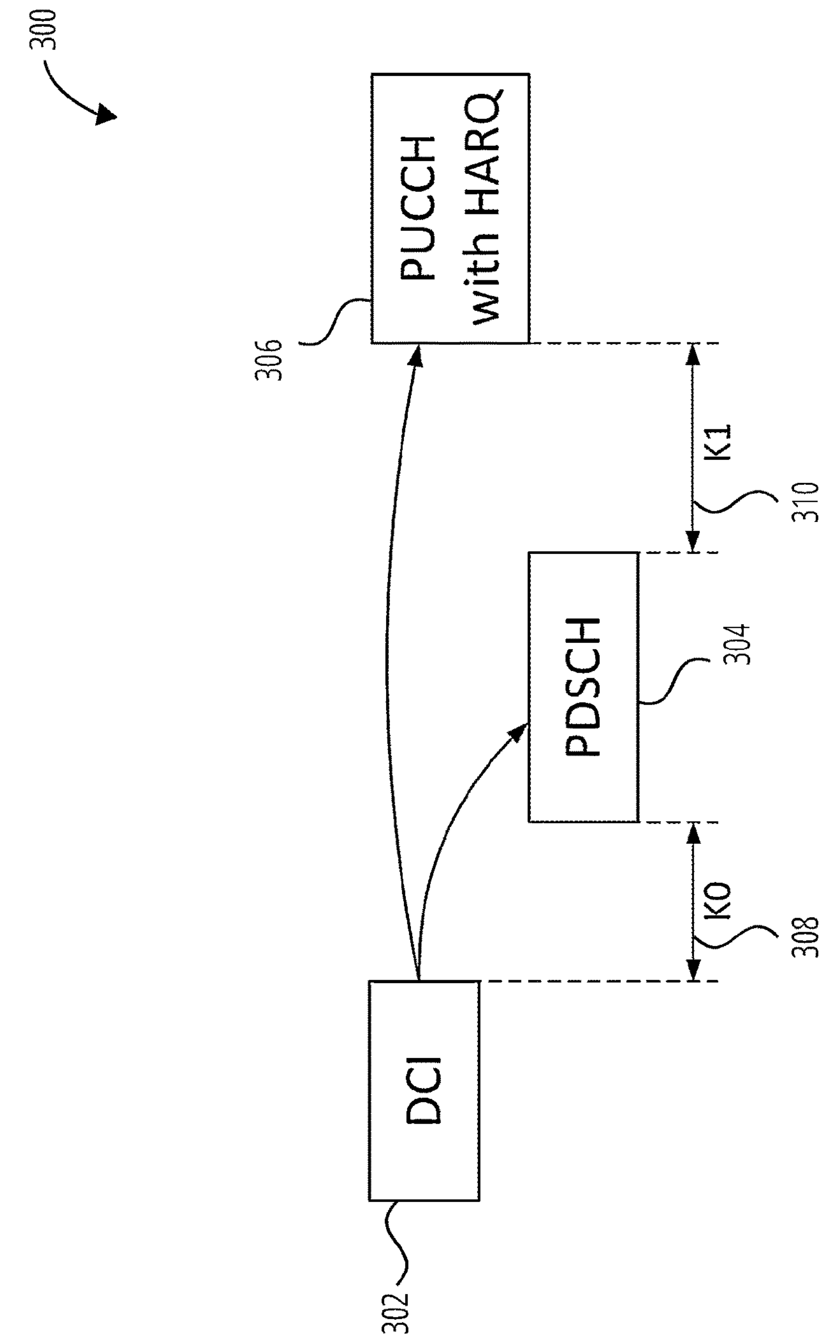


FIG. 3

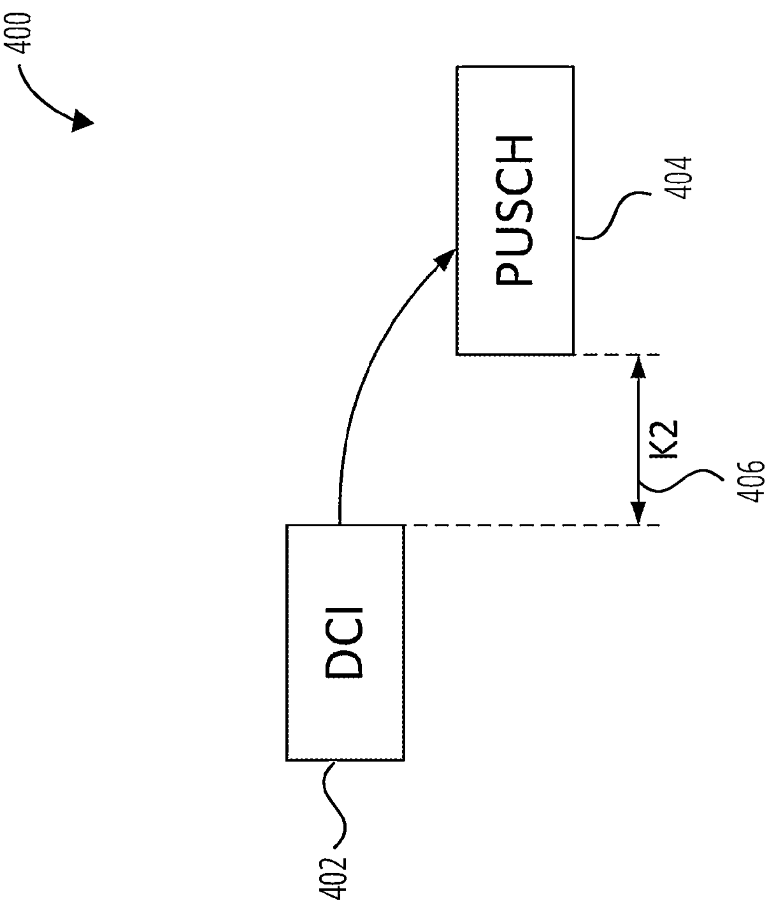


FIG. 4

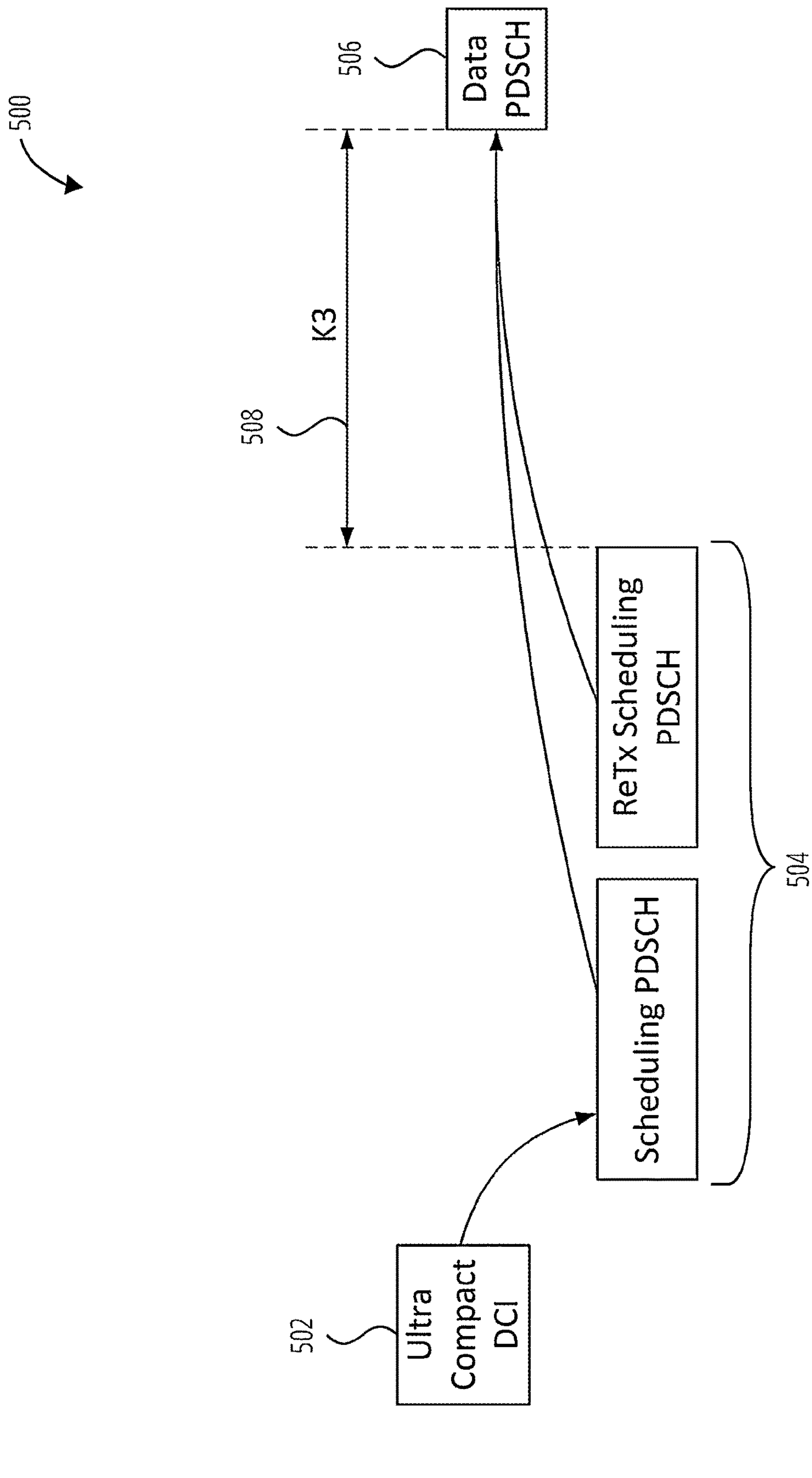

500
506
Data
PDSCH
508
K3
ReTx Scheduling
PDSCH
Scheduling PDSCH
504
502
Ultra
Compact
DCI

FIG. 5

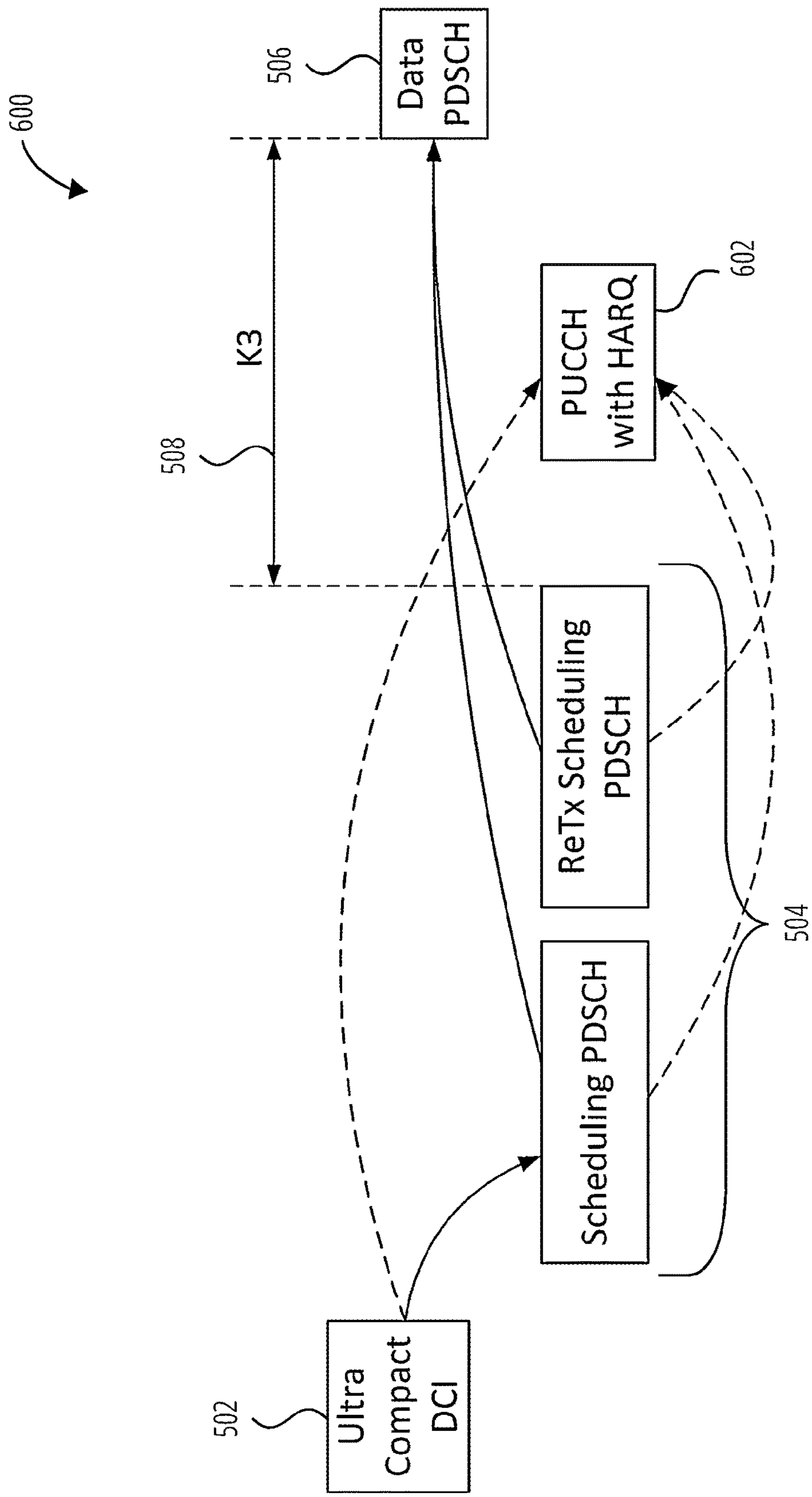

600
Data PDSCH
506
PUCCH with HARQ
602
K3
508
ReTx Scheduling PDSCH
Scheduling PDSCH
504
Ultra Compact DCI
502

FIG. 6

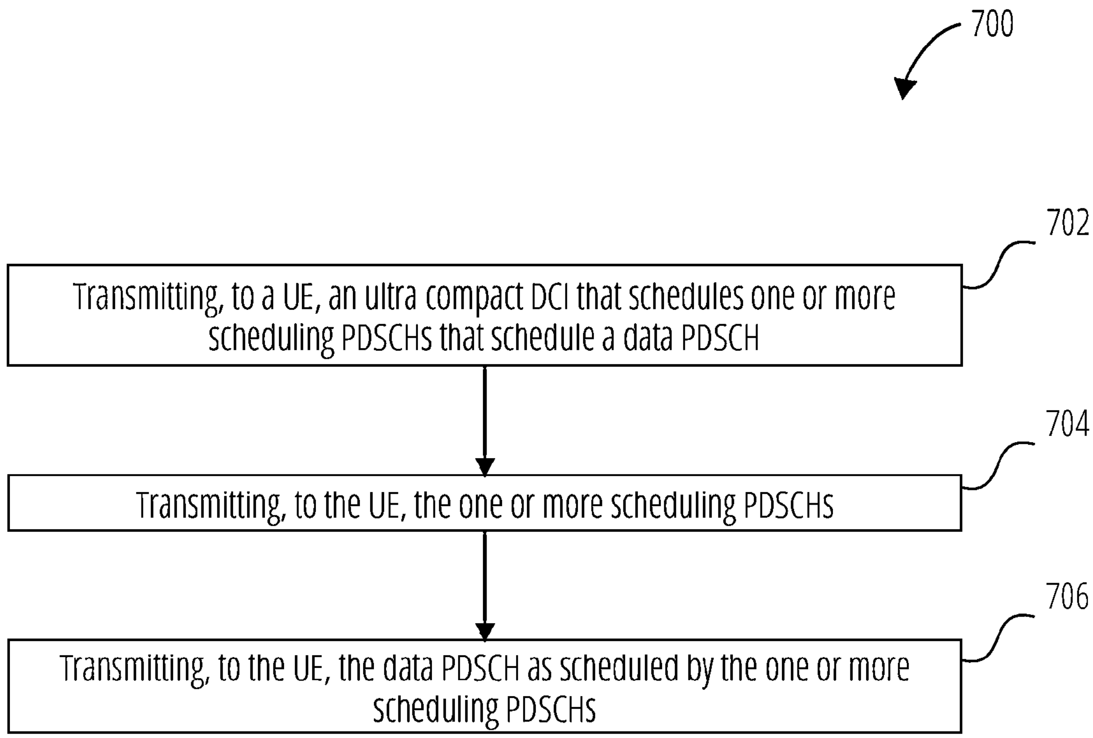

700
702
Transmitting, to a UE, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a data PDSCH
704
Transmitting, to the UE, the one or more scheduling PDSCHs
706
Transmitting, to the UE, the data PDSCH as scheduled by the one or more scheduling PDSCHs

FIG. 7

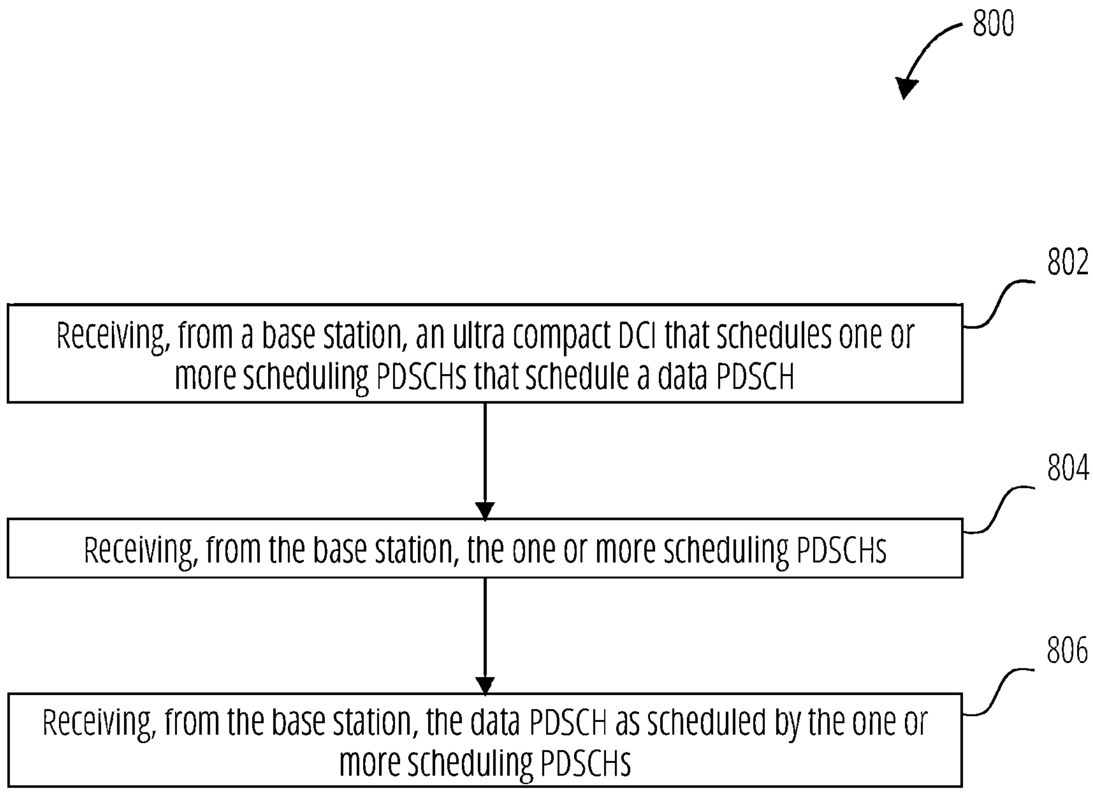

800
802
Receiving, from a base station, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a data PDSCH
804
Receiving, from the base station, the one or more scheduling PDSCHs
806
Receiving, from the base station, the data PDSCH as scheduled by the one or more scheduling PDSCHs

FIG. 8

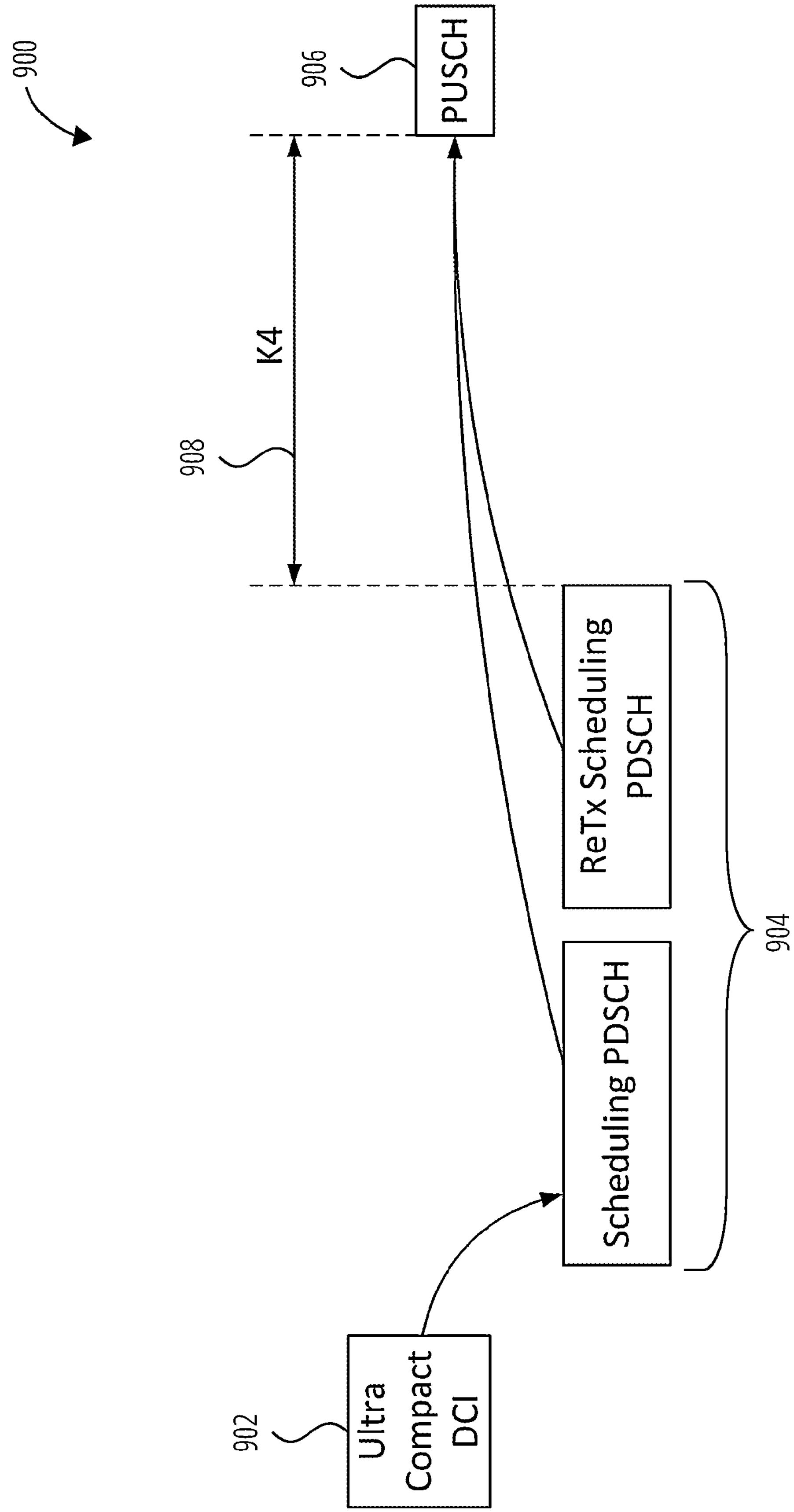

900
906
PUSCH
908
K4
ReTx Scheduling PDSCH
Scheduling PDSCH
904
902
Ultra Compact DCI

FIG. 9

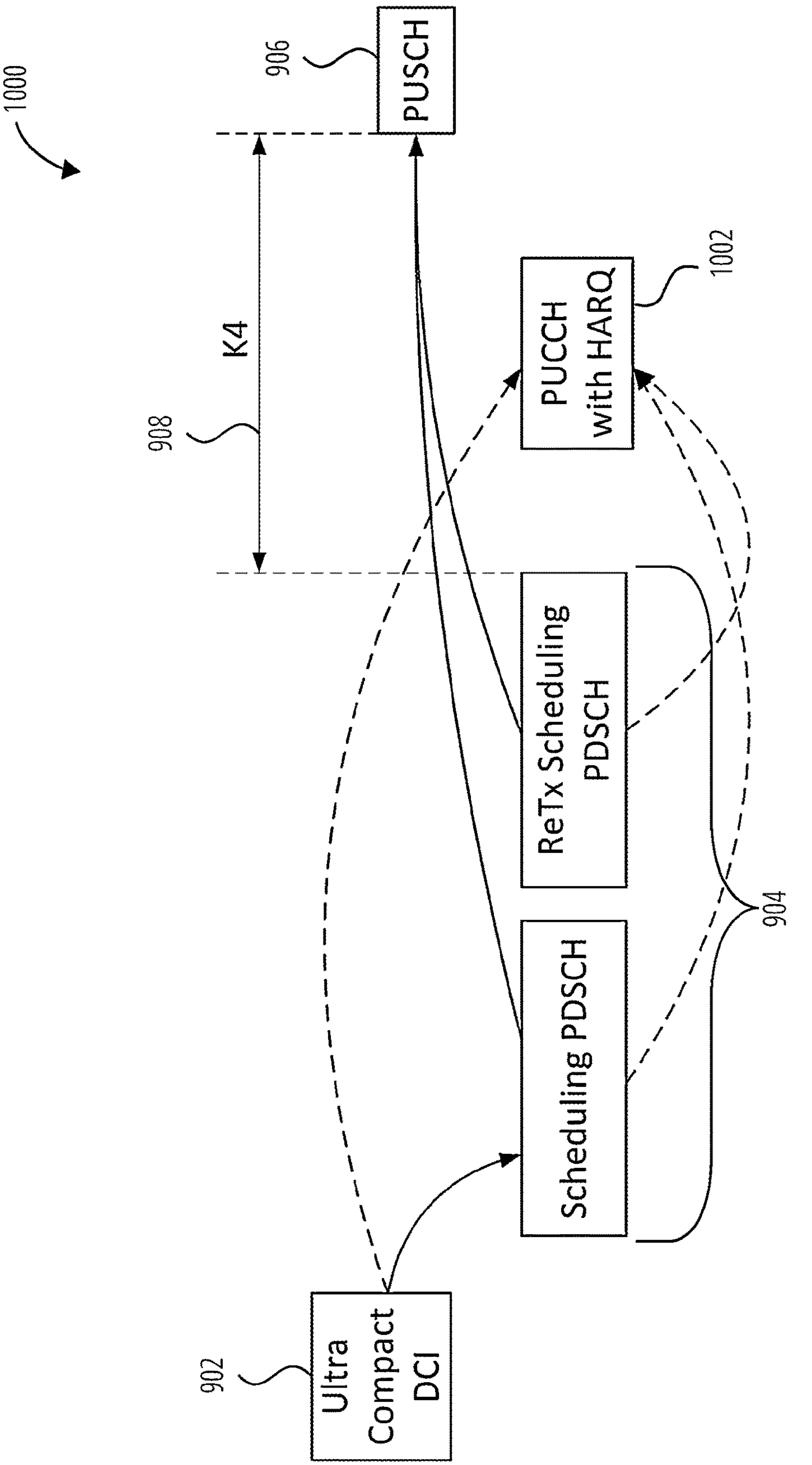

1000
906
PUSCH
908
K4
PUCCH with HARQ
1002
ReTx Scheduling PDSCH
Scheduling PDSCH
904
902
Ultra Compact DCI

FIG. 10

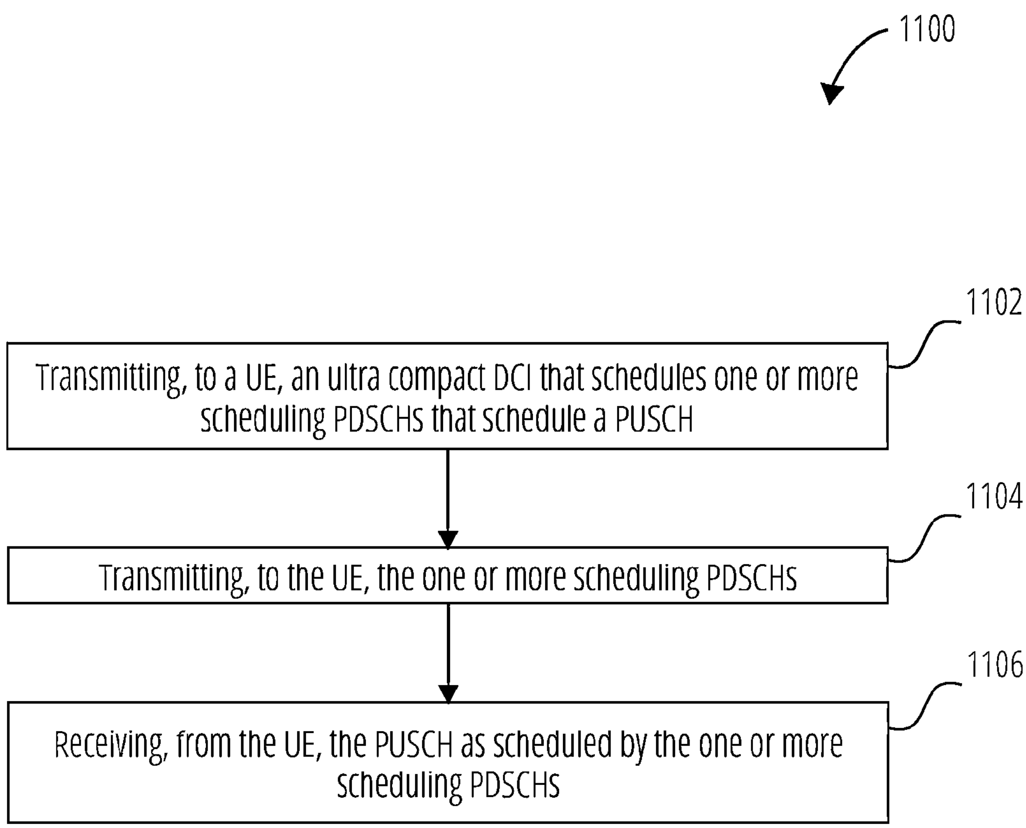

1100
1102
Transmitting, to a UE, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a PUSCH
1104
Transmitting, to the UE, the one or more scheduling PDSCHs
1106
Receiving, from the UE, the PUSCH as scheduled by the one or more scheduling PDSCHs

FIG. 11

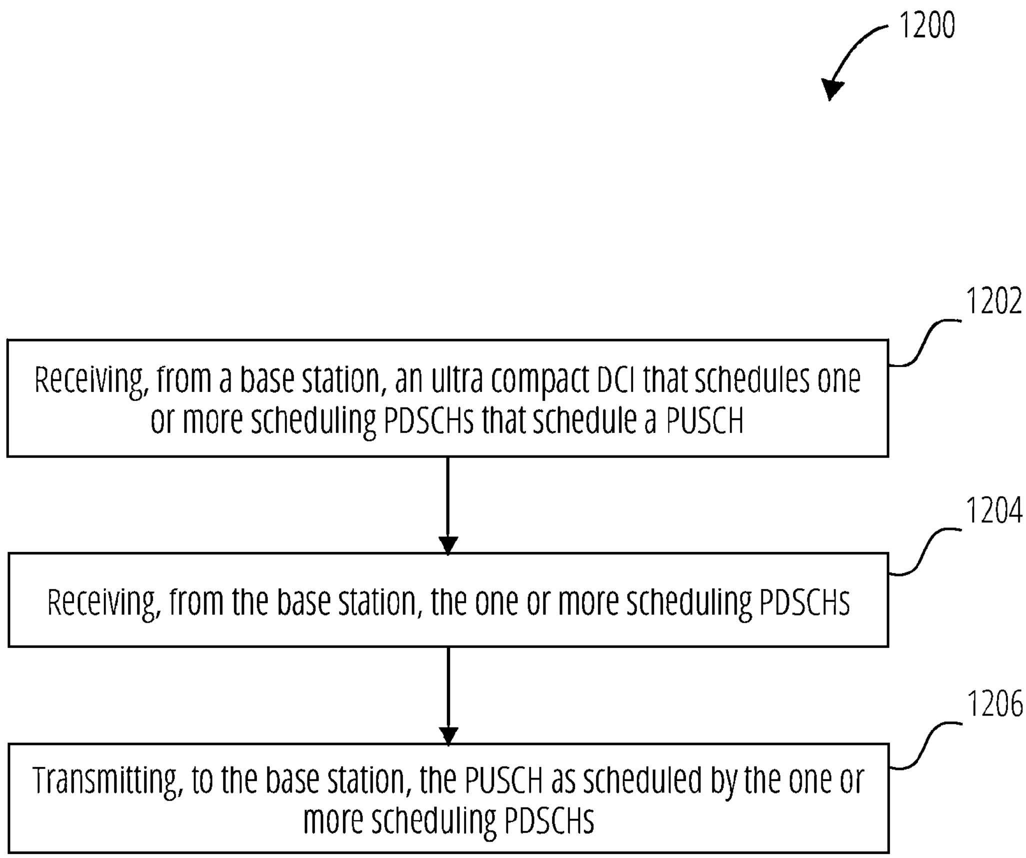

1200
1202
Receiving, from a base station, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a PUSCH
1204
Receiving, from the base station, the one or more scheduling PDSCHs
1206
Transmitting, to the base station, the PUSCH as scheduled by the one or more scheduling PDSCHs

FIG. 12

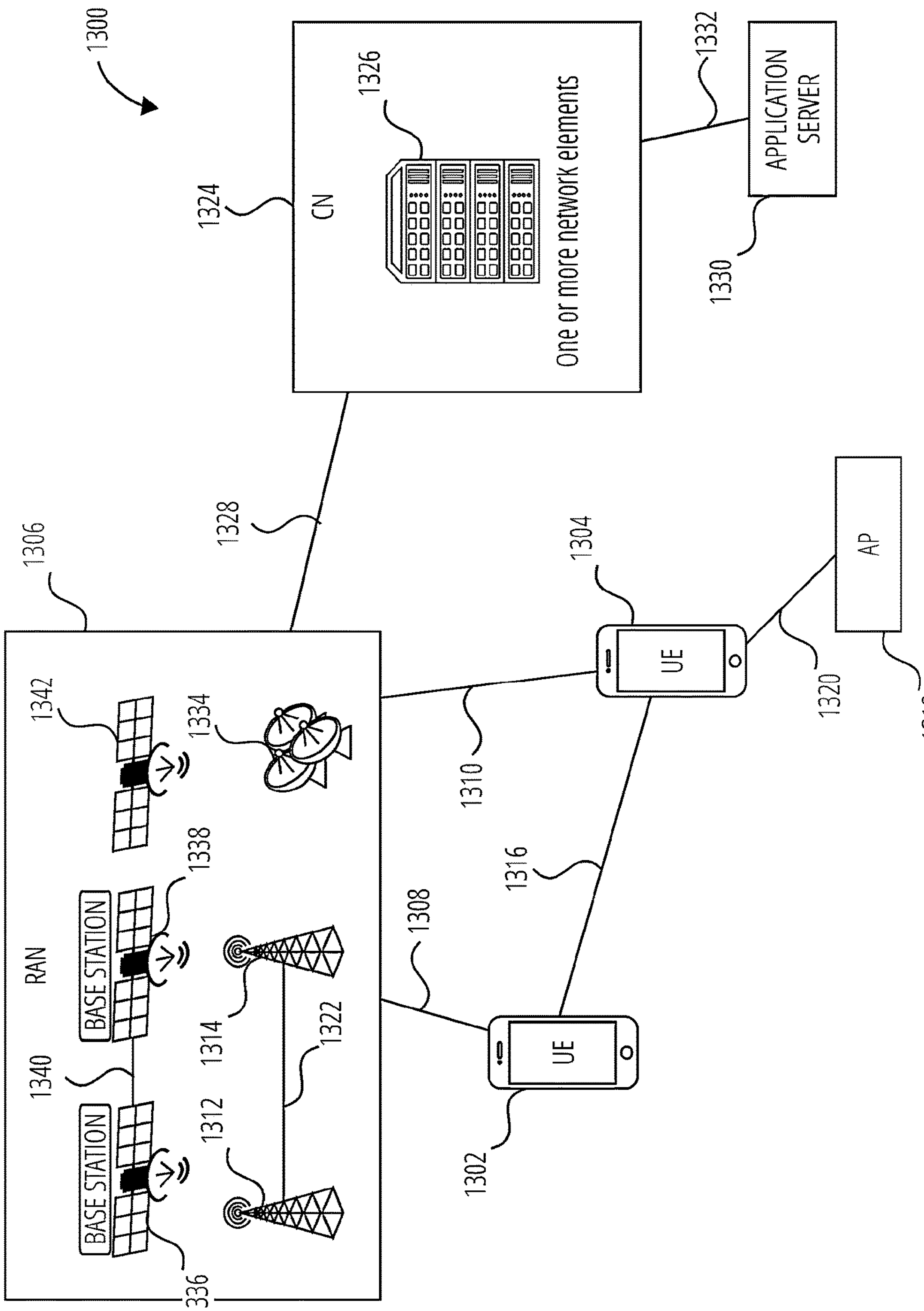

1300
CN
1324
1326
One or more network elements
1332
APPLICATION SERVER
1330
1328
1306
RAN
BASE STATION
BASE STATION
1342
1338
1340
1336
1334
1312
1314
1322
1308
1310
1316
1304
UE
1302
UE
1320
AP
1318

FIG. 13

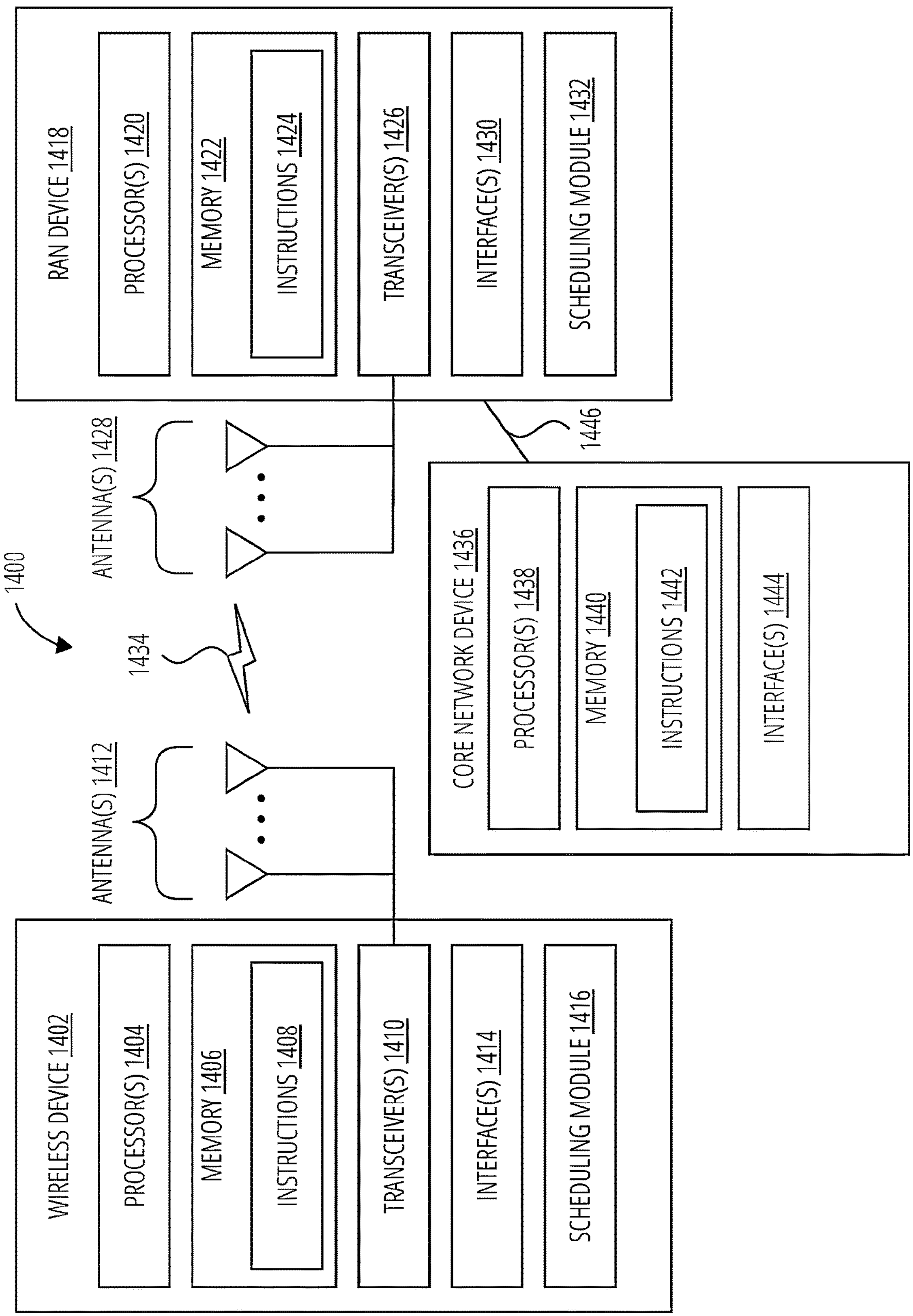

1400
RAN DEVICE 1418
PROCESSOR(S) 1420
MEMORY 1422
INSTRUCTIONS 1424
TRANSCEIVER(S) 1426
INTERFACE(S) 1430
SCHEDULING MODULE 1432
ANTENNA(S) 1428
1446
1434
CORE NETWORK DEVICE 1436
PROCESSOR(S) 1438
MEMORY 1440
INSTRUCTIONS 1442
INTERFACE(S) 1444
ANTENNA(S) 1412
WIRELESS DEVICE 1402
PROCESSOR(S) 1404
MEMORY 1406
INSTRUCTIONS 1408
TRANSCEIVER(S) 1410
INTERFACE(S) 1414
SCHEDULING MODULE 1416

FIG. 14

PROCEDURE FOR NON-TERRESTRIAL NETWORK COVERAGE ENHANCEMENT WITH ULTRA COMPACT DOWNLINK CONTROL INFORMATION AND SCHEDULING PHYSICAL DOWNLINK SHARED CHANNEL

TECHNICAL FIELD

[0001] This application relates generally to wireless communication systems, including wireless communication systems using ultra compact DCI and/or one or more scheduling physical downlink shared channel (PDSCH) for scheduling PDSCHs and/or physical uplink shared channel (PUSCHs) for data transmission (e.g., user/application data transmission).

BACKGROUND

[0002] Wireless mobile communication technology uses various standards and protocols to transmit data between a base station and a wireless communication device. Wireless communication system standards and protocols can include, for example, 3rd Generation Partnership Project (3GPP) long term evolution (LTE) (e.g., 4G), 3GPP new radio (NR) (e.g., 5G), and IEEE 802.11 standard for wireless local area networks (WLAN) (commonly known to industry groups as Wi-Fi®).

[0003] As contemplated by the 3GPP, different wireless communication systems standards and protocols can use various radio access networks (RANs) for communicating between a base station of the RAN (which may also sometimes be referred to generally as a RAN node, a network node, or simply a node) and a wireless communication device known as a user equipment (UE). 3GPP RANs can include, for example, global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE) RAN (GERAN), Universal Terrestrial Radio Access Network (UTRAN), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), and/or Next-Generation Radio Access Network (NG-RAN).

[0004] Each RAN may use one or more radio access technologies (RATs) to perform communication between the base station and the UE. For example, the GERAN implements GSM and/or EDGE RAT, the UTRAN implements universal mobile telecommunication system (UMTS) RAT or other 3GPP RAT, the E-UTRAN implements LTE RAT (sometimes simply referred to as LTE), and NG-RAN implements NR RAT (sometimes referred to herein as 5G RAT, 5G NR RAT, or simply NR). In certain deployments, the E-UTRAN may also implement NR RAT. In certain deployments, NG-RAN may also implement LTE RAT.

[0005] A base station used by a RAN may correspond to that RAN. One example of an E-UTRAN base station is an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node B (also commonly denoted as evolved Node B, enhanced Node B, eNodeB, or eNB). One example of an NG-RAN base station is a next generation Node B (also sometimes referred to as a g Node B or gNB).

[0006] A RAN provides its communication services with external entities through its connection to a core network (CN). For example, E-UTRAN may utilize an Evolved Packet Core (EPC), while NG-RAN may utilize a 5G Core Network (5GC).

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0007] To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

[0008] FIG. **1** illustrates an NTN architecture of a wireless communication system, according to an embodiment.

[0009] FIG. **2** illustrates an NTN architecture of a wireless communication system, according to an embodiment.

[0010] FIG. **3** illustrates a diagram for a dynamic resource grant procedure for DL data transmission, according to an embodiment.

[0011] FIG. **4** illustrates a diagram for a dynamic resource grant procedure for UL data transmission, according to an embodiment.

[0012] FIG. **5** illustrates a diagram for a dynamic resource grant procedure for DL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment.

[0013] FIG. **6** illustrates a diagram for a dynamic resource grant procedure for DL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment.

[0014] FIG. **7** illustrates a method of a base station, according to an embodiment.

[0015] FIG. **8** illustrates a method of a UE, according to an embodiment.

[0016] FIG. **9** illustrates a diagram for a dynamic resource grant procedure for UL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment.

[0017] FIG. **10** illustrates a diagram for a dynamic resource grant procedure for UL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment.

[0018] FIG. **11** illustrates a method of a base station, according to an embodiment.

[0019] FIG. **12** illustrates a method of a UE, according to an embodiment.

[0020] FIG. **13** illustrates an example architecture of a wireless communication system, according to embodiments disclosed herein.

[0021] FIG. **14** illustrates a system for performing signaling between a wireless device and a RAN device connected to a core network of a CN device, according to embodiments disclosed herein.

DETAILED DESCRIPTION

[0022] Various embodiments are described with regard to a UE. However, reference to a UE is merely provided for illustrative purposes. The example embodiments may be utilized with any electronic component that may establish a connection to a network and is configured with the hardware, software, and/or firmware to exchange information and data with the network. Therefore, the UE as described herein is used to represent any appropriate electronic component.

[0023] FIG. **1** illustrates a non-terrestrial network (NTN) architecture **100** of a wireless communication system, according to an embodiment. The NTN architecture **100** includes a core network (CN) **102**, a terrestrial base station **104**, a satellite gateway **106**, a satellite **108**, and a UE **110**.

The terrestrial base station **104**, the satellite gateway **106**, and the satellite **108** may be included in a RAN **112**.

[0024] In some embodiments, the RAN **112** includes E-UTRAN, the CN **102** includes an EPC, and the terrestrial base station **104** includes an eNB. In these cases, the CN link **114** connecting the CN **102** and the terrestrial base station **104** may include an S1 interface.

[0025] In some embodiments, RAN **112** includes NG-RAN, the CN **102** includes a 5GC, and the terrestrial base station **104** includes a gNB or a next generation eNB (ng-eNB). In such cases, the CN link **114** connecting the CN **102** and the terrestrial base station **104** may include an NG interface.

[0026] The NTN architecture **100** illustrates a "bent-pipe" or "transparent" satellite based architecture. In such bent-pipe systems, the terrestrial base station **104** uses the satellite gateway **106** to communicate with the satellite **108** over a feeder link **116**. The satellite **108** may be equipped with one or more antennas capable of broadcasting a cell according to the RAN **112**, and the UE **110** may be equipped with one or more antennas (e.g., a moving parabolic antenna, an omni-directional phased-array antenna, etc.) capable of communicating with the satellite **108** via a Uu interface on that cell (such communications may be said to use the illustrated service link **118**). A payload sited on the satellite **108** then transparently forwards data between the satellite gateway **106** and the UE **110** using the feeder link **116** between the satellite gateway **106** and the satellite **108** and the service link **118** between the satellite **108** and the UE **110**. The payload may perform RF conversion and/or amplification in both uplink (UL) and downlink (DL) to enable this communication.

[0027] In the embodiment shown in FIG. **1**, the terrestrial base station **104** is illustrated without the capability of terrestrial wireless communication directly with a UE. However, it is contemplated that in other embodiments, such a terrestrial base station using the satellite gateway **106** to communicate with the satellite **108** could (also) have this functionality (i.e., as in the terrestrial base station **1312** and the terrestrial base station **1314** of FIG. **13**, to be described below).

[0028] FIG. **2** illustrates an NTN architecture **200** of a wireless communication system, according to an embodiment. The NTN architecture **200** includes a CN **202**, a satellite gateway **204**, a satellite base station **206**, and a UE **208**. The satellite gateway **204** and the satellite base station **206** may be included in the RAN **210**.

[0029] In some embodiments, the RAN **210** includes E-UTRAN and the CN **202** includes an EPC. In these cases, the CN link **212** connecting the CN **202** and the satellite gateway **204** may include an S1 interface.

[0030] In some embodiments, RAN **210** includes NG-RAN and the CN **202** includes a 5GC. In such cases, the CN link **212** connecting the CN **202** and the satellite gateway **204** may include an NG interface.

[0031] The NTN architecture **200** implements a "regenerative" satellite based architecture. In such regenerative systems, the functionalities of a base station are sited on the satellite base station **206**, and the communications between these base station functions and the CN **202** occur through a forwarding of interface(s) (e.g., a S1 interface and/or an NG interface) found on the CN link **212** through the satellite gateway **204** and a feeder link **214** to the satellite base station **206**. The satellite base station **206** may be equipped with one or more antennas capable of broadcasting a cell according to the RAN **210**, and the UE **208** may be equipped with one or more antennas (e.g., a moving parabolic antenna, an omni-directional phased-array antenna, etc.) capable of communicating with the satellite base station **206** via a Uu interface on that cell (such communications may be said to use the illustrated service link **216**). A payload sited on the satellite base station **206** then forwards data between the satellite gateway **204** and the UE **208** using the feeder link **214** between the satellite gateway **204** and the satellite base station **206** and the service link **216** between the satellite base station **206** and the UE **208**. The payload may perform RF conversion and/or amplification in both uplink (UL) and downlink (DL) to enable this communication, as well as implement the functionalities of the base station (e.g., as an eNB, ng-eNB or a gNB, as corresponding to the type of the RAN **210**), as these have been sited on the satellite base station **206**.

[0032] In embodiments of NTN architectures comprising NG-RAN that also use integrated access and backhaul (IAB), it is possible that a gNB control unit functionality (CU) could be sited terrestrially and may use a satellite gateway to communicate with a satellite that hosts a corresponding gNB donor unit functionality (DU), with the F1 interface(s) between the CU and the DU underpinned by the feeder link **214**. In such cases, the CU and the DU may each be understood to be part of the NG-RAN.

[0033] Characteristic differences of NTNs versus terrestrial networks may include relatively larger propagation delays and the potential for movement of the satellite relative to a current position of a UE. Accordingly, improvements to wireless communications systems may be intended to help to alleviate undesirable effects stemming from these circumstances. Such improvements may respond to the need to improve various services provided to a UE by an NTN (e.g., voice service, data service), in view of real-world characteristics of NTN performance (e.g., as opposed to an idealized case). Such improvements to NTN use may be arranged to account for relevant regulatory restrictions, such as limitations on power flux density (PFD) at surface/ground level as established by the International Telecommunications Union (ITU). It will be understood that in some circumstances, such improvements may be achieved (at least in part) via a particular use of one or more physical radio channels in a way that helps to alleviate these and other NTN-related issues.

[0034] In some instances, pairing of the L-band (e.g., 1,610 megahertz (MHz) to 1,618.775 MHz) and the S-band (e.g., 2,483.5 MHz to 2,500 MHz) may be considered. For example, it may be that the L-band may be used for UL between a satellite and a UE while the S-band may be used for DL between the satellite and the UE.

[0035] A PFD limitation on the use of this S-band may be applicable according to various regulations. For example, as applicable in a mobile-satellite service context in in the 2,483.5 MHz to 2,500 MHz range, a PFD limitation may be expressed in terms of the PFD calculation factors P (expressed in dB (W/m^2) per MHz or per X kilohertz (kHz)) and r (expressed in dB/degree). Values for these PFD calculation factors may depend on whether a satellite is a GSO satellite or a non-GSO satellite. The appropriate values for the PFD calculation factors may be applied in a defined way relative to an angle of arrival above the horizontal plane (relative to a location on the earth's surface) δ (in degrees) to arrive at the PFD limitation.

[0036] For example, a satellite in a geostationary orbit (GSO) may correspond to PFD calculation factors P=−146 dB (W/m^2) in 4 kHz or −128 dB (W/m^2) in 1 MHz and r=0.5 dB/degree, while a satellite in a non-GSO may correspond to parameters P=−144 dB (W/m^2) in 4 kHz or −126 dB (W/m^2) in 1 MHz and r=0.65 dB/degree. In some regions, a satellite in a non-GSO may instead use P=−142.5 dB (W/m^2) in 4 kHz and −124.5 dB (W/m^2) in 1 MHz.

[0037] Then, using the appropriate PFD calculation factors P and r according to the applicable satellite information, a PFD limitation relative to the satellite can be calculated according to the applicable & between a UE location and the satellite using:

$$PFD = P, \text{ for } 0° \le \delta \le 5°;$$

$$PFD = P + r(\delta - 5), \text{ for } 5° \le \delta \le 25°; \text{ and}$$

$$PFD = P + 20r, \text{ for } 25° \le \delta \le 90°.$$

[0038] Within such PFD constraints as calculated, it may be that DL transmission power (or effective isotropic radiated power (EIRP)) in the 2,483.5 MHz to 2,500 MHz range cannot be large enough to cover the entire geographic cell of the satellite with strong coverage.

[0039] Accordingly, the use of embodiments described herein may, for example, enhance the DL coverage experienced by a UE within the cell of the satellite when such circumstances as described here are applicable.

[0040] FIG. **3** illustrates a diagram **300** for a dynamic resource grant procedure for DL data transmission, according to an embodiment. The diagram **300** illustrates that the downlink control information (DCI) **302** is sent from a base station to a UE. The DCI **302** may be carried in a physical downlink control channel (PDCCH). The DCI **302** may be, for example, of DCI format 1_0, 1_1, or 1_2.

[0041] The DCI **302** may indicate to the UE that the network has allocated the PDSCH **304** with DL data resources for the UE (e.g., the network has scheduled the use of the PDSCH **304** for the UE), and may further indicate to the UE the time and frequency location of the PDSCH **304**. As illustrated, a minimum offset K0 **308** between the DCI **302** scheduling the PDSCH **304** and the PDSCH **304** itself may be maintained by the network.

[0042] The DCI **302** may also indicate to the UE that the network has allocated the PUCCH **306** to be used by the UE for any hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling related to the receipt and attempted decoding of the PDSCH **304** by the UE (e.g., the network has scheduled the use of the PUCCH **306** by the UE). As illustrated, a minimum offset K1 **310** between the PDSCH **304** and the PUCCH **306** may be maintained by the network.

[0043] The UE may accordingly attempt to receive and decode the PDSCH **304** at the time/frequency resources that were indicated for the PDSCH **304** in the DCI **302**. The UE may then transmit HARQ-ACK signaling corresponding to the result on the PUCCH **306**. For example, if the receipt and decoding of the PDSCH **304** by the UE was successful, the HARQ-ACK signaling on the PUCCH **306** may comprise an acknowledgment (ACK). If the receipt and/or decoding of the PDSCH **304** was unsuccessful, the HARQ-ACK signaling on the PUCCH **306** may instead comprise a negative acknowledgement (NACK).

[0044] FIG. **4** illustrates a diagram **400** for a dynamic resource grant procedure for UL data transmission, according to an embodiment. The diagram **400** illustrates that the DCI **402** is sent from a base station to a UE. The DCI **402** may be carried in a PDCCH. The DCI **402** may be, for example, of DCI format 0_0, 0_1, or 0_2.

[0045] The DCI **402** may indicate to the UE that the network has allocated the PUSCH **404** for use by the UE for transmitting UL data (e.g., the network has scheduled the use of the PUSCH **404** for the UE), and may further indicate to the UE the time and frequency location of the PUSCH **404**. As illustrated, a minimum offset K2 **406** between the DCI **402** scheduling the PUSCH **404** and the PUSCH **404** itself may be maintained by the network.

[0046] The UE may accordingly transmit data on the PUSCH **404** at the time/frequency resources that were indicated for the PUSCH **404** in the DCI **402**.

[0047] The procedures of FIG. **3** and FIG. **4** may be successfully used in certain cases (e.g., cases involving fully terrestrial networks) where aspects of the behavior of and/or relationship between a base station and a UE are as may be implicitly assumed in those scenarios. However, it has been recognized that in various circumstances, modifications to the procedures illustrated in (and described in relation to) FIG. **3** and FIG. **4** may be beneficial.

[0048] For example, in order to address NTN-related issues of additional signaling propagation time and/or distance, and/or of PFD limitations, it has been determined that PDSCH coverage as provided by a satellite of an NTN may be improved by using (a relatively large number of) PDSCH repetitions.

[0049] Further, it has been recognized that in the NTN context, PDCCH transmissions (e.g., for DCI, as described herein) may represent a bottleneck in various circumstances. For example, in the case where repeated PDCCHs are not configured for use in an NTN network, a (accordingly single) PDCCH may be more likely to be missed in the NTN context than in another context (e.g., than in a fully terrestrial context). Further, the use of PDCCH repetitions in an NTN context (in an attempt to reduce the chance that PDCCH signaling is altogether missed) may have an outsized negative impact on network throughput overall in some cases (e.g., due to the relatively increased signaling propagation time for the PDCCHs in the NTN context).

[0050] Accordingly, it has been recognized that by simplifying DCI use, the impact(s) felt from these PDCCH-related aspects may be reduced. DCI that are structured and/or used according to such a simplified use may be referred to herein as "ultra compact DCI."

[0051] In some embodiments, this simplification may occur via the use of a DCI format for the ultra compact DCI that results in an overall reduced payload size for the ultra compact DCI as compared to payload sizes for DCI according to other DCI formats under the same parameters/circumstances. This may be accomplished in some embodiments by omitting one or more fields from the ultra compact DCI that would otherwise be present in the DCI of the other DCI formats. In some wireless communications networks, such as those that implement LTE RAT and/or NR RAT, it may be that such ultra compact DCI may accordingly have a reduced payload size as compared to a "compact DCI" (e.g., DCI of format 1_2 and/or 0_2) that are known to those networks.

[0052] In some embodiments, such a simplification may (alternatively or additionally) occur through the use of fixed values for one or more fields within the ultra compact DCI (which may aid in speeding and/or simplifying the decoding of the ultra compact DCI at the UE). In some of these embodiments, it may be that a payload size of an ultra compact DCI is accordingly not necessarily smaller than a payload size of a DCI of another DCI format known/used in the relevant wireless communication system.

[0053] It is noted that in some embodiments, a DCI format for an ultra compact DCI may define for fields beyond those provided for in other DCI formats known to/defined for the wireless communication system. Accordingly, in a subset of such embodiments, it is possible that an ultra compact DCI has a larger payload size than a payload size of a DCI of another DCI format known/used in the relevant wireless communication system (due to these additional fields).

[0054] Further, embodiments herein may provide at least some scheduling information for a PDSCH or PUSCH used for data transmission in one or more intervening PDSCHs that occur between the ultra compact DCI and the PDSCH/PUSCH for data transmission (rather than siting this information within the ultra compact DCI). These one or more intervening PDSCHs may be referred to herein as "scheduling PDSCHs." By using one or more such scheduling PDSCHs to transport scheduling information for the PDSCH/PUSCH for data transmission between the base station and the UE, the payload size of the ultra compact DCI may be accordingly reduced. Herein, a PDSCH for data transmission may be referred to as a "data PDSCH" in order to differentiate it from any scheduling PDSCHs under discussion.

[0055] As will be described, in some embodiments, an ultra compact DCI and/or scheduling PDSCHs may further include scheduling information for a PUCCH that may be used by the UE to provide HARQ-ACK signaling to the base station relative to the scheduling PDSCHs. In some embodiments, this PUCCH occurs between the scheduling PDSCHs and the data PDSCH/the PUSCH that is used for data transmission. In some embodiments, this PUCCH may occur after the scheduling PDSCHs and the data PDSCH/the PUSCH that is used for data transmission.

[0056] Finally, it may be that the one or more scheduling PDSCHs comprise PDSCH repetitions (and this may be so even in cases where, for example, PDCCH repetition for the ultra compact DCI is not available and/or is not used), thereby increasing the chance of successful reception and decoding at the UE of the attendant scheduling information for the data PDSCH/PUSCH/PUCCH for HARQ (as the case may be).

[0057] FIG. **5** illustrates a diagram **500** for a dynamic resource grant procedure for DL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment. More specifically, the diagram **500** illustrates the use of an ultra compact DCI **502** and one or more scheduling PDSCHs **504** to schedule a data PDSCH **506** for the DL data transmission.

[0058] The diagram **500** illustrates that the ultra compact DCI **502** is transmitted by the base station and received at the UE. The ultra compact DCI **502** provides the UE with sufficient information such that the UE is made aware of the time and frequency location(s) of the one or more scheduling PDSCHs **504** (e.g., the ultra compact DCI **502** schedules the one or more scheduling PDSCHs **504**).

[0059] The one or more scheduling PDSCHs **504** are then transmitted by the base station as scheduled and received at the UE. The one or more scheduling PDSCHs **504** may include one or more medium access control control elements (MAC CEs) that include scheduling information for the data PDSCH **506**. The one or more scheduling PDSCHs **504** accordingly provide the UE (e.g., in the MAC CE(s)) with sufficient information such that the UE is made aware of the time and frequency location of the data PDSCH **506** (e.g., the one or more scheduling PDSCHs **504** schedule the data PDSCH **506**).

[0060] In some embodiments, the one or more scheduling PDSCHs **504** comprises PDSCH repetitions. For example, in the case that the one or more scheduling PDSCHs **504** includes at least two PDSCHs, each of these two PDSCHs may be the same. In such cases, each of the one or more scheduling PDSCHs **504** would have, for example, a same MAC CE having scheduling information for the data PDSCH **506**. The use of such repetitions may provide the UE with additional reception opportunities for this data, thereby improving the probability that the UE will successfully receive and/or decode this data.

[0061] The data PDSCH **506** is then transmitted by the base station as scheduled and is received at the UE. The data PDSCH **506** may include, for example, user plane (UP) data (e.g., application layer data for an application operating on the UE).

[0062] As illustrated, a minimum offset K3 **508** between the last of the one or more scheduling PDSCHs **504** and the data PDSCH **506** may be maintained by the network. In other words, the ultra compact DCI **502** may schedule the one or more scheduling PDSCHs **504**, and the one or more scheduling PDSCHs **504** may schedule the data PDSCH **506**, such that a minimum offset K3 **508** is maintained.

[0063] The base station may transmit a system information block (SIB) that includes configuration information for the ultra compact DCI **502** and/or for the one or more scheduling PDSCHs **504**. The configuration information for the ultra compact DCI **502** as found in the SIB may be used by the UE to locate the ultra compact DCI **502**.

[0064] Further, the configuration information for the one or more scheduling PDSCHs **504** as found in the SIB may further be used to locate the one or more scheduling PDSCHs **504** (in other words, the ultra compact DCI **502** may schedule the one or more scheduling PDSCHs **504** in light of/with the background assumption of any configuration for the one or more scheduling PDSCHs **504** provided in the SIB). In some cases, the configuration information for the one or more scheduling PDSCHs **504** in the SIB may relate the time and/or frequency position(s) of any of the one or more scheduling PDSCHs **504** relative to a received ultra compact DCI **502**.

[0065] This SIB may be transmitted to the UE of the dynamic resource grant procedure of FIG. **5** by the base station of the dynamic resource grant procedure of FIG. **5** (e.g., that transmits the ultra compact DCI **502**). Alternatively, the SIB may be transmitted to the UE of FIG. **5** by another base station.

[0066] In some cases, after receiving the data PDSCH **506**, the UE may reply to the base station with HARQ-ACK signaling on a PUCCH (not illustrated in FIG. **5**). For example, if the receipt and decoding of the data PDSCH **506** by the UE was successful, the HARQ-ACK signaling may comprise an ACK. If the receipt and/or decoding of the data PDSCH **506** was unsuccessful, the HARQ-ACK signaling may instead comprise a NACK.

[0067] FIG. **6** illustrates a diagram **600** for a dynamic resource grant procedure for DL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment. The diagram **600** is an expansion of the diagram **500** as described in relation to FIG. **5**. Accordingly, the diagram **600** illustrates the use of the ultra compact DCI **502**, the one or more scheduling PDSCHs **504**, the data PDSCH **506**, and the offset K3 **508** as these were described in relation to the diagram **500** of FIG. **5**. In addition to these elements from the diagram **500** of FIG. **5**, the diagram **600** of FIG. **6** additionally illustrates the scheduling and use of the PUCCH **602** having HARQ-ACK signaling.

[0068] The PUCCH **602** may be used to provide HARQ-ACK signaling from the UE to the base station that indicates whether the UE was able to receive and decode the information provided by the one or more scheduling PDSCHs **504**. If the receipt and decoding of the scheduling information for the data PDSCH **506** from the one or more scheduling PDSCHs **504** by the UE was successful, the HARQ-ACK signaling in the PUCCH **602** may comprise an ACK. If the receipt and/or decoding of the scheduling information for the data PDSCH **506** from the one or more scheduling PDSCHs **504** by the UE was unsuccessful, the HARQ-ACK signaling in the PUCCH **602** may instead comprise a NACK. In the event of a NACK (or in the event that any expected PUCCH **602** does not arrive at the base station at all), the base station may determine that the UE may not in any event use the data PDSCH **506** and may accordingly cancel its transmission of the data PDSCH **506** in order to save network resources.

[0069] As illustrated in the diagram **600** of FIG. **6**, either of the ultra compact DCI **502** and the one or more scheduling PDSCHs **504** (or any ones of these in any combination) provides the UE with sufficient information such that the UE is made aware of the time and frequency location(s) of the PUCCH **602** (e.g., the ultra compact DCI **502** and/or the some/all of the one or more scheduling PDSCHs **504** schedule the PUCCH **602**).

[0070] Alternatively (or additionally), an SIB received at the UE may provide configuration information for the PUCCH **602**, including (but not limited to) providing information regarding the time and/or frequency location of the PUCCH **602**. In such circumstances, the configuration information for the PUCCH **602** in the SIB may relate the time and/or frequency position(s) of the PUCCH **602** relative to a received ultra compact DCI **502** and/or any of the one or more scheduling PDSCHs **504**.

[0071] The diagram **600** of FIG. **6** illustrates the PUCCH **602** in between the one or more scheduling PDSCHs **504** and the data PDSCH **506**. It is noted that in alternative embodiments, a PUCCH **602** as described herein might instead be positioned after the data PDSCH **506**.

[0072] FIG. **7** illustrates a method **700** of a base station, according to an embodiment. The method **700** includes transmitting **702**, to a UE, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a data PDSCH.

[0073] The method **700** further includes transmitting **704**, to the UE, the one or more scheduling PDSCHs.

[0074] The method **700** further includes transmitting **706**, to the UE, the data PDSCH as scheduled by the one or more scheduling PDSCHs.

[0075] In some embodiments, the method **700** further includes receiving, from the UE, a PUCCH with HARQ-ACK signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs. In some of these embodiments, the ultra compact DCI schedules the PUCCH. In some of these embodiments, the one or more scheduling PDSCHs schedule the PUCCH.

[0076] In some embodiments, the method **700** further includes transmitting an SIB comprising configuration information for the ultra compact DCI.

[0077] In some embodiments, the method **700** further includes transmitting an SIB comprising configuration information for the one or more scheduling PDSCHs.

[0078] In some embodiments, the method **700** further includes transmitting an SIB comprising configuration information for a PUCCH for HARQ-ACK signaling corresponding to the one or more scheduling PDSCHs.

[0079] In some embodiments of the method **700**, the one or more scheduling PDSCHs schedule the data PDSCH using a MAC CE.

[0080] In some embodiments of the method **700**, the one or more scheduling PDSCHs comprise PDSCH repetitions.

[0081] In some embodiments, the method **700** further includes receiving, from the UE, HARQ-ACK signaling indicating that the UE received the data PDSCH.

[0082] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method **700**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0083] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method **700**. This non-transitory computer-readable media may be, for example, a memory of a base station (such as a memory **1422** of a RAN device **1418** that is a base station, as described herein).

[0084] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method **700**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0085] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method **700**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0086] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method **700**.

[0087] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processing element is to cause the processing element to carry out one or more elements of the method **700**. The processor may be a processor of a base station (such as a processor(s) **1420** of a RAN device **1418** that is a base station, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the base station (such as a memory **1422** of a RAN device **1418** that is a base station, as described herein).

[0088] FIG. **8** illustrates a method **800** of a UE, according to an embodiment. The method **800** includes receiving **802**, from a base station, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a data PDSCH.

[0089] The method **800** further includes receiving **804**, from the base station, the one or more scheduling PDSCHs.

[0090] The method **800** further includes receiving **806**, from the base station, the data PDSCH as scheduled by the one or more scheduling PDSCHs.

[0091] In some embodiments, the method **800** further includes sending, to the base station, a PUCCH with HARQ-ACK signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs. In some of these embodiments, the ultra compact DCI schedules the PUCCH. In some of these embodiments, the one or more scheduling PDSCHs schedule the PUCCH.

[0092] In some embodiments, the method **800** further includes receiving an SIB comprising configuration information for the ultra compact DCI.

[0093] In some embodiments, the method **800** further includes receiving an SIB comprising configuration information for the one or more scheduling PDSCHs.

[0094] In some embodiments, the method **800** further includes receiving an SIB comprising configuration information for a PUCCH for HARQ-ACK signaling corresponding to the one or more scheduling PDSCHs.

[0095] In some embodiments of the method **800**, the one or more scheduling PDSCHs schedule the data PDSCH using a MAC CE.

[0096] In some embodiments of the method **800**, the one or more scheduling PDSCHs comprise PDSCH repetitions.

[0097] In some embodiments, the method **800** further comprises sending, to the base station, HARQ-ACK signaling indicating that the UE received the data PDSCH.

[0098] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method **800**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0099] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method **800**. This non-transitory computer-readable media may be, for example, a memory of a UE (such as a memory **1406** of a wireless device **1402** that is a UE, as described herein).

[0100] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method **800**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0101] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method **800**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0102] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method **800**.

[0103] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processor is to cause the processor to carry out one or more elements of the method **800**. The processor may be a processor of a UE (such as a processor(s) **1404** of a wireless device **1402** that is a UE, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the UE (such as a memory **1406** of a wireless device **1402** that is a UE, as described herein).

[0104] FIG. **9** illustrates a diagram **900** for a dynamic resource grant procedure for UL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment. More specifically, the diagram **900** illustrates the use of an ultra compact DCI **902** and one or more scheduling PDSCHs **904** to schedule a PUSCH **906** for the UL data transmission.

[0105] The diagram **900** illustrates that the ultra compact DCI **902** is transmitted by the base station and received at the UE. The ultra compact DCI **902** provides the UE with sufficient information such that the UE is made aware of the time and frequency location(s) of the one or more scheduling PDSCHs **904** (e.g., the ultra compact DCI **902** schedules the one or more scheduling PDSCHs **904**).

[0106] The one or more scheduling PDSCHs **904** are then transmitted by the base station as scheduled and received at the UE. The one or more scheduling PDSCHs **904** may include one or more medium access control control elements (MAC CEs) that include scheduling information for the PUSCH **906**. The one or more scheduling PDSCHs **904** accordingly provide the UE (e.g., in the MAC CE(s)) with sufficient information such that the UE is made aware of the time and frequency location of the PUSCH **906** (e.g., the one or more scheduling PDSCHs **904** schedule the PUSCH **906**).

[0107] In some embodiments, the one or more scheduling PDSCHs **904** comprises PDSCH repetitions. For example, in the case that the one or more scheduling PDSCHs **904** includes at least two PDSCHs, each of these two PDSCHs may be the same. In such cases, each of the one or more scheduling PDSCHs **904** would have, for example, a same MAC CE having scheduling information for the PUSCH **906**. The use of such repetitions may provide the UE with additional reception opportunities for this data, thereby improving the probability that the UE will successfully receive and/or decode this data.

[0108] The PUSCH **906** is then transmitted by the UE as scheduled. The PUSCH **906** may include, for example, user plane (UP) data (e.g., application layer data for an application operating on the UE).

[0109] As illustrated, a minimum offset K4 **908** between the last of the one or more scheduling PDSCHs **904** and the PUSCH **906** may be maintained by the network. In other words, the ultra compact DCI **902** may schedule the one or more scheduling PDSCHs **904**, and the one or more scheduling PDSCHs **904** may schedule the PUSCH **906**, such that a minimum offset K4 **908** is maintained.

[0110] The base station may transmit a system information block (SIB) that includes configuration information for the ultra compact DCI **902** and/or for the one or more scheduling PDSCHs **904**. The configuration information for the ultra compact DCI **902** as found in the SIB may be used by the UE to locate the ultra compact DCI **902**.

[0111] Further, the configuration information for the one or more scheduling PDSCHs **904** as found in the SIB may further be used to locate the one or more scheduling PDSCHs **904** (in other words, the ultra compact DCI **902** may schedule the one or more scheduling PDSCHs **904** in light of/with the background assumption of any configuration for the one or more scheduling PDSCHs **904** provided in the SIB). In some cases, the configuration information for the one or more scheduling PDSCHs **904** in the SIB may relate the time and/or frequency position(s) of any of the one or more scheduling PDSCHs **904** relative to a received ultra compact DCI **902**.

[0112] This SIB may be transmitted to the UE of the dynamic resource grant procedure of FIG. **9** by the base station of the dynamic resource grant procedure of FIG. **9** (e.g., that transmits the ultra compact DCI **902**). Alternatively, the SIB may be transmitted to the UE of FIG. **9** by another base station.

[0113] FIG. **10** illustrates a diagram **1000** for a dynamic resource grant procedure for UL data transmission using ultra compact DCI and one or more scheduling PDSCHs, according to an embodiment. The diagram **1000** is an expansion of the diagram **900** as described in relation to the diagram **900** of FIG. **9**. Accordingly, the diagram **1000** illustrates the use of the ultra compact DCI **902**, the one or more scheduling PDSCHs **904**, the PUSCH **906**, and the offset K4 **908** as these were described in relation to the diagram **900** of FIG. **9**. In addition to these elements from the diagram **900** of FIG. **9**, the diagram **1000** of FIG. **10** additionally illustrates the scheduling and use of the PUCCH **1002** having HARQ-ACK signaling.

[0114] The PUCCH **1002** may be used to provide HARQ-ACK signaling from the UE to the base station that indicates whether the UE was able to receive and decode the information provided by the one or more scheduling PDSCHs **904**. If the receipt and decoding of the scheduling information for the PUSCH **906** from the one or more scheduling PDSCHs **904** by the UE was successful, the HARQ-ACK signaling in the PUCCH **1002** may comprise an ACK. If the receipt and/or decoding of the scheduling information for the PUSCH **906** from the one or more scheduling PDSCHs **904** by the UE was unsuccessful, the HARQ-ACK signaling in the PUCCH **1002** may instead comprise a NACK. In the event of a NACK (or in the event that any expected PUCCH **1002** does not arrive at the base station at all), the base station may determine that the UE may not in any event use the PUSCH **906** and may accordingly cancel its scheduled reception attempt for the PUSCH **906** in order to save network resources.

[0115] As illustrated in the diagram **1000** of FIG. **10**, either of the ultra compact DCI **902** and the one or more scheduling PDSCHs **904** (or any ones of these in any combination) provides the UE with sufficient information such that the UE is made aware of the time and frequency location(s) of the PUCCH **1002** (e.g., the ultra compact DCI **902** and/or the some/all of the one or more scheduling PDSCHs **904** schedule the PUCCH **1002**).

[0116] Alternatively (or additionally), an SIB received at the UE may provide configuration information for the PUCCH **1002**, including (but not limited to) providing information regarding the time and/or frequency location of the PUCCH **1002**. In such circumstances, the configuration information for the PUCCH **1002** in the SIB may relate the time and/or frequency position(s) of the PUCCH **1002** relative to a received ultra compact DCI **902** and/or any of the one or more scheduling PDSCHs **904**.

[0117] The diagram **1000** of FIG. **10** illustrates the PUCCH **1002** in between the one or more scheduling PDSCHs **904** and the PUSCH **906**. It is noted that in alternative embodiments, a PUCCH **1002** as described herein might instead be positioned after the PUSCH **906**.

[0118] FIG. **11** illustrates a method **1100** of a base station, according to an embodiment. The method **1100** includes transmitting **1102**, to a UE, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a PUSCH.

[0119] The method **1100** further includes transmitting **1104**, to the UE, the one or more scheduling PDSCHs.

[0120] The method **1100** further includes receiving **1106**, from the UE, the PUSCH as scheduled by the one or more scheduling PDSCHs.

[0121] In some embodiments, the method **1100** further includes receiving, from the UE, a PUCCH with HARQ-ACK signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs. In some of these embodiments, the ultra compact DCI schedules the PUCCH. In some of these embodiments, the one or more scheduling PDSCHs schedule the PUCCH.

[0122] In some embodiments, the method **1100** further includes transmitting an SIB comprising configuration information for the ultra compact DCI.

[0123] In some embodiments, the method **1100** further includes transmitting an SIB comprising configuration information for the one or more scheduling PDSCHs.

[0124] In some embodiments, the method **1100** further includes transmitting an SIB comprising configuration information for a PUCCH for HARQ-ACK signaling corresponding to the one or more scheduling PDSCHs.

[0125] In some embodiments of the method **1100**, the one or more scheduling PDSCHs schedule the PUSCH using a MAC CE.

[0126] In some embodiments of the method **1100**, the one or more scheduling PDSCHs comprise PDSCH repetitions.

[0127] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method **1100**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0128] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method **1100**. This non-transitory computer-readable media may be, for example, a memory of a base station (such as a memory **1422** of a RAN device **1418** that is a base station, as described herein).

[0129] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method **1100**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0130] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method **1100**. This apparatus may be, for example, an apparatus of a base station (such as a RAN device **1418** that is a base station, as described herein).

[0131] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method **1100**.

[0132] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processing element is to cause the processing element to carry out one or more elements of the method **1100**. The processor may be a processor of a base station (such as a processor(s) **1420** of a RAN device **1418** that is a base station, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the base station (such as a memory **1422** of a RAN device **1418** that is a base station, as described herein).

[0133] FIG. **12** illustrates a method **1200** of a UE, according to an embodiment. The method **1200** includes receiving **1202**, from a base station, an ultra compact DCI that schedules one or more scheduling PDSCHs that schedule a PUSCH.

[0134] The method **1200** further includes receiving **1204**, from the base station, the one or more scheduling PDSCHs.

[0135] The method **1200** further includes transmitting **1206**, to the base station, the PUSCH as scheduled by the one or more scheduling PDSCHs.

[0136] In some embodiments, the method **1200** further includes sending, to the base station, a PUCCH with HARQ-ACK signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs. In some of these embodiments, the ultra compact DCI schedules the PUCCH. In some of these embodiments, the one or more scheduling PDSCHs schedule the PUCCH.

[0137] In some embodiments, the method **1200** further includes receiving an SIB comprising configuration information for the ultra compact DCI.

[0138] In some embodiments, the method **1200** further includes receiving an SIB comprising configuration information for the one or more scheduling PDSCHs.

[0139] In some embodiments, the method **1200** further includes receiving an SIB comprising configuration information for a PUCCH for HARQ-ACK signaling corresponding to the one or more scheduling PDSCHs.

[0140] In some embodiments of the method **1200**, the one or more scheduling PDSCHs schedule the PUSCH using a MAC CE

[0141] In some embodiments of the method **1200**, the one or more scheduling PDSCHs comprise PDSCH repetitions.

[0142] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method **1200**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0143] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method **1200**. This non-transitory computer-readable media may be, for example, a memory of a UE (such as a memory **1406** of a wireless device **1402** that is a UE, as described herein).

[0144] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method **1200**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0145] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method **1200**. This apparatus may be, for example, an apparatus of a UE (such as a wireless device **1402** that is a UE, as described herein).

[0146] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method **1200**.

[0147] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processor is to cause the processor to carry out one or more elements of the method **1200**. The processor may be a processor of a UE (such as a processor(s) **1404** of a wireless device **1402** that is a UE, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the UE (such as a memory **1406** of a wireless device **1402** that is a UE, as described herein).

[0148] FIG. **13** illustrates an example architecture of a wireless communication system **1300**, according to embodiments disclosed herein. The following description is provided for an example wireless communication system **1300** that operates in conjunction with the LTE system standards and/or 5G or NR system standards as provided by 3GPP technical specifications and other 3GPP documents.

[0149] As shown by FIG. **13**, the wireless communication system **1300** includes UE **1302** and UE **1304** (although any number of UEs may be used). In this example, the UE **1302** and the UE **1304** are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device configured for wireless communication.

[0150] The UE **1302** and UE **1304** may be configured to communicatively couple with a RAN **1306**. In embodiments, the RAN **1306** may be NG-RAN, E-UTRAN, etc. The UE **1302** and UE **1304** utilize connections (or channels) (shown as connection **1308** and connection **1310**, respectively) with the RAN **1306**, each of which comprises a physical communications interface. The RAN **1306** can include one or more base stations (such as terrestrial base station **1312**, the terrestrial base station **1314**, the satellite base station **1336** and the satellite base station **1338**) and/or other entities (e.g., the satellite **1342**, which may not have base station functionality) that enable the connection **1308** and connection **1310**. One or more satellite gateways **1334** may integrate the satellite base station **1336**, satellite base station **1338**, and/or the satellite **1342** into the RAN **1306**, in the manners (and with the appropriate elements) described in relation to the NTN architecture **100** of FIG. **1** and the NTN architecture **200** of FIG. **2**.

[0151] In this example, the connection **1308** and connection **1310** are air interfaces to enable such communicative coupling, and may be consistent with RAT(s) used by the RAN **1306**, such as, for example, an LTE and/or NR. It is contemplated that the connection **1308** and connection **1310** may include, in some embodiments, service links between their respective UE **1302**, UE **1304** and one or more of the satellite base station **1336**, the satellite base station **1338**, and the satellite **1342**.

[0152] In some embodiments, the UE **1302** and UE **1304** may also directly exchange communication data via a sidelink interface **1316**.

[0153] The UE **1304** is shown to be configured to access an access point (shown as AP **1318**) via connection **1320**. By way of example, the connection **1320** can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP **1318** may comprise a Wi-Fi® router. In this example, the AP **1318** may be connected to another network (for example, the Internet) without going through a CN **1324**.

[0154] In embodiments, the UE **1302** and UE **1304** can be configured to communicate using orthogonal frequency division multiplexing (OFDM) communication signals with each other, with the terrestrial base station **1312**, the terrestrial base station **1314**, the satellite base station **1336**, the satellite base station **1338**, and/or the satellite **1342** over a multicarrier communication channel in accordance with various communication techniques, such as, but not limited to, an orthogonal frequency division multiple access (OFDMA) communication technique (e.g., for downlink communications) or a single carrier frequency division multiple access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[0155] In some embodiments, all or parts of the terrestrial base station **1312**, terrestrial base station **1314**, the satellite base station **1336** and/or the satellite base station **1338** may be implemented as one or more software entities running on server computers as part of a virtual network.

[0156] In addition, or in other embodiments, the terrestrial base station **1312** or terrestrial base station **1314** may be configured to communicate with one another via interface **1322**. In embodiments where the wireless communication system **1300** is an LTE system (e.g., when the CN **1324** is an EPC), the interface **1322** may be an X2 interface. The X2 interface may be defined between two or more base stations (e.g., two or more eNBs and the like) that connect to an EPC, and/or between two eNBs connecting to the EPC. It is contemplated that an inter-satellite link (ISL) may carry the X2 interface between two satellite base stations.

[0157] In embodiments where the wireless communication system **1300** is an NR system (e.g., when CN **1324** is a 5GC), the interface **1322** may be an Xn interface. An Xn interface is defined between two or more base stations that connect to 5GC (e.g., CN **1324**). For example, the Xn interface may be between two or more gNBs that connect to 5GC, a gNB connecting to 5GC and an eNB, between two eNBs connecting to 5GC, and/or two or more satellite base stations via an ISL (as in, e.g., the interface **1340** between the satellite base station **1336** and the satellite base station **1338**).

[0158] The RAN **1306** is shown to be communicatively coupled to the CN **1324**. The CN **1324** may comprise one or more network elements **1326**, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UE **1302** and UE **1304**) who are connected to the CN **1324** via the RAN **1306**. The components of the CN **1324** may be implemented in one physical device or separate physical devices including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). For example, the components of the CN **1324** may be implemented in one or more processors and/or one or more associated memories.

[0159] In embodiments, the CN **1324** may be an EPC, and the RAN **1306** may be connected with the CN **1324** via an S1 interface **1328**. In embodiments, the S1 interface **1328** may be split into two parts, an S1 user plane (S1-U) interface, which carries traffic data between the terrestrial base station **1312**, terrestrial base station **1314**, the satellite base station **1336**, or the interface **1340** and a serving gateway (S-GW), and the S1-MME interface, which is a signaling interface between the terrestrial base station **1312**, the terrestrial base station **1314**, the satellite base station **1336**, or the interface **1340** and mobility management entities (MMEs).

[0160] In embodiments, the CN **1324** may be a 5GC, and the RAN **1306** may be connected with the CN **1324** via an NG interface **1328**. In embodiments, the NG interface **1328** may be split into two parts, an NG user plane (NG-U) interface, which carries traffic data between the terrestrial base station **1312**, terrestrial base station **1314**, satellite base station **1336**, or satellite base station **1338** and a user plane function (UPF), and the S1 control plane (NG-C) interface, which is a signaling interface between the terrestrial base station **1312**, terrestrial base station **1314**, satellite base station **1336**, or satellite base station **1338** and access and mobility management functions (AMFs).

[0161] Generally, an application server **1330** may be an element offering applications that use internet protocol (IP) bearer resources with the CN **1324** (e.g., packet switched data services). The application server **1330** can also be configured to support one or more communication services (e.g., VOIP sessions, group communication sessions, etc.) for the UE **1302** and UE **1304** via the CN **1324**. The application server **1330** may communicate with the CN **1324** through an IP communications interface **1332**.

[0162] FIG. **14** illustrates a system **1400** for performing signaling **1434** between a wireless device **1402** and a RAN device **1418** connected to a core network of a CN device **1436**, according to embodiments disclosed herein. The system **1400** may be a portion of a wireless communications system as herein described. The wireless device **1402** may be, for example, a UE of a wireless communication system. The RAN device **1418** may be, for example, a base station (e.g., an eNB or a gNB) of a wireless communication system that is a terrestrial base station or a satellite base station. In the case of a RAN device **1418** that is a terrestrial base station, the RAN device **1418** may be in communication with a satellite that directly provides radio access connectivity to a UE, in the manner described herein. The CN device **1436** may be one or more devices making up a CN, as described herein.

[0163] The wireless device **1402** may include one or more processor(s) **1404**. The processor(s) **1404** may execute instructions such that various operations of the wireless device **1402** are performed, as described herein. The processor(s) **1404** may include one or more baseband processors implemented using, for example, a central processing unit (CPU), a digital signal processor (DSP), an application specific integrated circuit (ASIC), a controller, a field programmable gate array (FPGA) device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein.

[0164] The wireless device **1402** may include a memory **1406**. The memory **1406** may be a non-transitory computer-readable storage medium that stores instructions **1408** (which may include, for example, the instructions being executed by the processor(s) **1404**). The instructions **1408** may also be referred to as program code or a computer program. The memory **1406** may also store data used by, and results computed by, the processor(s) **1404**.

[0165] The wireless device **1402** may include one or more transceiver(s) **1410** that may include radio frequency (RF) transmitter and/or receiver circuitry that use the antenna(s) **1412** of the wireless device **1402** to facilitate signaling (e.g., the signaling **1434**) to and/or from the wireless device **1402** with other devices (e.g., the RAN device **1418**) according to corresponding RATs. In some embodiments, the antenna(s) **1412** may include a moving parabolic antenna, an omni-directional phased-array antenna, or some other antenna suitable for communication with a satellite, (e.g., as described above in relation to the UE **110** of FIG. **1** and the UE **208** of FIG. **2**).

[0166] For a RAN device **1418** that is a terrestrial base station, the network device signaling **1434** may occur on a feeder link between the wireless device **1402** and a satellite, and on a service link between the satellite and the RAN device **1418** (e.g., as described in relation to FIG. **1**). For a RAN device **1418** that is a satellite base station, the signaling **1434** may occur on a feeder link between the wireless device **1402** and the RAN device **1418** (e.g., as described in relation to FIG. **2**).

[0167] The wireless device **1402** may include one or more antenna(s) **1412** (e.g., one, two, four, or more). For embodiments with multiple antenna(s) **1412**, the wireless device **1402** may leverage the spatial diversity of such multiple antenna(s) **1412** to send and/or receive multiple different data streams on the same time and frequency resources. This behavior may be referred to as, for example, multiple input multiple output (MIMO) behavior (referring to the multiple antennas used at each of a transmitting device and a receiving device that enable this aspect). MIMO transmissions by the wireless device **1402** may be accomplished according to precoding (or digital beamforming) that is applied at the wireless device **1402** that multiplexes the data streams across the antenna(s) **1412** according to known or assumed channel characteristics such that each data stream is received with an appropriate signal strength relative to other streams and at a desired location in the spatial domain (e.g., the location of a receiver associated with that data stream). Certain embodiments may use single user MIMO (SU-MIMO) methods (where the data streams are all directed to a single receiver) and/or multi user MIMO (MU-MIMO) methods (where individual data streams may be directed to individual (different) receivers in different locations in the spatial domain).

[0168] In certain embodiments having multiple antennas, the wireless device **1402** may implement analog beamforming techniques, whereby phases of the signals sent by the antenna(s) **1412** are relatively adjusted such that the (joint) transmission of the antenna(s) **1412** can be directed (this is sometimes referred to as beam steering).

[0169] The wireless device **1402** may include one or more interface(s) **1414**. The interface(s) **1414** may be used to provide input to or output from the wireless device **1402**. For example, a wireless device **1402** that is a UE may include interface(s) **1414** such as microphones, speakers, a touch-screen, buttons, and the like in order to allow for input and/or output to the UE by a user of the UE. Other interfaces of such a UE may be made up of transmitters, receivers, and other circuitry (e.g., other than the transceiver(s) **1410**/antenna(s) **1412** already described) that allow for communication between the UE and other devices and may operate according to known protocols (e.g., Wi-Fi®, Bluetooth®, and the like).

[0170] The wireless device **1402** may include a scheduling module **1416**. The scheduling module **1416** may be implemented via hardware, software, or combinations thereof. For example, the scheduling module **1416** may be implemented as a processor, circuit, and/or instructions **1408** stored in the memory **1406** and executed by the processor(s) **1404**. In some examples, the scheduling module **1416** may be integrated within the processor(s) **1404** and/or the transceiver(s) **1410**. For example, the scheduling module **1416** may be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the processor(s) **1404** or the transceiver(s) **1410**.

[0171] The scheduling module **1416** may be used for various aspects of the present disclosure, for example, aspects of FIG. **3** through FIG. **12**. The scheduling module **1416** is configured to, for example, process ultra compact DCI and/or scheduling PDSCHs received at the wireless device **1402**.

[0172] The RAN device **1418** may include one or more processor(s) **1420**. The processor(s) **1420** may execute instructions such that various operations of the RAN device **1418** are performed, as described herein. The processor(s) **1404** may include one or more baseband processors implemented using, for example, a CPU, a DSP, an ASIC, a controller, an FPGA device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein.

[0173] The RAN device **1418** may include a memory **1422**. The memory **1422** may be a non-transitory computer-readable storage medium that stores instructions **1424** (which may include, for example, the instructions being executed by the processor(s) **1420**). The instructions **1424** may also be referred to as program code or a computer program. The memory **1422** may also store data used by, and results computed by, the processor(s) **1420**.

[0174] The RAN device **1418** may include one or more transceiver(s) **1426** that may include RF transmitter and/or receiver circuitry that use the antenna(s) **1428** of the RAN device **1418** to facilitate signaling (e.g., the signaling **1434**) to and/or from the RAN device **1418** with other devices (e.g., the wireless device **1402**) according to corresponding RATs.

[0175] The RAN device **1418** may include one or more antenna(s) **1428** (e.g., one, two, four, or more). In embodiments having multiple antenna(s) **1428**, the RAN device **1418** may perform MIMO, digital beamforming, analog beamforming, beam steering, etc., as has been described.

[0176] For a RAN device **1418** that is a terrestrial base station, one or more of the transceiver(s) **1426** and/or the antenna(s) **1428** may instead be present on a satellite gateway associated with the base station (e.g., as shown in reference to the terrestrial base station **104** and the satellite gateway **106** of FIG. **1**). For a RAN device **1418** that is a satellite base station, the transceiver(s) **1426** and/or the antenna(s) **1428** may be present on the satellite, and one or more of those antenna(s) **1428** may be antenna(s) appropriate for satellite communication (such as a moving parabolic antenna, an omni-directional phased-array antenna, etc.)

[0177] The RAN device **1418** may include one or more interface(s) **1430**. The interface(s) **1430** may be used to provide input to or output from the RAN device **1418**. For example, a RAN device **1418** that is a base station may include interface(s) **1430** made up of transmitters, receivers, and other circuitry (e.g., other than the transceiver(s) **1426**/antenna(s) **1428** already described) that enables the base station to communicate with other equipment in a CN, and/or that enables the base station to communicate with external networks, computers, databases, and the like for purposes of operations, administration, and maintenance of the base station or other equipment operably connected thereto.

[0178] The RAN device **1418** may include a scheduling module **1432**. The scheduling module **1432** may be implemented via hardware, software, or combinations thereof. For example, the scheduling module **1432** may be implemented as a processor, circuit, and/or instructions **1424** stored in the memory **1422** and executed by the processor(s) **1420**. In some examples, the scheduling module **1432** may be integrated within the processor(s) **1420** and/or the transceiver(s) **1426**. For example, the scheduling module **1432** may be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the processor(s) **1420** or the transceiver(s) **1426**.

[0179] The scheduling module **1432** may be used for various aspects of the present disclosure, for example, aspects of FIG. **3** through FIG. **12**. The scheduling module **1432** is configured to, for example, generate and/or transmit ultra compact DCI and/or scheduling PDSCHs sent by the RAN device **1418**.

[0180] The RAN device **1418** may communicate with the CN device **1436** via the interface **1446**, which may be analogous to the interface **1328** of FIG. **13** (e.g., may be an S1 and/or NG interface, either of which may be split into user plane and control plane parts).

[0181] The CN device **1436** may include one or more processor(s) **1438**. The processor(s) **1438** may execute instructions such that various operations of the CN device **1436** are performed, as described herein. The processor(s) **1438** may include one or more baseband processors implemented using, for example, a CPU, a DSP, an ASIC, a controller, an FPGA device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein.

[0182] The CN device **1436** may include a memory **1440**. The memory **1440** may be a non-transitory computer-readable storage medium that stores instructions **1442** (which may include, for example, the instructions being executed by the processor(s) **1438**). The instructions **1442** may also be referred to as program code or a computer program. The memory **1440** may also store data used by, and results computed by, the processor(s) **1438**.

[0183] The CN device **1436** may include one or more interface(s) **1444**. The interface(s) **1444** may be used to provide input to or output from the CN device **1436**. For example, a CN device **1436** may include interface(s) **1430** made up of transmitters, receivers, and other circuitry that enables the CN device **1436** to communicate with other equipment in the CN, and/or that enables the CN device **1436** to communicate with external networks, computers, databases, and the like for purposes of operations, administration, and maintenance of the CN device **1436** or other equipment operably connected thereto.

[0184] For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth herein. For example, a baseband processor as described herein in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth herein. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth herein.

[0185] Any of the above described embodiments may be combined with any other embodiment (or combination of embodiments), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

[0186] Embodiments and implementations of the systems and methods described herein may include various operations, which may be embodied in machine-executable instructions to be executed by a computer system. A computer system may include one or more general-purpose or special-purpose computers (or other electronic devices). The computer system may include hardware components that include specific logic for performing the operations or may include a combination of hardware, software, and/or firmware.

[0187] It should be recognized that the systems described herein include descriptions of specific embodiments. These embodiments can be combined into single systems, partially combined into other systems, split into multiple systems or divided or combined in other ways. In addition, it is contemplated that parameters, attributes, aspects, etc. of one embodiment can be used in another embodiment. The parameters, attributes, aspects, etc. are merely described in one or more embodiments for clarity, and it is recognized that the parameters, attributes, aspects, etc. can be combined with or substituted for parameters, attributes, aspects, etc. of another embodiment unless specifically disclaimed herein.

[0188] It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

[0189] Although the foregoing has been described in some detail for purposes of clarity, it will be apparent that certain changes and modifications may be made without departing from the principles thereof. It should be noted that there are many alternative ways of implementing both the processes and apparatuses described herein. Accordingly, the present embodiments are to be considered illustrative and not restrictive, and the description is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

1. A method of a base station, comprising:

transmitting, to a user equipment (UE), an ultra compact downlink control information (DCI) that schedules one or more scheduling physical downlink shared channels (PDSCHs) that schedule a data PDSCH;

transmitting, to the UE, the one or more scheduling PDSCHs; and

transmitting, to the UE, the data PDSCH as scheduled by the one or more scheduling PDSCHs.

2. The method of claim **1**, further comprising receiving, from the UE, a physical uplink control channel (PUCCH) with hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs.

3. The method of claim **2**, wherein the ultra compact DCI schedules the PUCCH.

4. The method of claim **2**, wherein the one or more scheduling PDSCHs schedule the PUCCH.

5. The method of claim **1**, further comprising transmitting a system information block (SIB) comprising configuration information for the ultra compact DCI.

6. The method of claim **1**, further comprising transmitting a system information block (SIB) comprising configuration information for the one or more scheduling PDSCHs.

7. The method of claim **1**, further comprising transmitting a system information block (SIB) comprising configuration information for a physical uplink control channel (PUCCH) for hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling corresponding to the one or more scheduling PDSCHs.

8. The method of claim **1**, wherein the one or more scheduling PDSCHs schedule the data PDSCH using a medium access control control element (MAC CE).

9. The method of claim **1**, wherein the one or more scheduling PDSCHs comprise PDSCH repetitions.

10. The method of claim **1**, further comprising receiving, from the UE, hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling indicating that the UE received the data PDSCH.

11. A method of a user equipment (UE), comprising:

receiving, from a base station, an ultra compact downlink control information (DCI) that schedules one or more scheduling physical downlink shared channels (PDSCHs) that schedule a data PDSCH;

receiving, from the base station, the one or more scheduling PDSCHs; and

receiving, from the base station, the data PDSCH as scheduled by the one or more scheduling PDSCHs.

12. The method of claim **11**, further comprising sending, to the base station, a physical uplink control channel (PUCCH) with hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling indicating that the UE decoded scheduling information from the one or more scheduling PDSCHs.

13. The method of claim **12**, wherein the ultra compact DCI schedules the PUCCH.

14. The method of claim **12**, wherein the one or more scheduling PDSCHs schedule the PUCCH.

15. The method of claim **11**, further comprising receiving a system information block (SIB) comprising configuration information for the ultra compact DCI.

16. The method of claim **11**, further comprising receiving a system information block (SIB) comprising configuration information for the one or more scheduling PDSCHs.

17. The method of claim **11**, further comprising receiving a system information block (SIB) comprising configuration information for a physical uplink control channel (PUCCH) for hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling corresponding to the one or more scheduling PDSCHs.

18. The method of claim **11**, wherein the one or more scheduling PDSCHs schedule the data PDSCH using a medium access control control element (MAC CE).

19. The method of claim **11**, wherein the one or more scheduling PDSCHs comprise PDSCH repetitions.

20. The method of claim **11**, further comprising sending, to the base station, hybrid automatic repeat request acknowledgement (HARQ-ACK) signaling indicating that the UE received the data PDSCH.

21-41. (canceled)

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