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(54) **Title:** DOWNLINK PILOT SIGNAL COMPRESSION

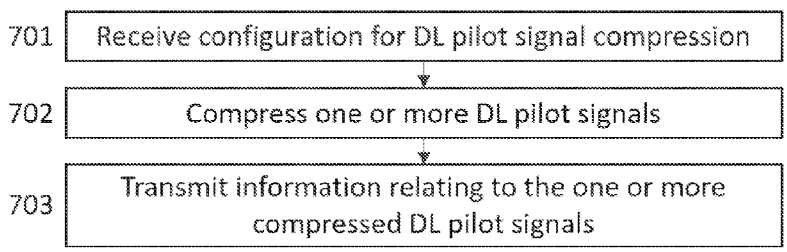

FIG. 7

(57) **Abstract:** Disclosed is a method comprising receiving, from a radio access network node, a configuration for downlink pilot signal compression; compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

DOWNLINK PILOT SIGNAL COMPRESSION

FIELD

The following example embodiments relate to wireless communication.

BACKGROUND

Pilot signals are known sequences of data transmitted within a communication system that may be used to facilitate the estimation of channel state information (CSI).

BRIEF DESCRIPTION

The scope of protection sought for various example embodiments is set out by the independent claims. The example embodiments and features, if any, described in this specification that do not fall under the scope of the independent claims are to be interpreted as examples useful for understanding various embodiments.

According to an aspect, there is provided an apparatus comprising at least one processor, and at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to: receive, from a radio access network node, a configuration for downlink pilot signal compression; compress, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmit, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided an apparatus comprising: means for receiving, from a radio access network node, a configuration for downlink pilot signal compression; means for compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and means for transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided a method comprising: receiving, from a radio access network node, a configuration for downlink pilot signal compression; compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided a computer program comprising instructions which, when executed by an apparatus, cause the apparatus to perform at least the following: receiving, from a radio access network node, a configuration for downlink pilot signal compression; compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided a computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following: receiving, from a radio access network node, a configuration for downlink pilot signal compression; compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided a non-transitory computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following: receiving, from a radio access network node, a configuration for downlink pilot signal compression; compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

According to another aspect, there is provided an apparatus comprising at least one processor, and at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to: transmit, to a user equipment, a configuration for downlink pilot signal compression; receive, from the user equipment, information relating to one or more compressed downlink pilot signals; construct one or more downlink pilot signals based on the information; and perform downlink channel estimation based at least on the one or more constructed downlink pilot signals.

According to another aspect, there is provided an apparatus comprising: means for transmitting, to a user equipment, a configuration for downlink pilot signal compression; receiving, from the user equipment, information relating to one or more compressed downlink pilot signals; means for constructing one or more downlink pilot signals based on the information; and means for performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

According to another aspect, there is provided a method comprising: transmitting, to a user equipment, a configuration for downlink pilot signal compression; receiving, from the user equipment, information relating to one or more compressed downlink pilot signals; constructing one or more downlink pilot signals based on the information; and performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

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According to another aspect, there is provided a computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following: transmitting, to a user equipment, a configuration for downlink pilot signal compression; receiving, from the user equipment, information relating to one or more compressed downlink pilot signals; constructing one or more downlink pilot signals based on the information; and performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

According to another aspect, there is provided a non-transitory computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following: transmitting, to a user equipment, a configuration for downlink pilot signal compression; receiving, from the user equipment, information relating to one or more compressed downlink pilot signals; constructing one or more downlink pilot signals based on the information; and performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

LIST OF DRAWINGS

In the following, various example embodiments will be described in greater detail with reference to the accompanying drawings, in which

FIG. 1 illustrates an example of a wireless communication network;

FIG. 2A illustrates an example of channel state information compression using a Type I or Type II codebook;

FIG. 2B illustrates an example of autoencoder-based channel state information compression;

FIG. 3A illustrates a system according to an example embodiment;

FIG. 3B illustrates a system according to an example embodiment;

FIG. 3C illustrates a system according to an example embodiment;

FIG. 4 illustrates a signal flow diagram according to an example embodiment;

FIG. 5 illustrates a signal flow diagram according to an example embodiment;

FIG. 6 illustrates a signal flow diagram according to an example embodiment;

FIG. 7 illustrates a flow chart according to an example embodiment;

FIG. 8 illustrates a flow chart according to an example embodiment;

FIG. 9 illustrates an example of an apparatus; and

FIG. 10 illustrates an example of an apparatus.

DETAILED DESCRIPTION

The following embodiments are exemplifying. Although the specification may refer to “an”, “one”, or “some” embodiment(s) in several locations of the text, this does not necessarily mean that each reference is made to the same embodiment(s), or that a particular feature only applies to a single embodiment. Single features of different embodiments may also be combined to provide other embodiments.

Some example embodiments described herein may be implemented in a wireless communication network comprising a radio access network based on one or more of the following radio access technologies (RATs): Global System for Mobile Communications (GSM) or any other second generation radio access technology, Universal Mobile Telecommunication System (UMTS, 3G) based on basic wideband-code division multiple access (W-CDMA), high-speed packet access (HSPA), Long Term Evolution (LTE), LTE-Advanced, fourth generation (4G), fifth generation (5G), 5G new radio (NR), 5G-Advanced (i.e., 3GPP NR Rel-18 and beyond), or sixth generation (6G). Some examples of radio access networks include the universal mobile telecommunications system (UMTS) radio access network (UTRAN), the Evolved Universal Terrestrial Radio Access network (E-UTRA), or the next generation radio access network (NG-RAN). The wireless communication network may further comprise a core network, and some example embodiments may also be applied to network functions of the core network.

It should be noted that the embodiments are not restricted to the wireless communication network given as an example, but a person skilled in the art may also apply the solution to other wireless communication networks or systems provided with necessary properties. For example, some example embodiments may also be applied to a communication system based on IEEE 802.11 specifications, or a communication system based on IEEE 802.15 specifications. IEEE is an abbreviation for the Institute of Electrical and Electronics Engineers.

FIG. 1 depicts an example of a simplified wireless communication network showing some physical and logical entities. The connections shown in FIG. 1 may be physical connections or logical connections. It is apparent to a person skilled in the art that the wireless communication network may also comprise other physical and logical entities than those shown in FIG. 1.

The example embodiments described herein are not, however, restricted to the wireless communication network given as an example but a person skilled in the art may apply the example embodiments described herein to other wireless communication networks provided with necessary properties.

The example wireless communication network shown in FIG. 1 includes a radio access network (RAN) and a core network 110.

FIG. 1 shows user equipment (UE) 100, 102 configured to be in a wireless connection on one or more communication channels in a radio cell with an access node 104 of a radio access network.

The access node 104 may comprise a computing device configured to control the radio resources of the access node 104 and to be in a wireless connection with one or more UEs 100, 102. The access node 104 may also be referred to as a base station, a base transceiver station (BTS), an access point, a cell site, a network node, a radio access network node, or a RAN node. The access node 104 may be, for example, an evolved NodeB (abbreviated as eNB or eNodeB), or a next generation evolved NodeB (abbreviated as ng-eNB), or a next generation NodeB (abbreviated as gNB or gNodeB), providing the radio cell. The access node 104 may include or be coupled to transceivers. From the transceivers of the access node 104, a connection may be provided to an antenna unit that establishes a bi-directional radio link to one or more UEs 100, 102. The antenna unit may comprise an antenna or antenna element, or a plurality of antennas or antenna elements.

The wireless connection (e.g., radio link) from a UE 100, 102 to the access node 104 may be called uplink (UL) or reverse link, and the wireless connection (e.g., radio link) from the access node 104 to the UE 100, 102 may be called downlink (DL) or forward link. A UE 100 may also communicate directly with another UE 102, and vice versa, via a wireless connection generally referred to as a sidelink (SL). It should be appreciated that the access node 104 or its functionalities may be implemented by using any node, host, server, access point or other entity suitable for providing such functionalities.

The radio access network may comprise more than one access node 104, in which case the access nodes may also be configured to communicate with one another over wired or wireless links. These links between access nodes may be used for sending and receiving control plane signaling and also for routing data from one access node to another access node.

The access node 104 may further be connected to a core network (CN) 110. The core network 110 may comprise an evolved packet core (EPC) network and/or a 5th generation core network (5GC). The EPC may comprise network entities, such as a serving gateway (S-GW for routing and forwarding data packets), a packet data network gateway (P-GW) for providing connectivity of UEs to external packet data networks, and/or a mobility management entity (MME). The 5GC may comprise one or more network functions, such as at least one of: a user plane function (UPF), an access and mobility management function (AMF), a location management function (LMF), and/or a session management function (SMF).

The core network 110 may also be able to communicate with one or more external networks 113, such as a public switched telephone network or the Internet, or utilize services provided by them. For example, in 5G wireless communication networks, the UPF of the core network 110 may be configured to communicate with an external data network via an N6 interface. In LTE wireless communication networks, the P-GW of the core network 110 may be configured to communicate with an external data network.

It should also be understood that the distribution of functions between core network operations and access node operations may differ in future wireless communication networks compared to that of the LTE or 5G, or even be non-existent.

The illustrated UE 100, 102 is one type of an apparatus to which resources on the air interface may be allocated and assigned. The UE 100, 102 may also be called a wireless communication device, a subscriber unit, a mobile station, a remote terminal, an access terminal, a user terminal, a terminal device, or a user device, just to mention but a few names. The UE 100, 102 may be a computing device operating with or without a subscriber identification module (SIM), including, but not limited to, the following types of computing devices: a mobile phone, a smartphone, a personal digital assistant (PDA), a handset, a computing device comprising a wireless modem (e.g., an alarm or measurement device, etc.), a laptop computer, a desktop computer, a tablet, a game console, a notebook, a multimedia device, a reduced capability (RedCap) device, a wearable device (e.g., a watch, earphones or eyeglasses) with radio parts, a sensor comprising a wireless modem, or a computing device comprising a wireless modem integrated in a vehicle.

It should be appreciated that the UE 100, 102 may also be a nearly exclusive uplink-only device, of which an example may be a camera or video camera loading images or video clips to a network. The UE 100, 102 may also be a device having capability to operate in an Internet of Things (IoT) network, which is a scenario in which objects may be provided with the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

The wireless communication network may also be able to support the usage of cloud services. For example, at least part of core network operations may be carried out as a cloud service (this is depicted in FIG. 1 by “cloud” 114). The UE 100, 102 may also utilize the cloud 114. In some applications, the computation for a given UE may be carried out in the cloud 114 or in another UE.

The wireless communication network may also comprise a central control entity, such as a network management system (NMS), or the like. The NMS is a centralized suite of software and hardware used to monitor, control, and administer the network infrastructure. The NMS is responsible for a wide range of tasks such as fault management, configuration management, security management, performance management, and accounting management. The NMS enables network operators to efficiently manage and optimize network resources, ensuring that the network delivers high performance, reliability, and security.

5G enables using multiple-input and multiple-output (MIMO) antennas in the access node 104 and/or the UE 100, 102, many more base stations or access nodes than an LTE network (a so-called small cell concept), including macro sites operating in co-operation with smaller stations and employing a variety of radio technologies depending on service needs, use cases and/or spectrum available. 5G wireless communication networks may support a wide range of use cases and related applications including video streaming, augmented reality, different ways of data sharing and various forms of machine-type applications, such as (massive) machine-type communications (mMTC), including vehicular safety, different sensors and real-time control.

In 5G wireless communication networks, access nodes and/or UEs may have multiple radio interfaces, such as below 6 gigahertz (GHz), centimeter wave (cmWave) and millimeter wave (mmWave), and also being integrable with legacy radio access technologies, such as LTE. Integration with LTE may be implemented, for example, as a system, where macro coverage may be provided by LTE, and 5G radio interface access may come from small cells by aggregation to LTE. In other words, a 5G wireless communication network may support both inter-RAT operability (such as interoperability between LTE and 5G) and inter-RI operability (inter-radio interface operability, such as between below 6GHz, cmWave, and mmWave).

5G wireless communication networks may also apply network slicing, in which multiple independent and dedicated virtual sub-networks (network instances) may be created within the same physical infrastructure to run services that have different requirements on latency, reliability, throughput and mobility.

In one embodiment, an access node 104 may comprise: a radio unit (RU) comprising a radio transceiver (TRX), i.e., a transmitter (Tx) and a receiver (Rx); one or more distributed units (DUs) 105 that may be used for the so-called Layer 1 (L1) processing and real-time Layer 2 (L2) processing; and a central unit (CU) 108 (also known as a centralized unit) that may be used for non-real-time L2 and Layer 3 (L3) processing. The CU 108 may be connected to the one or more DUs 105 for example via an F1 interface. Such an embodiment of the access node 104 may enable the centralization of CUs relative to the cell sites and DUs, whereas DUs may be more distributed and may even remain at cell sites. The CU and DU together may also be referred to as baseband or a baseband unit (BBU). The CU and DU may also be comprised in a radio access point (RAP).

The CU 108 may be a logical node hosting radio resource control (RRC), service data adaptation protocol (SDAP) and/or packet data convergence protocol (PDCP), of the NR protocol stack for an access node 104. The CU 108 may comprise a control plane (CU-CP), which may be a logical node hosting the RRC and the control plane part of the PDCP protocol of the NR protocol stack for the access node 104. The CU 108 may further comprise a user plane (CU-UP), which may be a logical node hosting the user plane part of the PDCP protocol and the SDAP protocol of the CU for the access node 104.

The DU 105 may be a logical node hosting radio link control (RLC), medium access control (MAC) and/or physical (PHY) layers of the NR protocol stack for the access node 104. The operations of the DU 105 may be at least partly controlled by the CU 108. It should also be understood that the distribution of functions between the DU 105 and the CU 108 may vary depending on the implementation.

Cloud computing systems may also be used to provide the CU 108 and/or DU 105. A CU provided by a cloud computing system may be referred to as a virtualized CU (vCU). In addition to the vCU, there may also be a virtualized DU (vDU) provided by a cloud computing system. Furthermore, there may also be a combination, where the DU may be implemented on so-called bare metal solutions, for example application-specific integrated circuit (ASIC) or customer-specific standard product (CSSP) system-on-a-chip (SoC).

Edge cloud may be brought into the radio access network by utilizing network function virtualization (NFV) and software defined networking (SDN). Using edge cloud may mean access node operations to be carried out, at least partly, in a computing system operationally coupled to a remote radio head (RRH) or a radio unit (RU) of an access node 104. It is also possible that access node operations may be performed on a distributed computing system or a cloud computing system located at the access node 104. Application of cloud RAN architecture enables RAN real-time functions being carried out at the radio access network (e.g., in a DU 105), and non-real-time functions being carried out in a centralized manner (e.g., in a CU 108).

5G (or new radio, NR) wireless communication networks may support multiple hierarchies, where multi-access edge computing (MEC) servers may be placed between the core network 110 and the access node 104. It should be appreciated that MEC may be applied in LTE wireless communication networks as well.

A 5G wireless communication network ("5G network") may also comprise a non-terrestrial communication network, such as a satellite communication network, to enhance or complement the coverage of the 5G radio access network. For example, satellite communication may support the transfer of data between the 5G radio access network and the core network 110, enabling more extensive network coverage. Possible use cases may include: providing service continuity for machine-to-machine (M2M) or Internet of Things (IoT) devices or for passengers on board of vehicles, or ensuring service availability for critical communications, and future railway, maritime, or aeronautical communications. Satellite communication may utilize geostationary earth orbit (GEO) satellite systems, but also low earth orbit (LEO) satellite systems, in particular mega-constellations (i.e., systems in which hundreds of (nano)satellites are deployed). A given satellite 106 in the mega-constellation may cover several satellite-enabled network entities that create on-ground cells. The on-ground cells may be created through an on-ground relay access node or by an access node located on-ground or in a satellite.

It is obvious for a person skilled in the art that the access node 104 depicted in FIG. 1 is just an example of a part of a radio access network, and in practice the radio access network may comprise a plurality of access nodes 104, the UEs 100, 102 may have access to a plurality of radio cells, and the radio access network may also comprise other apparatuses, such as physical layer relay access nodes or other entities. At least one of the access nodes may be a Home eNodeB or a Home gNodeB. A Home gNodeB or a Home eNodeB is a type of access node that may be used to provide indoor coverage inside a home, office, or other indoor environment.

Additionally, in a geographical area of a radio access network, a plurality of different kinds of radio cells as well as a plurality of radio cells may be provided. Radio cells may be macro cells (or umbrella cells) which may be large cells having a diameter of up to tens of kilometers, or smaller cells such as micro-, femto- or picocells. The access node(s) 104 of FIG. 1 may provide any kind of these cells. A cellular radio network may be implemented as a multilayer access networks including several kinds of radio cells. In multilayer access networks, one access node may provide one kind of a radio cell or radio cells, and thus a plurality of access nodes may be needed to provide such a multilayer access network.

For fulfilling the need for improving performance of radio access networks, the concept of “plug-and-play” access nodes may be introduced. A radio access network, which may be able to use “plug-and-play” access nodes, may include, in addition to Home eNodeBs or Home gNodeBs, a Home Node B gateway (HNB-GW) (not shown in FIG. 1). An HNB-GW, which may be installed within an operator’s radio access network, may aggregate traffic from a large number of Home eNodeBs or Home gNodeBs back to a core network 110 of the operator.

Channel state information (CSI) may be needed for precoding in massive MIMO communications with frequency division duplexing (FDD) schemes. Accurate CSI can be used by the RAN node 104 to obtain higher signal-to-noise-ratio (SNR) and channel capacity. However, in FDD networks, only the UE 100, 102 may be able to estimate the downlink CSI. Thus, the estimated CSI may need to be shared with the RAN node 104, which introduces overhead to the network.

To reduce the overhead, various vector quantization techniques may be used to generate a codebook that achieves a low compression ratio (CR), i.e., the ratio of uncompressed size to compressed size . The CR is a scalar value in the range of [1, ∞], wherein a higher CR means more compression. However, these techniques alone cannot provide enough accuracy for CSI reconstruction with limited feedback overhead.

Compressive sensing (CS) based techniques may be used to compress the CSI based on its spatial and temporal correlation. However, the channels may not be sparse, as assumed for the CS-based approach. Furthermore, CS-based techniques use random projections, which may lead to significant reconstruction loss at the RAN node 104.

For the task of compression and reconstruction, an autoencoder (AE) structure from deep learning (DL) techniques can be applied to the CSI feedback application. For example, a CSI sensing and recovery structure called CsiNet may be applied to perform the task of compression and reconstruction by using an encoder and a decoder. The encoder may generate a compressed representation of the input CSI, and the decoder may reconstruct the CSI from the compressed information. By joint training of the encoder and decoder, CsiNet learns the channel structures and provides a more accurate reconstruction compared to the CS-based techniques. A modified version of the CsiNet structure called CsiNet+ may be provided by modifying the convolution kernel size and reconstruction blocks.

Furthermore, a fully convolutional neural network (FullyConv) based CSI feedback may be used to enhance the quality of reconstructed CSI and decrease the number of trainable parameters and computational resources compared to the previous techniques. Although the CsiNet, CsiNet+, and FullyConv techniques may outperform legacy techniques (e.g., CS), these structures are designed for a fixed CR.

To reduce the feedback payload even more, the outputs of the encoder can be quantized. The quantizer output bits represent the encoder outputs. The UE 100, 102 may communicate these bits over the air and the RAN node 104 receives the bits. A de-quantizer at the RAN node 104 may then construct the decoder input using the received bits. Lastly, the decoder at the RAN node 104 processes the compressed signal and reconstructs the full CSI.

In CSI compression using a two-sided model use case, the following artificial intelligence (AI) or machine learning (ML) model training collaborations may be possible: joint training of the two-sided model at a single side or entity (e.g., UE-sided or network-sided); joint training of the two-sided model at the network side and UE side, respectively; and separate training at the network side and UE side, where the UE-side CSI generation part and the network-side CSI reconstruction part are trained by the UE side and network side, respectively.

Joint training means that the generation model and reconstruction model should be trained in the same loop for forward propagation and backward propagation. Joint training may be done both at a single node or across multiple nodes (e.g., through gradient exchange between nodes).

Separate training may include sequential training starting with the UE side training, or sequential training starting with the network side training, or parallel training at the UE and network side.

However, it should be noted that other collaboration types than the ones mentioned above may also be possible.

For the evaluation of the AI/ML-based CSI feedback enhancement, for channel estimation, ideal DL channel estimation may optionally be taken into the baseline of error vector magnitude (EVM) for the purpose of calibration and/or comparing intermediate results (e.g., accuracy of AI/ML output CSI, etc.). Realistic channel estimations should be considered in the performance evaluations.

FIG. 2A illustrates an example of CSI compression using a Type I or Type II codebook 200, 220.

FIG. 2B illustrates an example of autoencoder-based CSI compression.

In FIG. 2A and FIG. 2B, the UE 100 estimates the DL CSI 203 with a UE-specific channel estimation algorithm 202 based on the received DL pilot signals 201.

In FIG. 2A, a Type I or Type II codebook 200 is used to generate a compressed representation of the input CSI 203.

In FIG. 2B, the encoder 204 generates a compressed representation of the input CSI 203. Because the input CSI 203 to the encoder 204 is obtained using the UE-specific channel estimation algorithm 202, the distribution of the encoder input CSI and, consequently, the compressed CSI may change by using different channel estimators.

The quantizer 205 is a function that maps the compressed signal Z_e from the encoder 204 or codebook 200 to a compressed bit sequence denoted as Z_q.

In block 206, the UE 100 transmits the compressed bit sequence Z_q of the quantizer 205 to the RAN node 104 over the air interface by using orthogonal frequency-division multiplexing (OFDM).

In block 207, the RAN node 104 receives the OFDM transmission from the UE 100 and obtains a compressed bit sequence denoted as Y_q (corresponding to the bit sequence Z_q) from the transmission.

As the UE 100 transmits the bit sequence Z_q over the air, there may be some error in the bit sequence Y_q received by the RAN node 104. However, depending on the channel coder, such as low-density parity check (LDPC), used in the OFDM transmission and reception chain, the probability of error in the bit sequence Y_q may be very low. Thus, in most cases, the received bit sequence Y_q may be the same as the transmitted bit sequence Z_q.

The de-quantizer 208 constructs a compressed signal Y_e (corresponding to Z_e) by using the compressed bit sequence Y_q as input.

The codebook 220 or decoder 209 is used to process the compressed signal Y_e received from the de-quantizer 208 and output the reconstructed DL CSI 210 (corresponding to the estimated DL CSI 203 of the UE 100).

As described above, different UEs may use different algorithms for the channel estimation task, which results in different levels of precision for the estimated channel. In addition, UEs may not use complex channel estimators due to the high computational complexity involved and/or limited power in certain UEs. A UE-specific channel estimator 202 adds another degree of generalization requirement for the encoder 204 and decoder 209. As the compressed CSI may be different considering different channel estimators, it requires training encoders and decoders that can adapt themselves to different channel estimators.

Furthermore, the reconstructed channel at the RAN node 104 depends on the used channel estimator 202 at the UE 100, which can affect the beamforming performance of the RAN node 104. In addition, even with channel state information reference signal (CSI-RS) reception at the UE 100, UE vendors may not always use

CSI-RS-based channel estimation for CSI quantity determination, and they may use other channels and past measurements to fine-tune the CSI quantities before transmitting it to the RAN node 104. As the standard does not restrict such a possibility, such processing steps may change the actual channel characteristic that the RAN node 104 wishes to know from the UE side.

Some example embodiments are described below using principles and terminology of 5G radio access technology without limiting the example embodiments to 5G radio access technology, however.

Some example embodiments may provide a solution to solve the problem of the dependency of the CSI compression task on the considered channel estimation algorithm at the UE. Some example embodiments provide the signaling needed to enable direct compression of the received CSI-RS. The CSI-RS is based on a pseudo-random sequence, and this sequence is multiplied by a weighting sequence in both time domain and frequency domain. Also, it is then scaled by a power scaling factor and mapped to a set of specific resource elements in the resource grid.

In some example embodiments, the UE may directly compress the received DL pilot signals (e.g., CSI-RS). Herein a DL pilot signal refers to the received sequence after de-mapping from the resource elements in the resource grid. The RAN node receives the compressed information and (re)constructs the DL pilot signals. The RAN node may then use a channel estimator to estimate the DL CSI.

Depending on the UE and RAN node capabilities for the compression, (re)construction, and channel estimation tasks, the UE may be configured by the RAN node with different operational modes, such as a solely quantization scheme (SQS) or autoencoder quantization scheme (AQS) associated with the direct pilot signal compression and feedback.

In the SQS scheme, the RAN node shares the required pre-processing functions (e.g., normalization, reshaping, etc.) on the measured DL pilot signals. The UE follows the quantization configuration (scalar or vector quantization) indicated from the RAN node. In case of vector quantization, the RAN node may provide a configuration of the quantizer using channel coherence time and bandwidth as anticipated by the RAN node (e.g., providing the grouping technique and parameters for the pilot resource elements). In addition, the RAN node may share the vector quantization codebook for quantizing the grouped pilot resource elements.

In the AQS scheme, the RAN node shares the required pre-processing functions (e.g., normalization, reshaping, etc.) on the measured DL pilot signals. The UE is configured to use a trained encoder to compress the DL pilot signals. The UE follows the quantization configuration (scalar or vector quantization) received from the RAN node.

Furthermore, in case the channel estimator processes the UL pilot signals as additional inputs, the RAN node may configure the UL pilot pattern for coordinating the UL and DL pilot signals to maximize channel estimation accuracy and/or to monitor the performance of the autoencoder model.

The RAN node may also configure UL transmissions, such as sounding reference signal (SRS), as monitoring resources or as assistance resources to enable monitoring of the channel estimations or to enhance the accuracy of the channel estimations.

In addition, the RAN node may switch among the CSI reporting modes using the legacy CSI reporting framework and select a suitable mode depending on the monitoring of the direct pilot compression.

As shown in FIG. 3A, FIG. 3B, and FIG. 3C, the UE may use different approaches for compressing the received DL pilot signals. Depending on the compression approach used at the UE, the RAN node may use different blocks for the reconstruction task.

FIG. 3A illustrates a system according to an example embodiment for the SQS scheme, where the UE 100 only uses a scalar or vector quantizer 303 for compressing the received DL pilot signals 301, and the RAN node 104 only uses a scalar or vector de-quantizer 306 for (re)constructing the DL pilot signals 301. The RAN node 104 may use an advanced channel estimator 308 for estimating the DL channel based on the (re)constructed DL pilot signals.

The DL channel estimation 308 at the RAN node 104 can be done with various options. For example, the RAN node 104 may use a non-ML-based algorithm, such as linear minimum mean square error (LMMSE), least squares (LS), etc., for the DL channel estimation.

As another example, the RAN node 104 may use an ML-based solution for the DL channel estimation task 308. For example, the ML-based solution may comprise a fully-connected neural network, a convolutional neural network, a transformer neural network, or any other suitable architecture. For obtaining the labels in the training phase of the ML-based channel estimator 308, the RAN node 104 may transmit the CSI-RS with maximum power to increase the signal-to-noise-ratio (SNR). In addition, the RAN node 104 may ask the UE 100 to share both the uncompressed and compressed DL pilot signals for the training.

FIG. 3B illustrates a system according to an example embodiment for the AQS scheme, where the UE 100 first uses an encoder 302 to reduce the dimensionality of the received DL pilot signals 301, and the UE 100 then uses a scalar or vector quantizer 303 for further compression. After using the scalar or vector de-quantizer 306, the RAN node 104 uses a decoder 307 to (re)construct the DL pilot signals 301.

FIG. 3C illustrates a system according to an example embodiment, wherein uplink pilot signals are also used (in addition to the (re)constructed DL pilot signals) for the downlink channel estimation 308 at the RAN node 104. In other words, the RAN node 104 may use the uplink pilot signals as additional information for the DL channel estimation 308.

FIG. 4 illustrates a signal flow diagram according to an example embodiment with an SQS compression scheme corresponding to FIG. 3A. In other words, in this example embodiment, the UE 100 may only use a scalar or vector quantizer 303 for the compression task, and the RAN node 104 may accordingly only use a scalar or vector de-quantizer 306 for the reconstruction task.

Referring to FIG. 4, at 401, the UE 100 transmits, to the RAN node 104 (e.g., gNB), capability information indicating at least a capability of the UE 100 for supporting downlink pilot signal compression. The RAN node 104 receives the capability information.

The capability may be indicated as a mode of CSI reporting similar to Type-II reporting, CSI compression, or any other. The UE 100 may also indicate any specific conditions in which the downlink pilot signal compression is supported. For example, the UE 100 may set at least one of the following conditions: a supported number of antennas at the RAN node 104, a supported range of CR, and/or a supported range of payload size.

At 402, the RAN node 104 transmits, to the UE 100, a configuration for the downlink pilot signal compression. The RAN node 104 may determine the configuration based on the capability information received from the UE 100. The UE 100 receives the configuration.

In other words, the RAN node 104 may select and configure direct downlink pilot signal compression as a CSI reporting mode for the UE 100. The UE 100 may support different modes (e.g., pilot compression, legacy reporting, CSI compression, etc..) at the same time but with different CSI reporting configurations.

As an example, the RAN node 104 may configure the CSI reporting mode based on the CSI reporting configuration (e.g., let us assume that CSI_reportconfig 1 is for direct pilot signal compression), where there may be associated parameters or configurations within a CSI reporting configuration to identify that CSI_reportconfig 1 has a different CSI reporting mode than the other modes.

At 403, the UE 100 transmits, to the RAN node 104, an indication indicating a capability for the SQS scheme and/or the AQS scheme. In this example embodiment, the UE 100 may indicate a capability at least for the SQS scheme. The RAN node 104 receives the indication.

At 404, the RAN node 104 transmits, to the UE 100, a configuration for the compression scheme to be used at the UE 100. In this example embodiment, the RAN node 104 may configure SQS as the compression scheme to be used at the UE 100. For example, this configuration may indicate at least one of: one or more pre-processing functions (e.g., normalization and/or reshaping), a grouping technique for a set of resource elements of one or more downlink pilot signals, or a quantization codebook and parameters for quantizing the set of resource elements of the one or more downlink pilot signals.

In other words, the RAN node 104 may share the required information for alignment on the compression, compression ratio, and quantization scheme and configuration, as well as potential pre-processing procedures.

At 405, the RAN node 104 transmits the one or more downlink pilot signals to the UE 100. The UE 100 receives the one or more downlink pilot signals. For example, the one or more downlink pilot signals may comprise one or more channel state information reference signals (CSI-RS), or any other type of reference signal.

At 406, the UE 100 may pre-process, prior to the compression, the one or more downlink pilot signals according to the one or more pre-processing functions indicated by the RAN node 104 at 404. For example, the UE 100 may normalize and/or reshape the one or more downlink pilot signals.

At 407, the UE 100 compresses, based on the configurations received at 402 and 404, the one or more downlink pilot signals received from the RAN node 104. The compression may be performed by using the quantizer 303, wherein the quantizer 303 comprises a scalar quantizer or a vector quantizer. The UE 100 may quantize the one or more downlink pilot signals by using the compression scheme (i.e., SQS in this case) indicated by the RAN node 104 at 404.

In other words, the UE 100 may measure the one or more downlink pilot signals and directly compress the received (noisy) one or more downlink pilot signals.

At 408, the UE 100 transmits, to the RAN node 104, information relating to the one or more compressed downlink pilot signals. The information may be referred to as a compressed CSI report herein. The information may comprise, for example, a compressed bit sequence representing the one or more downlink pilot signals. For example, the UE 100 may use channel coding, a modulation scheme such as quadrature amplitude modulation (QAM), and a data transmission technique such as orthogonal frequency-division multiplexing (OFDM) to transmit the one or more downlink pilot signals as a compressed bit sequence.

At 409, the RAN node 104 obtains or extracts the compressed bit sequence from the received information by using, for example, OFDM demodulation, a QAM demapper, and a channel decoder.

At 410, the RAN node 104 constructs or reconstructs the one or more downlink pilot signals based on the information. In other words, the goal of the RAN node 104 is to create a signal similar to the observations or measurements at the UE 100. In this case, the (re)construction is performed by using the de-quantizer 306 to de-quantize the compressed bit sequence. In other words, the RAN node 104 uses the corresponding de-quantizer according to the selected compression scheme (i.e., SQS in this case) and quantization properties. The de-quantizer 306 may comprise a scalar de-quantizer or a vector de-quantizer. The RAN node 104 may use the inverse of the normalization function to obtain the one or more downlink pilot signals.

At 411, the RAN node 104 performs downlink channel estimation based at least on the one or more (re)constructed downlink pilot signals. In other words, the RAN node 104 estimates the downlink channel between the RAN node 104 and the UE 100.

For example, the downlink channel estimation may be performed by using a non-machine-learning-based algorithm, such as linear minimum mean square error or least squares.

As another example, the downlink channel estimation may be performed by using a machine learning algorithm. The machine learning algorithm may comprise, for example, one of: a fully-connected neural network, a convolutional neural network, a transformer neural network, or any other suitable architecture.

The downlink channel estimation may be performed based further on at least one of: one or more uplink pilot signals received from the UE 100, or an uplink channel correlation function.

A channel correlation function (CCF) is a time-averaged function indicating the correlation between the channel responses of antenna elements. The uplink channel correlation function refers to the correlation of the uplink channel between the UE 100 and the RAN node 104.

At 412, the RAN node 104 may utilize the estimated downlink channel for a target application, such as beamforming. For example, based on the estimated downlink channel, the RAN node 104 may transmit a signal in a specific direction that maximizes the received signal quality at the UE 100.

FIG. 5 illustrates a signal flow diagram according to an example embodiment with an AQS compression scheme corresponding to FIG. 3B. In other words, in this example embodiment, the UE 100 may first use an encoder 302 to reduce the dimensionality of the received DL pilot signal(s), and the UE 100 may then use a scalar or vector quantizer 303 for further compression. After using a scalar or vector de-quantizer 306, the RAN node 104 may use a decoder 307 to reconstruct the DL pilot signal(s).

Referring to FIG. 5, at 501, the UE 100 transmits, to the RAN node 104 (e.g., gNB), capability information indicating at least a capability of the UE 100 for supporting downlink pilot signal compression. The RAN node 104 receives the capability information.

The capability may be indicated as a mode of CSI reporting similar to Type-II reporting, CSI compression, or any other. The UE 100 may also indicate any specific conditions in which the downlink pilot signal compression is supported.

At 502, the RAN node 104 transmits, to the UE 100, a configuration for the downlink pilot signal compression. The RAN node 104 may determine the configuration based on the capability information received from the UE 100. The UE 100 receives the configuration.

In other words, the RAN node 104 may select and configure direct downlink pilot signal compression as a CSI reporting mode for the UE 100. The UE 100 may support different modes (e.g., pilot compression, legacy reporting, CSI compression, etc..) at the same time but with different CSI reporting configurations.

As an example, the RAN node 104 may configure the CSI reporting mode based on the CSI reporting configuration (e.g., let us assume that CSI_reportconfig 1 is for direct pilot signal compression), where there may be associated parameters or configurations within a CSI reporting configuration to identify that CSI_reportconfig 1 has a different CSI reporting mode than the other modes.

At 503, the UE 100 transmits, to the RAN node 104, an indication indicating a capability for the SQS scheme and/or the AQS scheme. In this example embodiment, the UE 100 may indicate a capability at least for the AQS scheme. The RAN node 104 receives the indication.

At 504, the RAN node 104 transmits, to the UE 100, a configuration for the compression scheme to be used at the UE 100. In this example embodiment, the RAN node 104 may configure AQS as the compression scheme to be used at the UE 100. For example, this configuration may indicate at least one of: one or more pre-processing functions (e.g., normalization and/or reshaping), a grouping technique for a set of resource elements of one or more downlink pilot signals, or a quantization codebook and parameters for quantizing the set of resource elements of the one or more downlink pilot signals.

In other words, the RAN node 104 may share the required information for alignment on the compression, compression ratio, and quantization scheme and configuration, as well as potential pre-processing procedures.

At 505, depending on the autoencoder training approach (e.g., joint or separate training) the UE 100 and the RAN node 104 may align their machine learning models (i.e., the encoder 302 and the decoder 307).

For example, in joint training, an entity (e.g., the RAN node 104 or the UE 100) may train both the encoder 302 and the decoder 307. Then the entity may share the trained encoder 302 or the trained decoder 307 with the other entity (e.g., the RAN node 104 may transmit the trained encoder 302 to the UE 100, or the UE 100 may transmit the trained decoder 307 to the RAN node 104).

As another example, in separate training, the first entity (e.g., the RAN node 104 or UE 100) trains its own encoder 302 and decoder 307, and then shares a training dataset with the other entity (e.g., the UE 100 or the RAN node 104) for alignment. Each sample in the dataset may include a pair of input CSI and the corresponding compressed (and quantized) CSI.

At 506, the RAN node 104 transmits the one or more downlink pilot signals to the UE 100. The UE 100 receives the one or more downlink pilot signals. For example, the one or more downlink pilot signals may comprise one or more channel state information reference signals (CSI-RS), or any other type of reference signal.

At 507, the UE 100 may pre-process, prior to the compression, the one or more downlink pilot signals according to the one or more pre-processing functions indicated by the RAN node 104 at 504. For example, the UE 100 may normalize and/or reshape the one or more downlink pilot signals.

At 508, the UE 100 compresses, based on the configurations received at 502 and 504, the one or more downlink pilot signals received from the RAN node 104. The UE 100 may compress the one or more downlink pilot signals by using the compression scheme (i.e., AQS in this case) indicated by the RAN node 104 at 504. In this case, the compression is performed by using the encoder 302 and the quantizer 303, wherein the encoder 302 is used for reducing a dimensionality of the one or more downlink pilot signals, and wherein the quantizer 303 is used for further compression of the one or more downlink pilot signals. The encoder 302 is (or was) trained to compress the one or more downlink pilot signals.

In other words, the UE 100 may measure the one or more downlink pilot signals and directly compress the received (noisy) one or more downlink pilot signals.

At 509, the UE 100 transmits, to the RAN node 104, information relating to the one or more compressed downlink pilot signals. The information may be referred to as a compressed CSI report herein. The information may comprise, for example, a compressed bit sequence representing the one or more downlink pilot signals. For example, the UE 100 may use channel coding, a modulation scheme such as quadrature amplitude modulation (QAM), and a data transmission technique such as orthogonal frequency-division multiplexing (OFDM) to transmit the one or more downlink pilot signals as a compressed bit sequence.

At 510, the RAN node 104 obtains or extracts the compressed bit sequence from the received information by using, for example, OFDM demodulation, a QAM demapper, and a channel decoder.

At 511, the RAN node 104 constructs or reconstructs the one or more downlink pilot signals based on the information. In other words, the goal of the RAN node 104 is to create a signal similar to the observations or measurements at the UE 100. In this case, the (re)construction is performed by using the de-quantizer 306 and the decoder 307 according to the selected compression scheme (i.e., AQS in this case). The RAN node 104 uses the de-quantizer 306 to de-quantize the compressed bit sequence according to the quantization properties indicated at 504, and the RAN node 104 uses the decoder 307 to decode the output of the de-quantizer 306. The de-quantizer 306 may comprise a scalar de-quantizer or a vector de-quantizer. The RAN node 104 may use the inverse of the normalization function to obtain the one or more downlink pilot signals.

At 512, the RAN node 104 performs downlink channel estimation based at least on the one or more (re)constructed downlink pilot signals. In other words, the RAN node 104 estimates the downlink channel between the RAN node 104 and the UE 100.

For example, the downlink channel estimation may be performed by using a non-machine-learning-based algorithm, such as linear minimum mean square error or least squares.

As another example, the downlink channel estimation may be performed by using a machine learning algorithm. The machine learning algorithm may comprise, for example, one of: a fully-connected neural network, a convolutional neural network, a transformer neural network, or any other suitable architecture.

The downlink channel estimation may be performed based further on at least one of: one or more uplink pilot signals received from the UE 100, or an uplink channel correlation function.

At 513, the RAN node 104 may utilize the estimated downlink channel for a target application, such as beamforming. For example, based on the estimated downlink channel, the RAN node 104 may transmit a signal in a specific direction that maximizes the received signal quality at the UE 100.

FIG. 6 illustrates a signal flow diagram according to an example embodiment with an AQS compression scheme and using received UL pilot signal(s) as additional information for DL channel estimation at the RAN node 104 (corresponding to FIG. 3C).

Referring to FIG. 6, at 601, the UE 100 transmits, to the RAN node 104 (e.g., gNB), capability information indicating at least a capability of the UE 100 for supporting downlink pilot signal compression. The RAN node 104 receives the capability information.

The capability may be indicated as a mode of CSI reporting similar to Type-II reporting, CSI compression, or any other. The UE 100 may also indicate any specific conditions in which the downlink pilot signal compression is supported.

At 602, the RAN node 104 transmits, to the UE 100, a configuration for the downlink pilot signal compression. The RAN node 104 may determine the configuration based on the capability information received from the UE 100. The UE 100 receives the configuration.

In other words, the RAN node 104 may select and configure direct downlink pilot signal compression as a CSI reporting mode for the UE 100. The UE 100 may support different modes (e.g., pilot compression, legacy reporting, CSI compression, etc..) at the same time but with different CSI reporting configurations.

As an example, the RAN node 104 may configure the CSI reporting mode based on the CSI reporting configuration (e.g., let us assume that CSI_reportconfig 1 is for direct pilot signal compression), where there may be associated parameters or configurations within a CSI reporting configuration to identify that CSI_reportconfig 1 has a different CSI reporting mode than the other modes.

At 603, the UE 100 transmits, to the RAN node 104, an indication indicating a capability for the SQS scheme and/or the AQS scheme. In this example embodiment, the UE 100 may indicate a capability at least for the AQS scheme. The RAN node 104 receives the indication.

At 604, the RAN node 104 transmits, to the UE 100, a configuration for the compression scheme to be used at the UE 100. In this example embodiment, the RAN node 104 may configure AQS as the compression scheme to be used at the UE 100. For example, this configuration may indicate at least one of: one or more pre-processing functions (e.g., normalization and/or reshaping), a grouping technique for a set of resource elements of one or more downlink pilot signals, or a quantization codebook and parameters for quantizing the set of resource elements of the one or more downlink pilot signals.

In other words, the RAN node 104 may share the required information for alignment on the compression, compression ratio, and quantization scheme and configuration, as well as potential pre-processing procedures.

At 605, depending on the autoencoder training approach (e.g., joint or separate training) the UE 100 and the RAN node 104 may align their machine learning models (i.e., the encoder 302 and the decoder 307).

At 606, the RAN node 104 transmits, to the UE 100, a downlink pilot signal pattern and an uplink pilot signal pattern for coordinating between downlink pilot signals and uplink pilot signals to optimize the channel estimation accuracy and/or monitor the performance of the autoencoder model (which comprises the encoder 302 and the decoder 307). The UE 100 receives the downlink pilot signal pattern and the uplink pilot signal pattern.

An uplink pilot signal pattern refers to a predefined structure or sequence of pilot symbols to be transmitted from the UE 100 to the RAN node 104. These pilot symbols are known at both the transmitter (i.e., the UE 100) and receiver (i.e., the RAN node 104) and may be used for channel estimation. The pattern in which these pilot symbols are inserted into the uplink signal, in terms of timing, frequency, and spatial dimensions, is what defines the uplink pilot signal pattern.

Similarly, a downlink pilot signal pattern refers to a specific arrangement or sequence of pilot symbols to be transmitted from the RAN node 104 to the UE 100.

At 607, the RAN node 104 transmits the one or more downlink pilot signals to the UE 100 according to the downlink pilot signal pattern. The UE 100 receives the one or more downlink pilot signals. For example, the one or more downlink pilot signals may comprise one or more channel state information reference signals (CSI-RS), or any other type of reference signal.

At 608, the UE 100 may pre-process, prior to the compression, the one or more downlink pilot signals according to the one or more pre-processing functions indicated by the RAN node 104 at 604. For example, the UE 100 may normalize and/or reshape the one or more downlink pilot signals.

At 609, the UE 100 compresses, based on the configurations received at 602 and 604, the one or more downlink pilot signals received from the RAN node 104. The UE 100 may compress the one or more downlink pilot signals by using the compression scheme (i.e., AQS in this case) indicated by the RAN node 104 at 604. In this case, the compression is performed by using the encoder 302 and the quantizer 303, wherein the encoder 302 is used for reducing a dimensionality of the one or more downlink pilot signals, and wherein the quantizer 303 is used for further compression of the one or more downlink pilot signals. The encoder 302 is (or was) trained to compress the one or more downlink pilot signals.

In other words, the UE 100 may measure the one or more downlink pilot signals and directly compress the received (noisy) one or more downlink pilot signals.

At 610, the UE 100 transmits, to the RAN node 104, information relating to the one or more compressed downlink pilot signals. The information may be referred to as a compressed CSI report herein. The information may comprise, for example, a compressed bit sequence representing the one or more downlink pilot signals. For example, the UE 100 may use channel coding, a modulation scheme such as quadrature amplitude modulation (QAM), and a data transmission technique such as orthogonal frequency-division multiplexing (OFDM) to transmit the one or more downlink pilot signals as a compressed bit sequence.

At 611, the UE 100 transmits the one or more uplink pilot signals to the RAN node 104 according to the uplink pilot signal pattern. The RAN node 104 receives the one or more uplink pilot signals.

The one or more uplink pilot signals may be transmitted together with the information relating to the one or more compressed downlink pilot signals, or the one or more uplink pilot signals may be transmitted separately from the information. The one or more compressed pilot signals may be part of uplink control information (UCI), and the UCI may be carried by a physical uplink control channel (PUCCH) or a physical uplink shared channel (PUSCH) depending on the situation.

At 612, the RAN node 104 obtains or extracts the compressed bit sequence from the received information by using, for example, OFDM demodulation, a QAM demapper, and a channel decoder.

At 613, the RAN node 104 constructs or reconstructs the one or more downlink pilot signals based on the information. In other words, the goal of the RAN node 104 is to create a signal similar to the observations or measurements at the UE 100. In this case, the (re)construction is performed by using the de-quantizer 306 and the decoder 307 according to the selected compression scheme (i.e., AQS in this case). The RAN node 104 uses the de-quantizer 306 to de-quantize the compressed bit sequence according to the quantization properties indicated at 504, and the RAN node 104 uses the decoder 307 to decode the output of the de-quantizer 306. The de-quantizer 306 may comprise a scalar de-quantizer or a vector de-quantizer. The RAN node 104 may use the inverse of the normalization function to obtain the one or more downlink pilot signals.

At 614, the RAN node 104 extracts the one or more uplink pilot signals from the received signal (in case the one or more uplink pilot signals were transmitted together with the one or more compressed downlink pilot signals).

At 615, the RAN node 104 performs downlink channel estimation based at least on the one or more (re)constructed downlink pilot signals and at least one of: the one or more uplink pilot signals received from the UE 100, or an uplink channel correlation function.

In other words, the RAN node 104 estimates the downlink channel between the RAN node 104 and the UE 100.

For example, the downlink channel estimation may be performed by using a non-machine-learning-based algorithm, such as linear minimum mean square error or least squares.

As another example, the downlink channel estimation may be performed by using a machine learning algorithm. The machine learning algorithm may comprise, for example, one of: a fully-connected neural network, a convolutional neural network, a transformer neural network, or any other suitable architecture.

At 616, the RAN node 104 may utilize the estimated downlink channel for a target application, such as beamforming. For example, based on the estimated downlink channel, the RAN node 104 may transmit a signal in a specific direction that maximizes the received signal quality at the UE 100.

At 617, the RAN node 104 may monitor, based on the one or more downlink pilot signals and the one or more uplink pilot signals, performance of at least one of: the encoder used for compressing the one or more downlink pilot signals, or a decoder used for constructing the one or more downlink pilot signals. The performance is related to the correlation between the downlink and uplink channels. The RAN node 104 may monitor the performance by comparing the correlation with a threshold.

Based on the monitoring, the RAN node 104 may select a suitable CSI reporting mode for the UE 100. For example, if the performance of the encoder 302 and/or the decoder 307 is good (e.g., the correlation is above the threshold), then the RAN node 104 may decide to continue using the direct downlink pilot signal compression as the CSI reporting mode for the UE 100. As another example, if the performance of the encoder 302 and/or the decoder 307 is poor (e.g., the correlation is below the threshold), then the UE 100 and the RAN node 104 may switch to using type-II codebooks 200, 220 for the CSI compression (e.g., as shown in FIG. 2A), instead of continuing to use the direct downlink pilot signal compression as the CSI reporting mode.

FIG. 7 illustrates a flow chart according to an example embodiment of a method performed by an apparatus 900 depicted in FIG. 9. For example, the apparatus 900 may be, or comprise, or be comprised in, a user equipment (UE) 100, 102.

Referring to FIG. 7, in block 701, the apparatus 900 receives, from a radio access network node 104, a configuration for downlink pilot signal compression.

In block 702, the apparatus 900 compresses, based on the configuration, one or more downlink pilot signals received from the radio access network node 104.

In block 703, the apparatus 900 transmits, to the radio access network node 104, information relating to the one or more compressed downlink pilot signals.

The apparatus 900 may transmit, to the radio access network node 104, capability information indicating at least a capability for supporting the downlink pilot signal compression, wherein the configuration may be received based on or in response to transmitting the capability information.

The apparatus 900 may pre-process, prior to the compression, the one or more downlink pilot signals according to one or more pre-processing functions indicated by the radio access network node 104.

As an example, the compression may be performed by using at least a quantizer 303, wherein the quantizer 303 may comprise a scalar quantizer or a vector quantizer.

The apparatus 900 may receive, from the radio access network node 104, a configuration for the quantizer 303, wherein the configuration for the quantizer 303 may indicate at least one of: a grouping technique for a set of resource elements of the one or more downlink pilot signals, or a quantization codebook for quantizing the set of resource elements of the one or more downlink pilot signals.

As another example, the compression may be performed by using an encoder 302 and the quantizer 303, wherein the encoder 302 may be used for reducing a dimensionality of the one or more downlink pilot signals, and wherein the quantizer 303 may be used for further compression of the one or more downlink pilot signals.

The encoder 302 may be trained to compress the one or more downlink pilot signals. In other words, the encoder 302 may comprise a pre-trained machine learning model configured to compress the one or more downlink pilot signals.

The apparatus 900 may receive, from the radio access network node 104, an uplink pilot signal pattern for coordinating between the one or more downlink pilot signals and one or more uplink pilot signals; and transmit the one or more uplink pilot signals to the radio access network node 104 according to the uplink pilot signal pattern.

FIG. 8 illustrates a flow chart according to an example embodiment of a method performed by an apparatus 1000 depicted in FIG. 10. For example, the apparatus 1000 may be, or comprise, or be comprised in, a radio access network node 104.

Referring to FIG. 8, in block 801, the apparatus 1000 transmits, to a user equipment 100, a configuration for downlink pilot signal compression.

In block 802, the apparatus 1000 receives, from the user equipment 100, information relating to one or more compressed downlink pilot signals.

In block 803, the apparatus 1000 constructs or reconstructs one or more downlink pilot signals based on the information.

In block 804, the apparatus 1000 performs downlink channel estimation based at least on the one or more (re)constructed downlink pilot signals.

The apparatus 1000 may receive, from the user equipment 100, capability information indicating at least a capability for supporting the downlink pilot signal compression; and determine the configuration based on the capability information.

As an example, the (re)construction may be performed by using at least a de-quantizer 306, wherein the de-quantizer 306 may comprise a scalar de-quantizer or a vector de-quantizer.

As another example, the (re)construction may be performed by using the de-quantizer 306 and a decoder 307.

The downlink channel estimation may be performed by using a non-machine-learning-based algorithm.

Alternatively, the downlink channel estimation may be performed by using a machine learning algorithm. The machine learning algorithm may comprise, for example, one of: a fully-connected neural network, a convolutional neural network, a transformer neural network, or any other suitable architecture.

The downlink channel estimation may be performed based further on at least one of: one or more uplink pilot signals received from the user equipment 100, or an uplink channel correlation function.

The apparatus 1000 may transmit, to the user equipment 100, an uplink pilot signal pattern for coordinating between the one or more downlink pilot signals and the one or more uplink pilot signals.

The apparatus 1000 may monitor, based on the one or more downlink pilot signals and the one or more uplink pilot signals, performance of at least one of: an encoder 302 used for compressing the one or more downlink pilot signals, or the decoder 307 used for (re)constructing the one or more downlink pilot signals.

The blocks, related functions, and information exchanges (messages) described above by means of FIGS. 4-8 are in no absolute chronological order, and some of them may be performed simultaneously or in an order differing from the described one. Other functions can also be executed between them or within them, and other information may be sent, and/or other rules applied. Some of the blocks or part of the blocks or one or more pieces of information can also be left out or replaced by a corresponding block or part of the block or one or more pieces of information.

As used herein, “at least one of the following: <a list of two or more elements>” and “at least one of <a list of two or more elements>” and similar wording, where the list of two or more elements are joined by “and” or “or”, mean at least any one of the elements, or at least any two or more of the elements, or at least all the elements.

FIG. 9 illustrates an example of an apparatus 900 comprising means for performing one or more of the example embodiments described above. For example, the apparatus 900 may be an apparatus such as, or comprising, or comprised in, a user equipment (UE) 100, 102. The user equipment may also be called a wireless communication device, a subscriber unit, a mobile station, a remote terminal, an access terminal, a user terminal, a terminal device, or a user device.

The apparatus 900 may comprise a circuitry or a chipset applicable for realizing one or more of the example embodiments described above. For example, the apparatus 900 may comprise at least one processor 910. The at least one processor 910 interprets instructions (e.g., computer program instructions) and processes data. The at least one processor 910 may comprise one or more programmable processors. The at least one processor 910 may comprise programmable hardware with embedded firmware and may, alternatively or additionally, comprise one or more application-specific integrated circuits (ASICs).

The at least one processor 910 is coupled to at least one memory 920. The at least one processor is configured to read and write data to and from the at least one memory 920. The at least one memory 920 may comprise one or more memory units. The memory units may be volatile or non-volatile. It is to be noted that there may be one or more units of non-volatile memory and one or more units of volatile memory or, alternatively, one or more units of non-volatile memory, or, alternatively, one or more units of volatile memory. Volatile memory may be for example random-access memory (RAM), dynamic random-access memory (DRAM) or synchronous dynamic random-access memory (SDRAM). Non-volatile memory may be for example read-only memory (ROM), programmable read-only memory (PROM), electronically erasable programmable read-only memory (EEPROM), flash memory, optical storage or magnetic storage. In general, memories may be referred to as non-transitory computer readable media. The term “non-transitory,” as used herein, is a limitation of the medium itself (i.e., tangible, not a signal) as opposed to a limitation on data storage persistency (e.g., RAM vs. ROM). The at least one memory 920 stores computer readable instructions that are executed by the at least one processor 910 to perform one or more of the example embodiments described above. For example, non-volatile memory stores the computer readable instructions, and the at least one processor 910 executes the instructions using volatile memory for temporary storage of data and/or instructions. The computer readable instructions may refer to computer program code.

The computer readable instructions may have been pre-stored to the at least one memory 920 or, alternatively or additionally, they may be received, by the apparatus, via an electromagnetic carrier signal and/or may be copied from a physical entity such as a computer program product. Execution of the computer readable instructions by the at least one processor 910 causes the apparatus 900 to perform one or more of the example embodiments described above. That is, the at least one processor and the at least one memory storing the instructions may provide the means for providing or causing the performance of any of the methods and/or blocks described above.

In the context of this document, a “memory” or “computer-readable media” or “computer-readable medium” may be any non-transitory media or medium or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer. The term “non-transitory,” as used herein, is a limitation of the medium itself (i.e., tangible, not a signal) as opposed to a limitation on data storage persistency (e.g., RAM vs. ROM).

The apparatus 900 may further comprise, or be connected to, an input unit 930. The input unit 930 may comprise one or more interfaces for receiving input. The one or more interfaces may comprise for example one or more temperature, motion and/or orientation sensors, one or more cameras, one or more accelerometers, one or more microphones, one or more buttons and/or one or more touch detection units. Further, the input unit 930 may comprise an interface to which external devices may connect to.

The apparatus 900 may also comprise an output unit 940. The output unit may comprise or be connected to one or more displays capable of rendering visual content, such as a light emitting diode (LED) display, a liquid crystal display (LCD) and/or a liquid crystal on silicon (LCoS) display. The output unit 940 may further comprise one or more audio outputs. The one or more audio outputs may be for example loudspeakers.

The apparatus 900 further comprises a connectivity unit 950. The connectivity unit 950 enables wireless connectivity to one or more external devices. The connectivity unit 950 comprises at least one transmitter and at least one receiver that may be integrated to the apparatus 900 or that the apparatus 900 may be connected to. The at least one transmitter comprises at least one transmission antenna, and the at least one receiver comprises at least one receiving antenna. The connectivity unit 950 may comprise an integrated circuit or a set of integrated circuits that provide the wireless communication capability for the apparatus 900. Alternatively, the wireless connectivity may be a hardwired application-specific integrated circuit (ASIC). The connectivity unit 950 may also provide means for performing at least some of the blocks or functions of one or more example embodiments described above. The connectivity unit 950 may comprise one or more components, such as: power amplifier, digital front end (DFE), analog-to-digital converter (ADC), digital-to-analog converter (DAC), frequency converter, (de)modulator, and/or encoder/decoder circuitries, controlled by the corresponding controlling units.

It is to be noted that the apparatus 900 may further comprise various components not illustrated in FIG. 9. The various components may be hardware components and/or software components.

FIG. 10 illustrates an example of an apparatus 1000 comprising means for performing one or more of the example embodiments described above. For example, the apparatus 1000 may be an apparatus such as, or comprising, or comprised in, a radio access network node 104.

The radio access network node may also be referred to, for example, as a network element, a next generation radio access network (NG-RAN) node, a NodeB, an eNB, a gNB, a base transceiver station (BTS), a base station, an NR base station, a 5G base station, an access node, an access point (AP), a cell site, a relay node, a repeater, an integrated access and backhaul (IAB) node, an IAB donor node, a distributed unit (DU), a central unit (CU), a baseband unit (BBU), or a transmission and reception point (TRP).

The apparatus 1000 may comprise, for example, a circuitry or a chipset applicable for realizing one or more of the example embodiments described above. The apparatus 1000 may be an electronic device comprising one or more electronic circuitries. The apparatus 1000 may comprise a communication control circuitry 1010 such as at least one processor, and at least one memory 1020 storing instructions 1022 which, when executed by the at least one processor, cause the apparatus 1000 to carry out one or more of the example embodiments described above. Such instructions 1022 may, for example, include computer program code (software). The at least one processor and the at least one memory storing the instructions may provide the means for providing or causing the performance of any of the methods and/or blocks described above.

The processor is coupled to the memory 1020. The processor is configured to read and write data to and from the memory 1020. The memory 1020 may comprise one or more memory units. The memory units may be volatile or non-volatile. It is to be noted that there may be one or more units of non-volatile memory and one or more units of volatile memory or, alternatively, one or more units of non-volatile memory, or, alternatively, one or more units of volatile memory. Volatile memory may be for example random-access memory (RAM), dynamic random-access memory (DRAM) or synchronous dynamic random-access memory (SDRAM). Non-volatile memory may be for example read-only memory (ROM), programmable read-only memory (PROM), electronically erasable programmable read-only memory (EEPROM), flash memory, optical storage or magnetic storage. In general, memories may be referred to as non-transitory computer readable media. The term "non-transitory," as used herein, is a limitation of the medium itself (i.e., tangible, not a signal) as opposed to a limitation on data storage persistency (e.g., RAM vs. ROM). The memory 1020 stores computer readable instructions that are executed by the processor. For example, non-volatile memory stores the computer readable instructions, and the processor executes the instructions using volatile memory for temporary storage of data and/or instructions.

The computer readable instructions may have been pre-stored to the memory 1020 or, alternatively or additionally, they may be received, by the apparatus, via an electromagnetic carrier signal and/or may be copied from a physical entity such as a computer program product. Execution of the computer readable instructions causes the apparatus 1000 to perform one or more of the functionalities described above.

The memory 1020 may be implemented using any suitable data storage technology, such as semiconductor-based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and/or removable memory. The memory may comprise a configuration database for storing configuration data, such as a current neighbour cell list, and, in some example embodiments, structures of frames used in the detected neighbour cells.

The apparatus 1000 may further comprise or be connected to a communication interface 1030, such as a radio unit, comprising hardware and/or software for realizing communication connectivity with one or more wireless communication devices according to one or more communication protocols. The communication interface 1030 comprises at least one transmitter (Tx) and at least one receiver (Rx) that may be integrated to the apparatus 1000 or that the apparatus 1000 may be connected to. The communication interface 1030 may provide means for performing some of the blocks for one or more example embodiments described above. The communication interface 1030 may comprise one or more components, such as: power amplifier, digital front end (DFE), analog-to-digital converter (ADC), digital-to-analog converter (DAC), frequency converter, (de)modulator, and/or encoder/decoder circuitries, controlled by the corresponding controlling units.

The communication interface 1030 provides the apparatus with radio communication capabilities to communicate in the wireless communication network. The communication interface may, for example, provide a radio interface to one or more UEs 100, 102. The apparatus 1000 may further comprise or be connected to another interface towards a core network 110, such as the network coordinator apparatus or AMF, and/or to the access nodes 104 of the wireless communication network.

The apparatus 1000 may further comprise a scheduler 1040 that is configured to allocate radio resources. The scheduler 1040 may be configured along with the communication control circuitry 1010 or it may be separately configured.

It is to be noted that the apparatus 1000 may further comprise various components not illustrated in FIG. 10. The various components may be hardware components and/or software components.

As used in this application, the term “circuitry” may refer to one or more or all of the following: a) hardware-only circuit implementations (such as implementations in only analog and/or digital circuitry); and b) combinations of hardware circuits and software, such as (as applicable): i) a combination of analog and/or digital hardware circuit(s) with software/firmware and ii) any portions of hardware processor(s) with software (including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone, to perform various functions); and c) hardware circuit(s) and/or processor(s), such as a microprocessor(s) or a portion of a microprocessor(s), that requires software (for example firmware) for operation, but the software may not be present when it is not needed for operation.

This definition of circuitry applies to all uses of this term in this application, including in any claims. As a further example, as used in this application, the term circuitry also covers an implementation of merely a hardware circuit or processor (or multiple processors) or portion of a hardware circuit or processor and its (or their) accompanying software and/or firmware. The term circuitry also covers, for example and if applicable to the particular claim element, a baseband integrated circuit or processor integrated circuit for a mobile device or a similar integrated circuit in server, a cellular network device, or other computing or network device.

The techniques and methods described herein may be implemented by various means. For example, these techniques may be implemented in hardware (one or more devices), firmware (one or more devices), software (one or more modules), or combinations thereof. For a hardware implementation, the apparatus(es) of example embodiments may be implemented within one or more application-specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), graphics processing units (GPUs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof. For firmware or software, the implementation can be carried out through modules of at least one chipset (for example procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in a memory unit and executed by processors. The memory unit may be implemented within the processor or externally to the processor. In the latter case, it can be communicatively coupled to the processor via various means, as is known in the art. Additionally, the components of the systems described herein may be rearranged and/or complemented by additional components in order to facilitate the achievements of the various aspects, etc., described with regard thereto, and they are not limited to the precise configurations set forth in the given figures, as will be appreciated by one skilled in the art.

It will be obvious to a person skilled in the art that, as technology advances, the inventive concept may be implemented in various ways within the scope of the claims. The embodiments are not limited to the example embodiments described above, but may vary within the scope of the claims. Therefore, all words and expressions should be interpreted broadly, and they are intended to illustrate, not to restrict, the embodiments.

Claims

1. An apparatus comprising at least one processor, and at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to:

receive, from a radio access network node, a configuration for downlink pilot signal compression;

compress, based on the configuration, one or more downlink pilot signals received from the radio access network node; and

transmit, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

2. The apparatus according to claim 1, further being caused to:

transmit, to the radio access network node, capability information indicating at least a capability for supporting the downlink pilot signal compression,

wherein the configuration is received based on transmitting the capability information.

3. The apparatus according to any preceding claim, further being caused to:

pre-process, prior to the compression, the one or more downlink pilot signals according to one or more pre-processing functions indicated by the radio access network node.

4. The apparatus according to any preceding claim, wherein the compression is performed by using at least a quantizer, wherein the quantizer comprises a scalar quantizer or a vector quantizer.

5. The apparatus according to claim 4, further being caused to:

receive, from the radio access network node, a configuration for the quantizer, wherein the configuration for the quantizer indicates at least one of:

a grouping technique for a set of resource elements of the one or more downlink pilot signals, or

a quantization codebook for quantizing the set of resource elements of the one or more downlink pilot signals.

6. The apparatus according to any of claims 4 to 5, wherein the compression is performed by using an encoder and the quantizer,

wherein the encoder is used for reducing a dimensionality of the one or more downlink pilot signals, and

wherein the quantizer is used for further compression of the one or more downlink pilot signals.

7. The apparatus according to claim 6, wherein the encoder is trained to compress the one or more downlink pilot signals.

8. The apparatus according to any preceding claim, further being caused to:

receive, from the radio access network node, an uplink pilot signal pattern for coordinating between the one or more downlink pilot signals and one or more uplink pilot signals; and

transmit the one or more uplink pilot signals to the radio access network node according to the uplink pilot signal pattern.

9. An apparatus comprising at least one processor, and at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to:

transmit, to a user equipment, a configuration for downlink pilot signal compression;

receive, from the user equipment, information relating to one or more compressed downlink pilot signals;

construct one or more downlink pilot signals based on the information; and

perform downlink channel estimation based at least on the one or more constructed downlink pilot signals.

10. The apparatus according to claim 9, further being caused to:

receive, from the user equipment, capability information indicating at least a capability for supporting the downlink pilot signal compression; and

determine the configuration based on the capability information.

11. The apparatus according to any of claims 9 to 10, wherein the construction is performed by using at least a de-quantizer, wherein the de-quantizer comprises a scalar de-quantizer or a vector de-quantizer.

12. The apparatus according to claim 11, wherein the construction is performed by using the de-quantizer and a decoder.

13. The apparatus according to any of claims 9 to 12, wherein the downlink channel estimation is performed by using a non-machine-learning-based algorithm.

14. The apparatus according to any of claims 9 to 12, wherein the downlink channel estimation is performed by using a machine learning algorithm.

15. The apparatus according to any of claims 9 to 14, wherein the downlink channel estimation is performed based further on at least one of: one or more uplink pilot signals received from the user equipment, or an uplink channel correlation function.

16. The apparatus according to claim 15, further being caused to:

transmit, to the user equipment, an uplink pilot signal pattern for coordinating between the one or more downlink pilot signals and the one or more uplink pilot signals.

17. The apparatus according to any of claims 15 to 16, further being caused to:

monitor, based on the one or more downlink pilot signals and the one or more uplink pilot signals, performance of at least one of: an encoder used for compressing the one or more downlink pilot signals, or a decoder used for constructing the one or more downlink pilot signals.

18. A method comprising:

receiving, from a radio access network node, a configuration for downlink pilot signal compression;

compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and

transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

19. A method comprising:

transmitting, to a user equipment, a configuration for downlink pilot signal compression;

receiving, from the user equipment, information relating to one or more compressed downlink pilot signals;

constructing one or more downlink pilot signals based on the information; and

performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

20. A non-transitory computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following:

receiving, from a radio access network node, a configuration for downlink pilot signal compression;

compressing, based on the configuration, one or more downlink pilot signals received from the radio access network node; and

transmitting, to the radio access network node, information relating to the one or more compressed downlink pilot signals.

21. A non-transitory computer readable medium comprising program instructions which, when executed by an apparatus, cause the apparatus to perform at least the following:

transmitting, to a user equipment, a configuration for downlink pilot signal compression;

receiving, from the user equipment, information relating to one or more compressed downlink pilot signals;

constructing one or more downlink pilot signals based on the information; and

performing downlink channel estimation based at least on the one or more constructed downlink pilot signals.

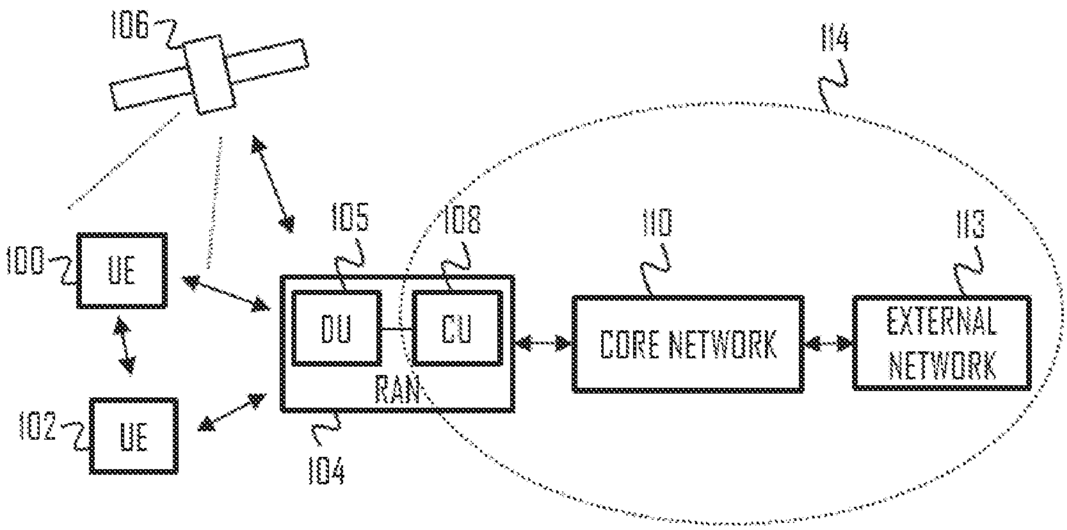
106
114
105
108
110
113
100
UE
DU
CU
CORE NETWORK
EXTERNAL NETWORK
RAN
102
UE
104

FIG. 1

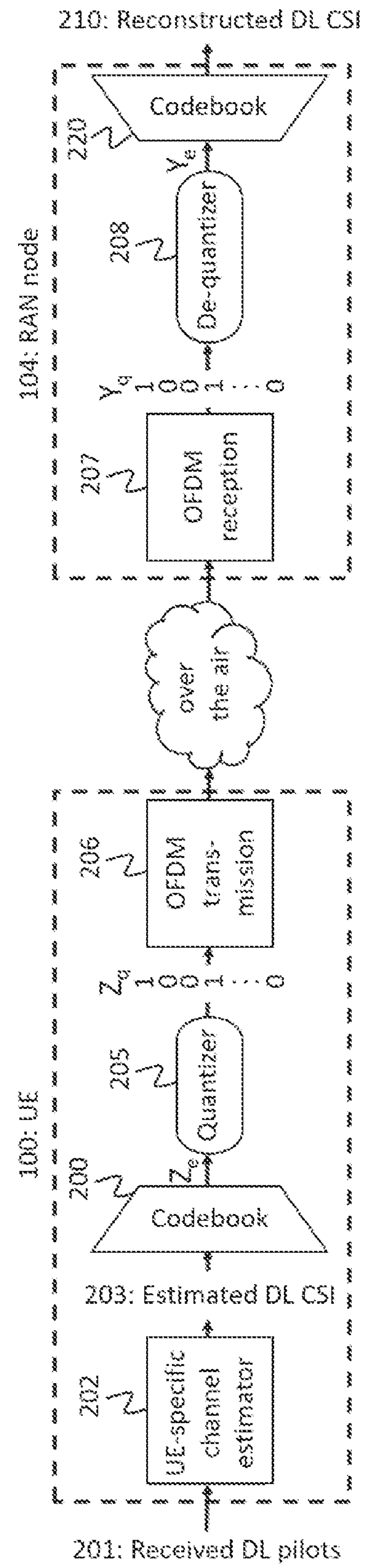
210: Reconstructed DL CSI
104: RAN node
Codebook
220
Y_e
208
De-quantizer
Y_q
1 0 0 1 · · · 0
207
OFDM reception
over the air
100: UE
206
OFDM trans-mission
Z_q
1 0 0 1 · · · 0
205
Quantizer
Z_e
200
Codebook
203: Estimated DL CSI
202
UE-specific channel estimator
201: Received DL pilots

FIG. 2A

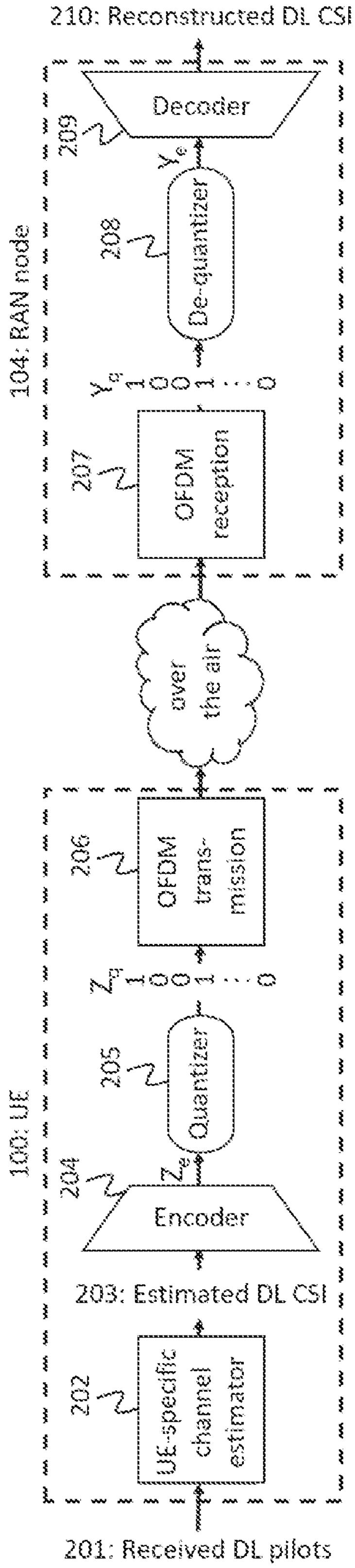
210: Reconstructed DL CSI
104: RAN node
209
Decoder
Y_e
208
De-quantizer
Y_q
1 0 0 1 ··· 0
207
OFDM reception
over the air
100: UE
206
OFDM trans-mission
Z_q
1 0 0 1 ··· 0
205
Quantizer
204
Z_e
Encoder
203: Estimated DL CSI
202
UE-specific channel estimator
201: Received DL pilots

FIG. 2B

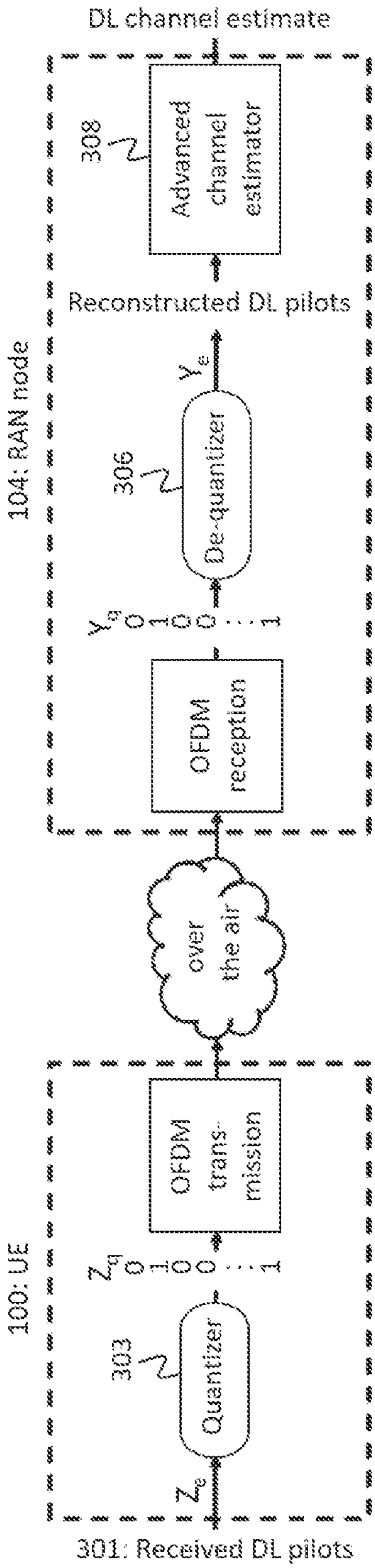
DL channel estimate
308
Advanced channel estimator
Reconstructed DL pilots
104: RAN node
306
De-quantizer
Y_e
Y_q
0 1 0 0 ... 1
OFDM reception
over the air
100: UE
OFDM trans-mission
Z_q
0 1 0 0 ... 1
303
Quantizer
Z_e
301: Received DL pilots

FIG. 3A

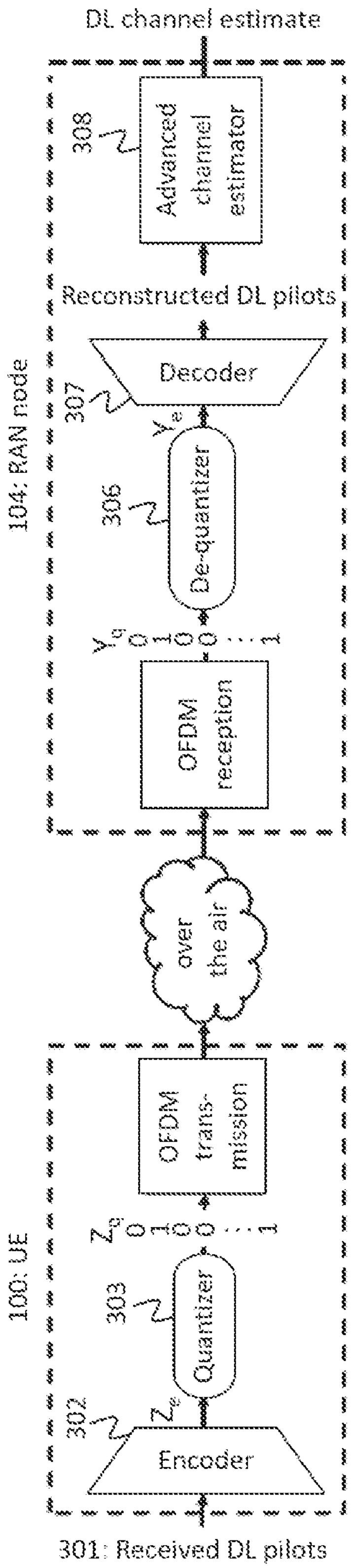
DL channel estimate
104: RAN node
308
Advanced channel estimator
Reconstructed DL pilots
307
Decoder
Y_e
306
De-quantizer
Y_q 0 1 0 0 ... 1
OFDM reception
over the air
100: UE
OFDM trans-mission
Z_q 0 1 0 0 ... 1
303
Quantizer
302
Z_e
Encoder
301: Received DL pilots

FIG. 3B

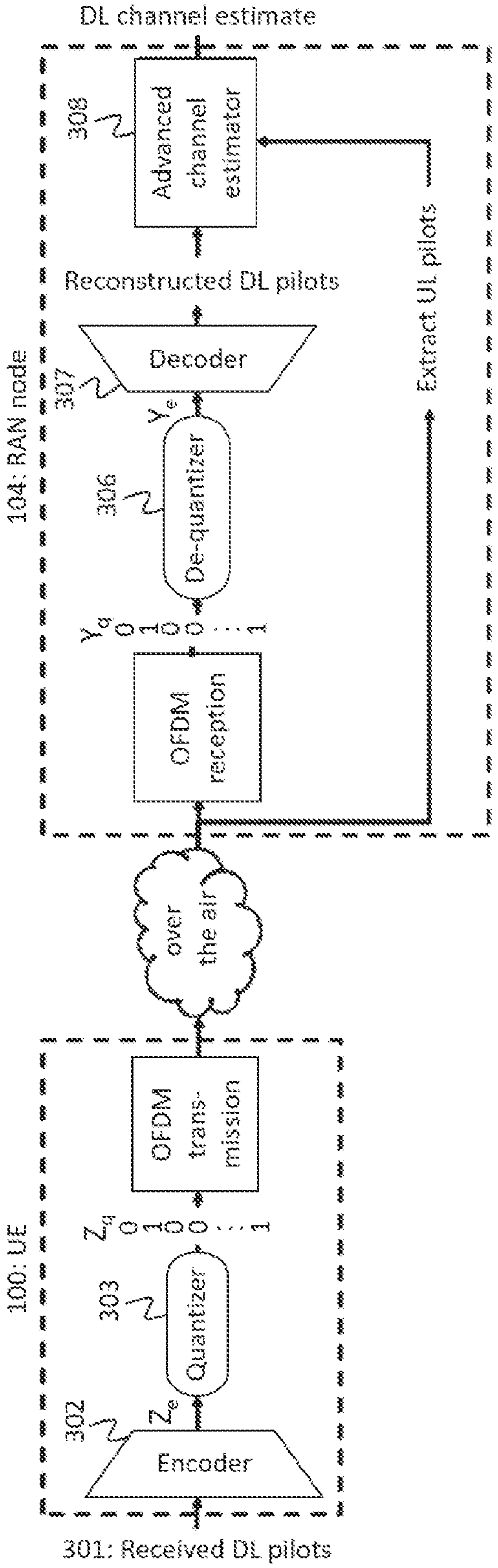
301: Received DL pilots
100: UE
302
Encoder
Z_e
303
Quantizer
Z_q
0 1 0 0 ... 1
OFDM trans-mission
over the air
104: RAN node
OFDM reception
Y_q
0 1 0 0 ... 1
306
De-quantizer
Y_e
307
Decoder
Reconstructed DL pilots
308
Advanced channel estimator
Extract UL pilots
DL channel estimate

FIG. 3C

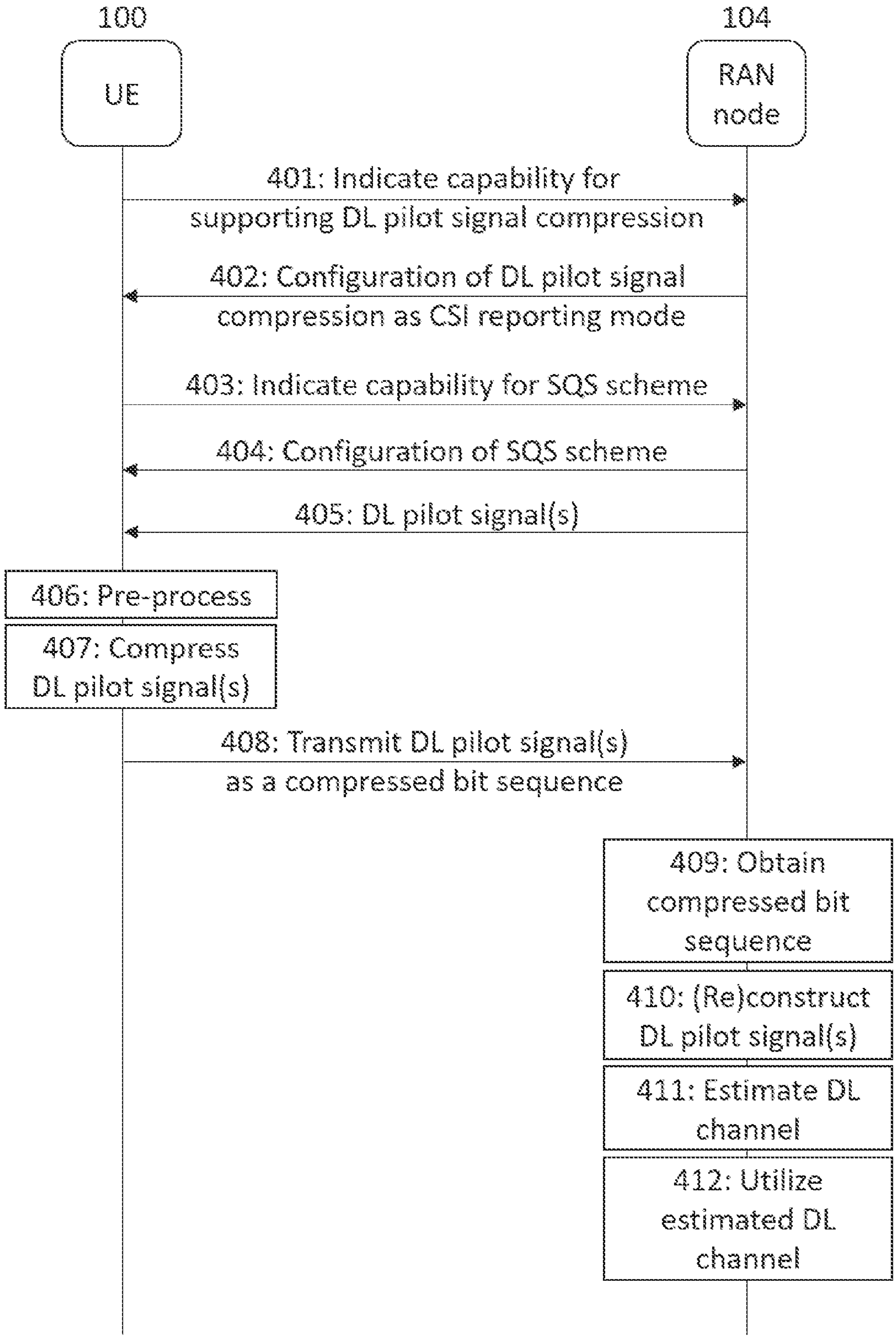
100
UE
104
RAN node
401: Indicate capability for supporting DL pilot signal compression
402: Configuration of DL pilot signal compression as CSI reporting mode
403: Indicate capability for SQS scheme
404: Configuration of SQS scheme
405: DL pilot signal(s)
406: Pre-process
407: Compress DL pilot signal(s)
408: Transmit DL pilot signal(s) as a compressed bit sequence
409: Obtain compressed bit sequence
410: (Re)construct DL pilot signal(s)
411: Estimate DL channel
412: Utilize estimated DL channel

FIG. 4

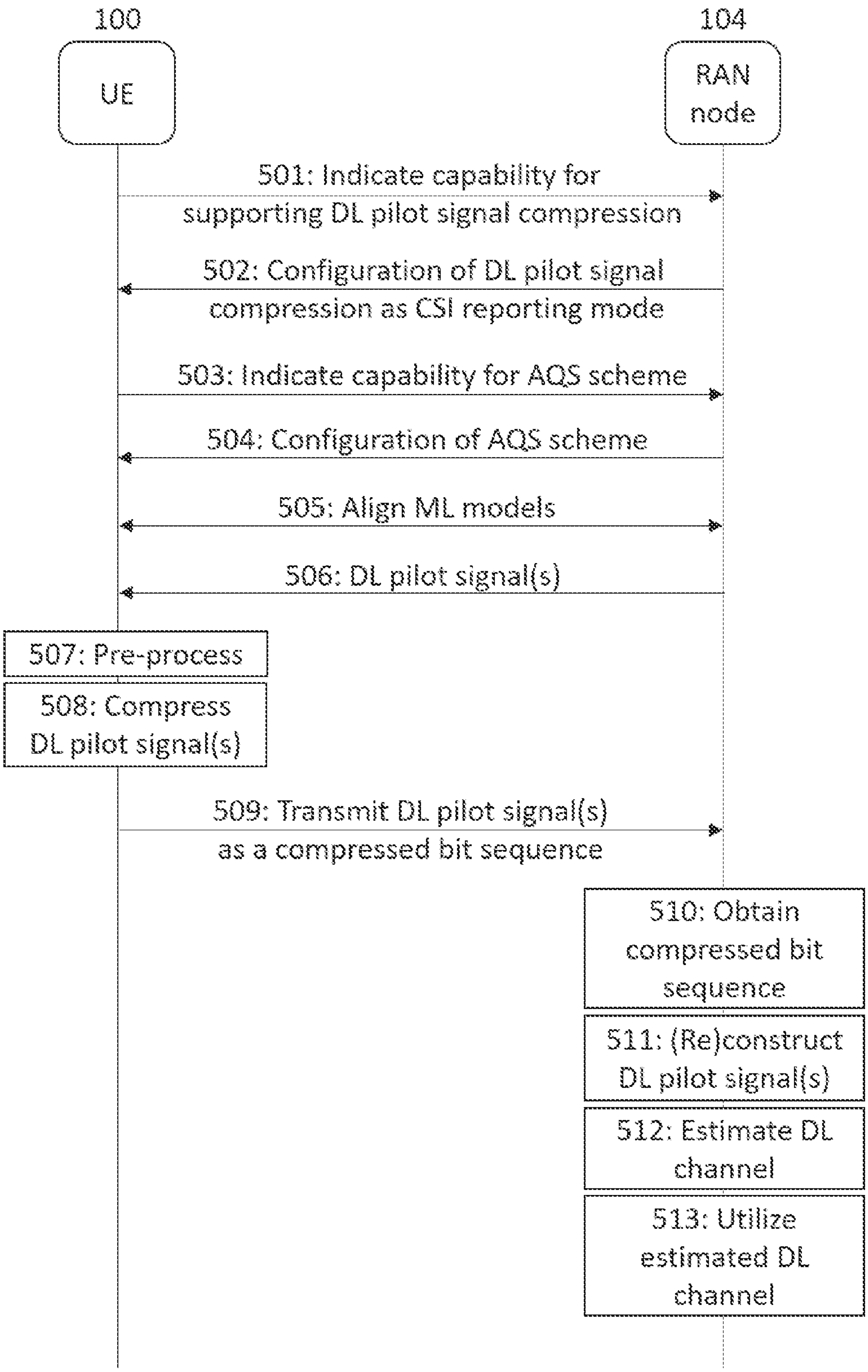
100
UE
104
RAN node
501: Indicate capability for supporting DL pilot signal compression
502: Configuration of DL pilot signal compression as CSI reporting mode
503: Indicate capability for AQS scheme
504: Configuration of AQS scheme
505: Align ML models
506: DL pilot signal(s)
507: Pre-process
508: Compress DL pilot signal(s)
509: Transmit DL pilot signal(s) as a compressed bit sequence
510: Obtain compressed bit sequence
511: (Re)construct DL pilot signal(s)
512: Estimate DL channel
513: Utilize estimated DL channel

FIG. 5

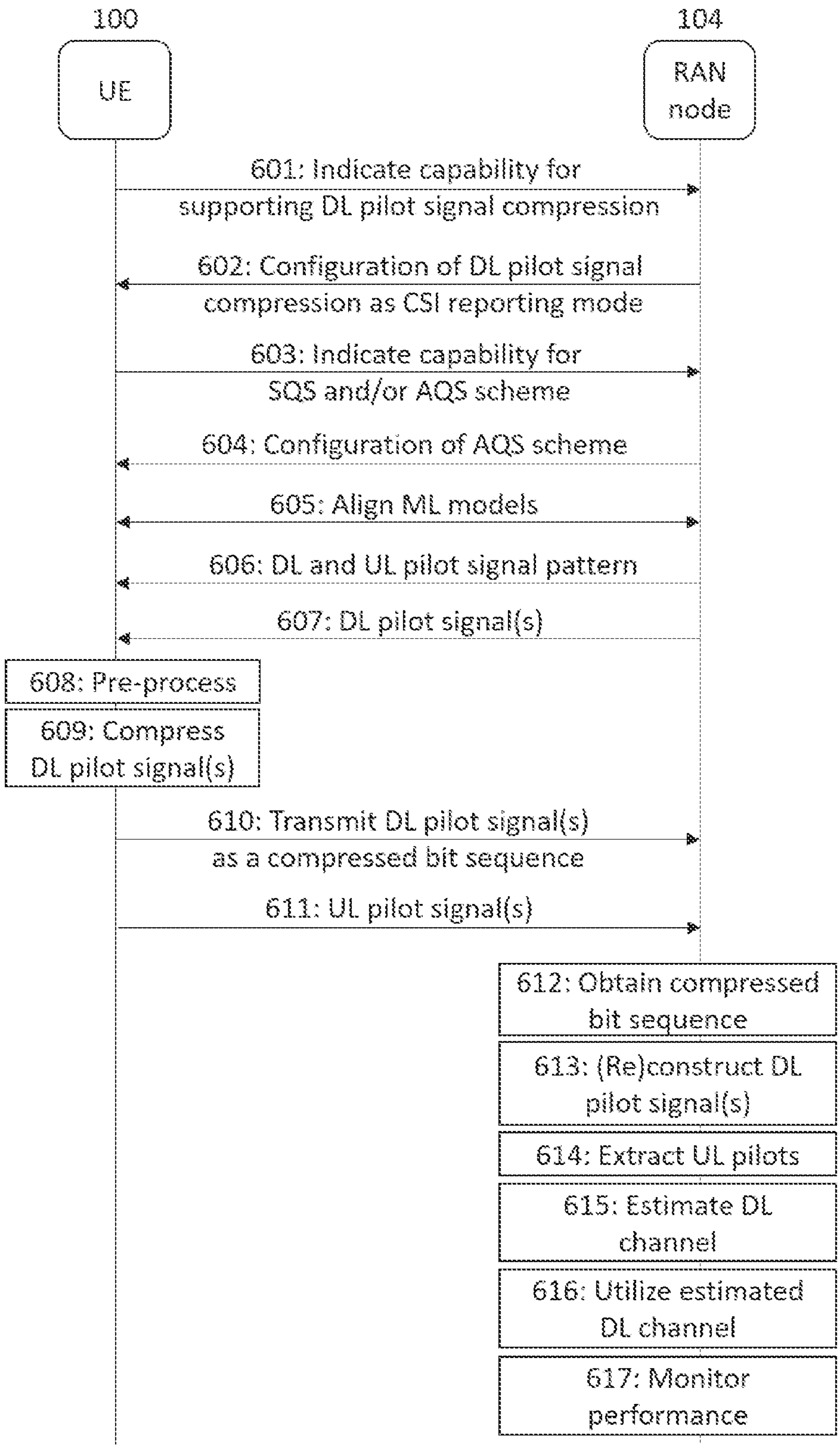
100
UE
104
RAN node
601: Indicate capability for supporting DL pilot signal compression
602: Configuration of DL pilot signal compression as CSI reporting mode
603: Indicate capability for SQS and/or AQS scheme
604: Configuration of AQS scheme
605: Align ML models
606: DL and UL pilot signal pattern
607: DL pilot signal(s)
608: Pre-process
609: Compress DL pilot signal(s)
610: Transmit DL pilot signal(s) as a compressed bit sequence
611: UL pilot signal(s)
612: Obtain compressed bit sequence
613: (Re)construct DL pilot signal(s)
614: Extract UL pilots
615: Estimate DL channel
616: Utilize estimated DL channel
617: Monitor performance

FIG. 6

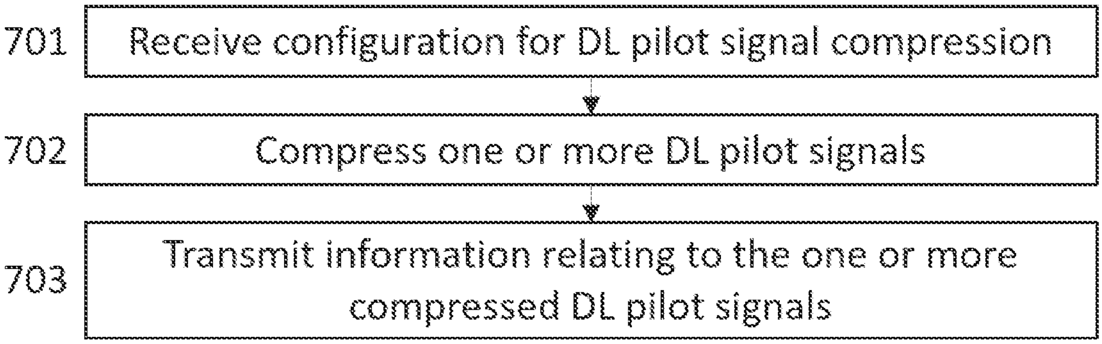
701
Receive configuration for DL pilot signal compression
702
Compress one or more DL pilot signals
703
Transmit information relating to the one or more compressed DL pilot signals

FIG. 7

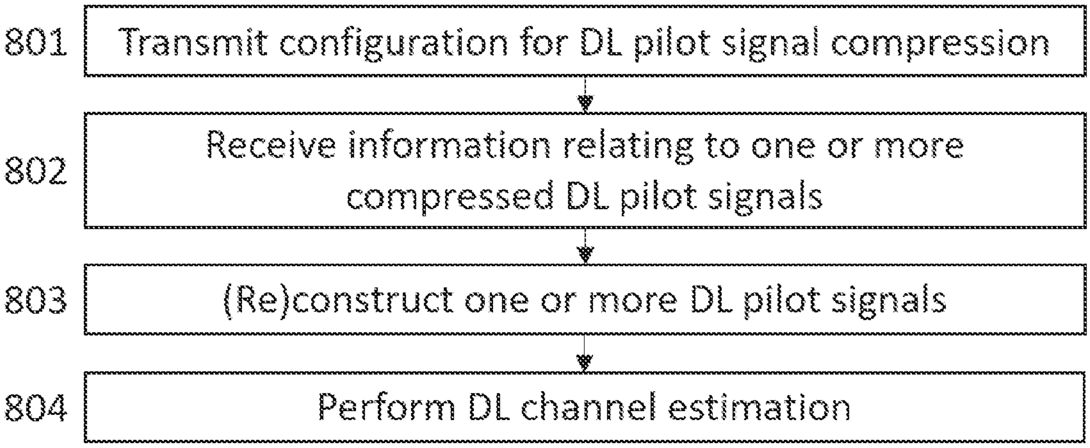
801
Transmit configuration for DL pilot signal compression
802
Receive information relating to one or more compressed DL pilot signals
803
(Re)construct one or more DL pilot signals
804
Perform DL channel estimation

FIG. 8

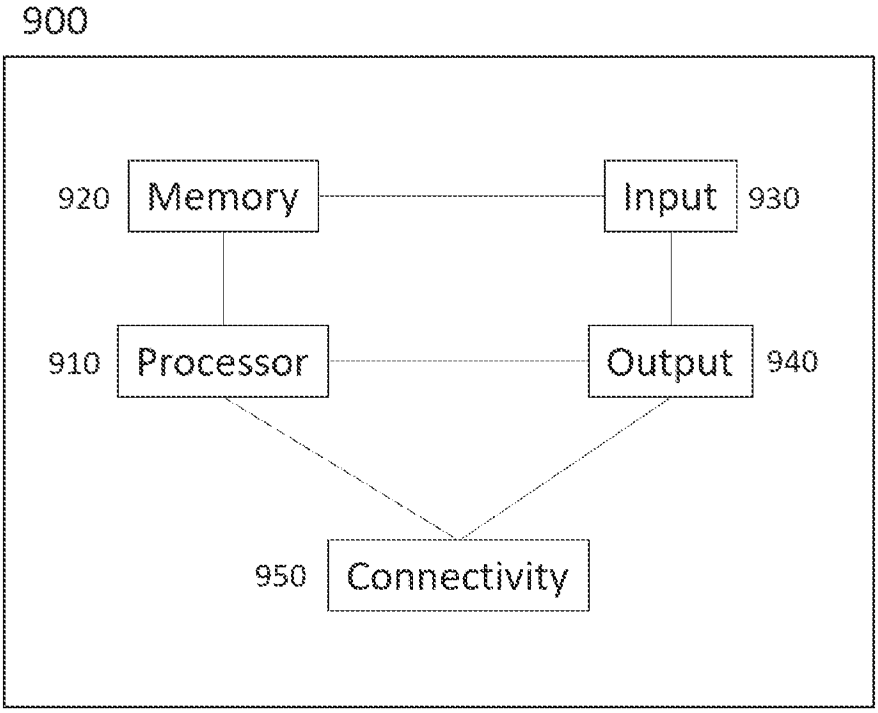
900
920 Memory
Input 930
910 Processor
Output 940
950 Connectivity

FIG. 9

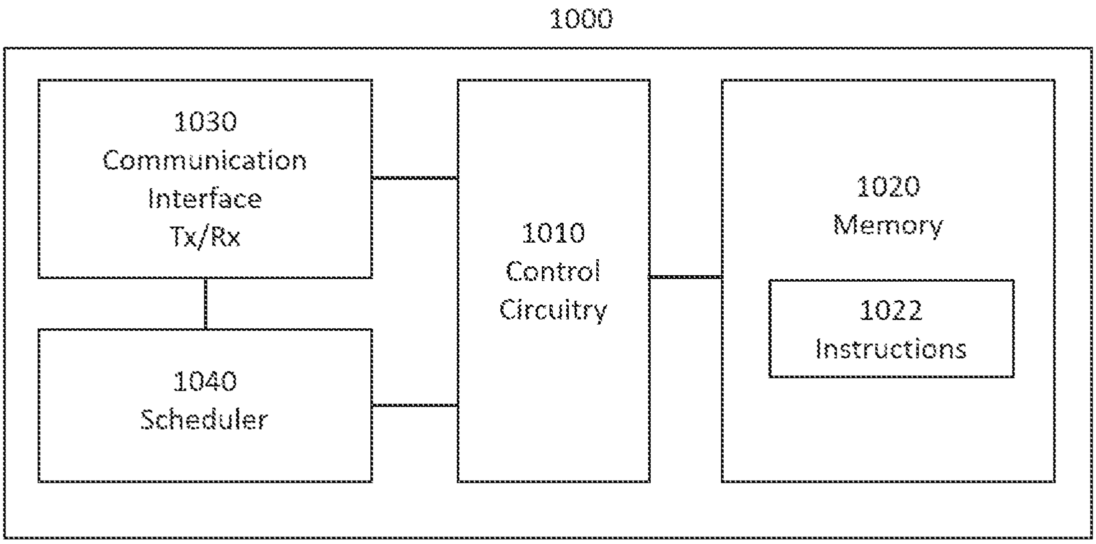
1000
1030
Communication
Interface
Tx/Rx
1040
Scheduler
1010
Control
Circuitry
1020
Memory
1022
Instructions

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/057974

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L25/02 H04L5/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020/007200 A1 (SCHRECK JAN [US] ET AL) 2 January 2020 (2020-01-02) paragraph [0056] paragraph [0059] - paragraph [0067] paragraph [0131] - paragraph [0139] paragraph [0210] - paragraph [0211] figures 3, 10 -----	1-6, 8-12, 15-21
X	US 2023/163824 A1 (SONG NUAN [CN]) 25 May 2023 (2023-05-25) paragraph [0048] - paragraph [0049] paragraph [0055] - paragraph [0070] paragraph [0075] - paragraph [0078] paragraph [0089] figures 3-6 -----	1,4,9, 11,13, 14,18-21

-/--

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 2024	16/12/2024

Name and mailing address of the ISA/	Authorized officer
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