(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 May 2024 (10.05.2024)

(10) International Publication Number
WO 2024/094314 A1

(51) International Patent Classification:
H04L 5/00 (2006.01) *H04L 27/26* (2006.01)
H04L 25/02 (2006.01)

(21) International Application Number: PCT/EP2022/080852

(22) International Filing Date: 04 November 2022 (04.11.2022)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title:** GENERATING A DEMODULATION REFERENCE SIGNAL PATTERN OVER RESOURCE GRID BASED ON CHANNEL MEASUREMENTS

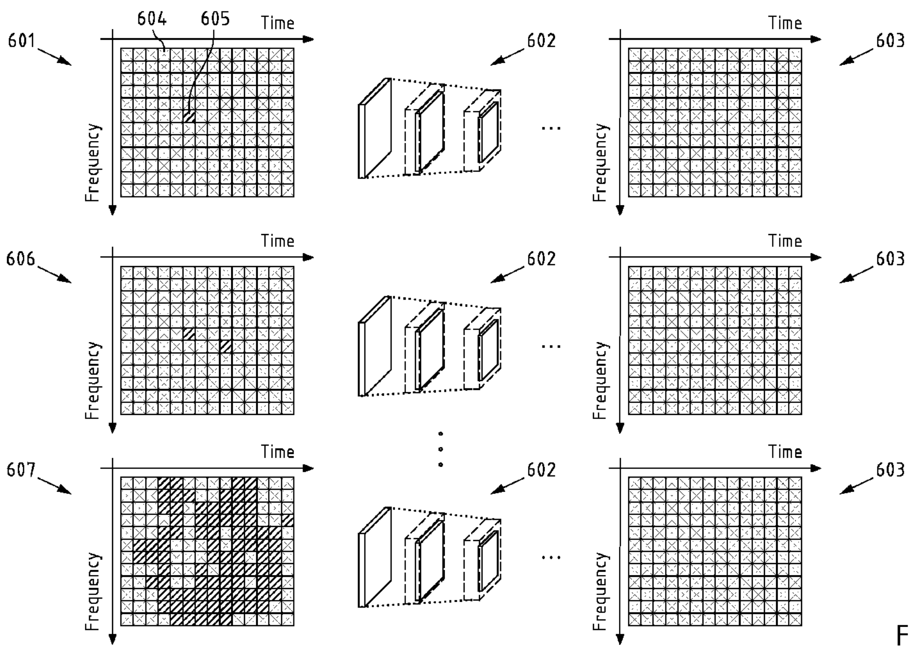

Fig.6

(57) **Abstract:** Inter-alia, a method is disclosed comprising obtaining channel measurements of a radio channel between a first apparatus and a second apparatus measured over a resource grid, generating a demodulation reference signal pattern over the resource grid based on the channel measurements, and transmitting, to the second apparatus, the generated demodulation reference signal pattern. It is further disclosed according first and second apparatuses, computer program and system.

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GENERATING A DEMODULATION REFERENCE SIGNAL PATTERN OVER RESOURCE GRID BASED ON CHANNEL MEASUREMENTS

FIELD OF DISCLOSURE

The following disclosure relates to the field of wireless networks, or more particularly relates to systems, apparatuses, and methods for obtaining a demodulation reference signal pattern.

BACKGROUND

In 5G systems, demodulation reference signals (DMRS) may be used for radio channel estimation for demodulation of associated physical or control channels. Current standards define legacy DRMS patterns with Mapping Type A and B, wherein Mapping Type A can start only at symbol 2 or 3 within a slot and Mapping Type B starts always at the first symbols of scheduled start and length indicator (SLIV). DMRS transmission may be configured by high layer signaling (RRC setup/reconfiguration), once configured to a UE the DMRS patterns are fixed throughout the lifetime of the RRC connection.

SUMMARY OF SOME EXEMPLARY EMBODIMENTS

Exemplary aspects and exemplary embodiments provided below may enable enhanced signaling, efficient resource reservation and interworking. Generated or derived DMRS patterns may allow for reducing overhead e.g. for signaling the patterns and/or to achieve the tradeoff between DMRS overhead and channel recovery Mean Squared Error (MSE). Exemplary aspects and exemplary embodiments provided below may enable adaptively scheduling of DMRS patterns, e.g. based on a Bit Error Rate (BER)/MSE performance requirement of a UE.

According to a first exemplary aspect, a first apparatus is disclosed, the first apparatus comprising:

- means for obtaining channel measurements (e.g. at least one channel measurement) of a radio channel between the first apparatus and a second apparatus measured over a resource grid;
- means for generating (or deriving) a demodulation reference signal pattern over the resource grid based on the channel measurements; and
- means for transmitting, to the second apparatus, the generated demodulation reference signal pattern.

The first apparatus may for instance be or comprise a mobile entity (e.g., a mobile telecommunication device or a mobile phone or a user equipment or a terminal device).

According to a second exemplary aspect, a second apparatus is disclosed, the second apparatus comprising:

- means for receiving, from a first apparatus, a demodulation reference signal pattern over a resource grid, wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between the first and second apparatuses measured over the resource grid.

The second apparatus may for instance be or comprise a server, server cloud, or a Radio Access Network (RAN) node or part thereof.

The apparatus according to any aspect may comprise 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 perform the specified steps.

The means of the apparatus (e.g. first and/or second apparatus) can be implemented in hardware and/or software. They may comprise for instance at least one processor for executing processor instructions for performing the required functions, at least one memory storing the instructions, or both. Alternatively, they could comprise for instance circuitry that is designed or configured to implement the required functions, for instance implemented in a chipset or a chip, like an integrated circuit. In general, the means may comprise for instance one or more processing means or processors.

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 e.g. 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 or server, 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 (e.g., 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.

According to a third exemplary aspect, a first method is disclosed, the method comprising:

- obtaining channel measurements of a radio channel between a first apparatus and a second apparatus measured over a resource grid;
- generating (or deriving) a demodulation reference signal pattern over the resource grid based on the channel measurements; and
- transmitting, (e.g. to the second apparatus,) the generated demodulation reference signal pattern.

The first method may comprise the steps the apparatus of the first exemplary aspect is configured to perform or has means for. The method may for instance be performed and/or controlled by an/the apparatus, for instance a mobile entity (e.g., a mobile telecommunication device or a mobile phone or a user equipment or a terminal device).

According to a fourth exemplary aspect, a second method is disclosed, the method comprising:

- receiving (e.g. from a first apparatus) a demodulation reference signal pattern over a resource grid, wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between the first and second apparatuses measured over the resource grid.

The second method may comprise the steps the apparatus of the second exemplary aspect is configured to perform or has means for. The method may for instance be performed and/or controlled by an/the apparatus, for instance a server, a server cloud, or a RAN node or part thereof.

Alternatively, the method according to any aspect may be performed and/or controlled by more than one apparatus, for instance a server cloud comprising at least two servers or a system of apparatus, e.g. a system comprising at least one RAN node and at least one UE. For instance, the method may be performed and/or controlled by using at least one processor of an/the apparatus. A method may comprise steps according to the third and fourth exemplary aspect and may e.g. be performed by system of apparatus, e.g. a system comprising at least one RAN node and at least one UE.

According to a fifth exemplary aspect, a system is disclosed, the system comprising a mobile entity or a part thereof and a server or a part thereof together performing the method according to at least one of the third and fourth exemplary aspect.

The system may comprise one or more apparatus, such as the apparatus of any exemplary aspect (e.g. the first or second apparatus), and/or a server, server cloud, a RAN node, a UE or a mobile terminal (e.g., a mobile telecommunication device or a mobile phone).

According to a sixth exemplary aspect, a computer program product is disclosed, the computer program product when executed by a processor of an apparatus causing said apparatus to perform a method according to at least one of the third and fourth exemplary aspect or a method comprising at least one of:

- obtaining channel measurements of a radio channel between a first apparatus and a second apparatus measured over a resource grid;
- generating (or deriving) a demodulation reference signal pattern over the resource grid based on the channel measurements;
- transmitting, (e.g. to the second apparatus,) the generated demodulation reference signal pattern; and
- receiving (e.g. from the first apparatus) a demodulation reference signal pattern (over a resource grid), wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between the first and second apparatuses measured over the resource grid.

According to a further exemplary aspect, an apparatus is disclosed, configured to perform and/or control or comprising respective means for performing and/or controlling the method according to any exemplary aspect. According to a further exemplary aspect, an apparatus is disclosed comprising at least one processor; and at least one memory storing instructions that, when executed by the at least one processor, cause the first apparatus at least to perform the method according to any exemplary aspect.

The disclosed apparatus according to any aspect may be a module or a component for a device, for example a chip. Alternatively, the disclosed apparatus according to any aspect may be a device, for instance a server, server cloud, a RAN node, or a user equipment. The disclosed apparatus according to any aspect may comprise only the disclosed components, for instance means, processor, memory, or may further comprise one or more additional components.

According to a further exemplary aspect, a computer program is disclosed, the computer program when executed by a processor causing an apparatus, for instance a server, to perform and/or control the actions of the method according to at least one of the third and fourth exemplary aspect.

According to a further exemplary aspect, a computer readable storage medium is disclosed, the computer readable storage medium comprising a computer program product according to the sixth exemplary aspect.

Any disclosure herein relating to any exemplary aspect is to be understood to be equally disclosed with respect to any subject-matter according to the respective exemplary aspect, e.g. relating to an apparatus, a method, a computer program, and a computer-readable medium. Thus, for instance, the disclosure of a method step shall also be considered as a disclosure of means for performing and/or caused to perform the respective method step. Likewise, the disclosure of means for performing and/or causing to perform a method step shall also be considered as a disclosure of the method step itself. The same holds for any passage describing at least one processor; and at least one memory including instructions; the at least one memory and the instructions configured to, with the at least one processor, cause an apparatus at least to perform a step.

In the following, exemplary features and exemplary embodiments of all aspects will be described in further detail.

According to all disclosed exemplary aspects, a channel measurement may be understood as a measurement of channel properties, e.g. channel attenuation, noise power, fading, Doppler shift, Doppler spread, gain, K-factor, path loss. A channel measurement may e.g. be performed to obtain a channel frequency response. A channel measurement may e.g. be performed based on a demodulation reference signal pattern over the resource grid, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the demodulation reference signal pattern.

A channel measurement over the resource grid (e.g. a full channel resource grid or part thereof) may be obtained e.g. using data-aided channel estimation or alternatively by estimating the channel or part thereof using reference (or pilot) signals and by interpolating the channel between the reference (or pilot) signals, e.g. channel properties may be measured for resource elements in the resource grid having DMRS inserted and inter- or extrapolated to the other resource elements of the resource grid. Through a channel measurement over the resource grid, a channel frequency response may be obtained on which generating (or deriving) a demodulation reference signal pattern over the resource grid may be based. A channel frequency response may represent the relationship between a transmitted and a received signal, e.g. the relationship of input and output of the radio channel.

Chanel recovery or estimation may be understood as reconstructing the channel frequency response over the resource grid. The channel recovery or estimation may be based on signals received on resource elements which have been affected by the channel properties (e.g. gains or noise). A channel may be recovered or estimated using (known) reference (or pilot) signals inserted in a resource element of the resource grid.

According to all disclosed exemplary aspects, a resource element may be understood as an element of a resource grid, e.g. a resource element may represent one symbol (e.g. OFDM) in time domain and one subcarrier in frequency domain.

A resource grid may be a grid of resource elements, e.g. a grid of 12 subcarriers and 14 OFDM symbols yielding 168 resource elements. A resource grid may be e.g. the full resource grid (of a radio channel) spanning over the entire carrier bandwidth as defined in 3GPP TS 38.211, e.g. a slot over the full frequency bandwidth of a radio channel, or the resource grid may be a subset of the full resource grid, e.g. by applying some restriction and/or decimation over the frequency and/or time domain to the full resource grid, for instance by restricting channel measurements and DMRS pattern generation to a certain defined bandwidth and/or time duration or to one PRB and/or TTI every e.g. two or four or eight PRBs and/or TTIs of the full resource grid and/or to one OFDM symbol every 2 or 4 OFDM symbols. For instance, a RAN node may restrict a mobile entity to (only) obtain or collect (channel measurements) over a certain defined bandwidth and/or time duration, e.g. for training data collection. For instance, a RAN node may perform decimation over the frequency and/or time domain e.g. on the bandwidth data collection complexity.

According to all disclosed exemplary aspects, a demodulation reference signal pattern may be a pattern of demodulation reference signals inserted in a resource grid (e.g. inserted in resource elements of the resource grid). A demodulation reference signal pattern may be a distribution of resource element(s) designated for or carrying reference signal(s) in a resource grid associated with a radio channel (e.g. physical resource block - Transmission Time Interval (PRB - TTI) grid). A reference signal pattern may be specific for or tailored to the radio channel or specifically derived for the radio channel based on obtained channel measurements over the resource grid, so it may not be a pre-determined (or default or legacy) demodulation reference pattern, e.g. not a reference signal pattern pre-defined in a standard.

According to all disclosed exemplary aspects, a trained machine learning algorithm fed with the channel measurements may be a machine learning algorithm that is fed with the channel measurements over the resource grid, e.g. the channel measurements can be used as input to the machine learning algorithm. For instance a second apparatus (e.g. gNB) may signal a first apparatus (e.g. UE) default DMRS patterns for the training stage, e.g. by predefining the DMRS patterns in a specification and configuring them or a part of them to the first apparatus. At the ML algorithm training phase, the second apparatus may transmit with the default DMRS patterns, the first apparatus may apply data-aided channel estimation to obtain a channel measurement (or a channel frequency response) over the (e.g. full channel) resource grid or part thereof and use the channel measurement over the resource grid or part thereof as training data to train the ML algorithm or as test data to test e.g. the channel recovery performance of a trained ML algorithm. A machine learning algorithm may e.g. be a convolutional neural network (CNN). Alternatively or additionally deep learning techniques may be used e.g. to perform channel recovery or estimation. For example, by viewing the resource grid as a 2-D image, the problem of channel recovery or estimation may be transformed into an image processing problem, e.g. similar to denoising or super-resolution. Training or test data for e.g. the machine learning algorithm may be obtained using generated (e.g. standard-compliant) waveforms and generated channel models. This training data may be used to train a channel estimation CNN.

According to all disclosed exemplary aspects, an error performance metric may allow to obtain a measure of the error of a recovered channel with respect to the original channel, e.g. a difference between the actual channel frequency response and a recovered or estimated channel frequency response. It may be or comprise a channel recovery performance metric allowing e.g. to measure the channel recovery performance, for example a means square error (MSE) between the actual channel frequency response and a recovered or estimated channel frequency response. An error performance metric may be or comprise a bit-error-rate or block error rate.

A channel recovery performance may be determined based on an error performance metric, e.g. using a channel frequency response.

According to all disclosed exemplary aspects, nested demodulation reference signal patterns may be understood as patterns arranged in a hierarchical structure, e.g. if the patterns are structured in a sequence or serial, a pattern being positioned before another pattern in the sequence or having a lower index than another pattern may be contained in the other pattern, e.g. w.r.t. the positions of resource elements designated or carrying reference signals or data. Nested patterns may, for example, be obtained by an iterative approach.

According to all disclosed exemplary aspects, pre-determined (or default or legacy) demodulation reference signal pattern may be pre-defined patterns from a standard, e.g. DMRS patterns obtained using Mapping Type A or B, wherein Mapping Type A can start only at symbol 2 or 3 within a slot and Mapping Type B starts always at the first symbols of scheduled start and length indicator (SLIV). DMRS transmission may be configured by high layer signaling (RRC setup/reconfiguration), once configured to a first apparatus the pre-determined DMRS patterns may be fixed throughout the lifetime of a RRC connection.

According to all disclosed exemplary aspects, a change in the radio channel may be a change in at least one property of the radio channel. A change may be determined e.g. when the difference between a previous measurement of a property and a new measurement of the property exceeds a certain threshold, e.g. a difference by at least 50 % in a property may be determined as a change in the radio channel.

According to all disclosed exemplary aspects, past demodulation reference signal patterns may refer to demodulation reference signals generated or derived at an earlier occasion, e.g. for the radio channel. It may e.g. be retrieved from a memory of the first apparatus and may e.g. be tailored (e.g. by a method according to the third exemplary aspect) to the radio channel during past communication sessions between the first and second apparatuses.

According to an exemplary embodiment of the first exemplary aspect, the demodulation reference signal pattern is generated by means of a trained machine learning algorithm fed with the channel measurements.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for receiving, from the second apparatus, at least one of:
  - a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
  - a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

  and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for generating a plurality of demodulation reference signal patterns over the resource grid based on the channel measurements; and
- means for transmitting, to the second apparatus, the plurality of demodulation reference signal patterns,

  wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion or to different channel recovery performances associated with the respective demodulation reference signal patterns.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for transmitting, to the second apparatus, a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for transmitting the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns.

This may e.g. allow for reducing signaling overhead.

According to an exemplary embodiment of the first exemplary aspect, the channel measurements are performed based on a pre-determined (or default or legacy) demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the pre-determined demodulation reference signal pattern (e.g. data-aided channel estimation).

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for transmitting, to the second apparatus, a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises at least one of:

- means for detecting a change in the radio channel, e.g. detecting a switch to a new radio channel;
- means for triggering a fallback onto a pre-determined demodulation reference signal pattern (for the radio channel or the new radio channel);
- means for generating a new demodulation reference signal pattern over the resource grid (of the radio channel) or a resource grid of a new radio channel based on new channel measurements performed following the detection of the change in the radio channel, the new channel measurements being based on the pre-determined demodulation reference signal pattern.

According to an exemplary embodiment of the first exemplary aspect, the first apparatus further comprises:

- means for transmitting, to the second apparatus, one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus (e,g, a user equipment memory) and tailored to the radio channel (e.g. during past communication sessions between the first and second apparatuses).

One or more past demodulation reference signal patterns may be retrieved from a memory based on at least one of an information element indicative of a number of demodulation reference signal patterns to generate or to derive, an information element indicative of a minimum number of resource elements to be used for insertion of DMRS, an information element indicative of a maximum number of resource elements to be used for insertion of DMRS, an information element indicative of the location of a (tailored) DMRS pattern within a plurality of (e.g. nested) DMRS patterns, wherein said information elements may be received from an apparatus according to the second exemplary aspect.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving, from the first apparatus, a plurality of demodulation reference signal patterns,
  wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for insertion of demodulation reference signals or to different channel recovery performances associated with the respective demodulation reference signal patterns.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving, from the first apparatus, a third information element (or third information elements) indicative of the channel recovery performance(s) associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for selecting a demodulation reference signal pattern from the plurality of demodulation reference signal patterns to achieve a given error performance metric (e.g. a bit error rate, a block error rate, or a channel recovery performance metric),
  wherein the error performance metric is determined based on at least one of:
- an effective number of resource elements used for insertion of demodulation reference signals in the selected demodulation reference signal pattern;
- a channel recovery performance for the selected demodulation reference signal pattern; and
- channel measurements of the radio channel.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns (e.g. to reduce the signaling overhead).

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for transmitting, to the first apparatus, at least one of:
- a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
- a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,
  and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving, from the first apparatus, a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving, from the first apparatus, one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus (e.g. the user equipment memory) and tailored to the radio channel (e.g. during past communication sessions between the first and second apparatuses).

According to an exemplary embodiment of the second exemplary aspect, the second apparatus further comprises:

- means for receiving, from the first apparatus, a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

According to an exemplary embodiment of the third exemplary aspect, the demodulation reference signal pattern is generated by means of a trained machine learning algorithm fed with the channel measurements.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- receiving (e.g. from the second apparatus) at least one of:
  - a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
  - a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

  and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- generating a plurality of demodulation reference signal patterns over the resource grid based on the channel measurements; and

- transmitting (e.g. to the second apparatus) the plurality of demodulation reference signal patterns,
wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion or to different channel recovery performances associated with the respective demodulation reference signal patterns.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- transmitting (e.g. to the second apparatus) a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- transmitting (e.g. to the second apparatus) the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns (e.g. to reduce the signaling overhead).

According to an exemplary embodiment of the third exemplary aspect, the channel measurements are performed based on a pre-determined (or default or legacy) demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the pre-determined demodulation reference signal pattern.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- transmitting (e.g. to the second apparatus) a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises at least one of:

- detecting a change in the radio channel, e.g. detecting a switch to a new radio channel;
- triggering a fallback onto a pre-determined demodulation reference signal pattern (for the radio channel or the new radio channel);
- generating a new demodulation reference signal pattern over the resource grid (of the radio channel) or a resource grid of a new radio channel based on new channel measurements performed following the detection of the change in the radio channel, the new channel measurements being based on the pre-determined demodulation reference signal pattern..

According to an exemplary embodiment of the third exemplary aspect, the first method further comprises:

- transmitting (e.g. to the second apparatus) one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus (e,g, a user equipment memory) and tailored to the radio channel (e.g. during past communication sessions between the first and second apparatuses).

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- receiving (e.g. from the first apparatus) a plurality of demodulation reference signal patterns, wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for insertion of demodulation reference signals or to different channel recovery performances associated with the respective demodulation reference signal patterns.

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- receiving (e.g. from the first apparatus) a third information element (or third information elements) indicative of the channel recovery performance(s) associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- selecting a demodulation reference signal pattern from the plurality of demodulation reference signal patterns to achieve a given error performance metric (e.g. a bit error rate, a block error rate, or a channel recovery performance metric),
  wherein the error performance metric is determined based on at least one of:
- an effective number of resource elements used for insertion of demodulation reference signals in the selected demodulation reference signal pattern;
- a channel recovery performance for the selected demodulation reference signal pattern; and
- channel measurements of the radio channel.

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- receiving (e.g. from the first apparatus) the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns (e.g. to reduce the signaling overhead).

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- transmitting (e.g. to the first apparatus) at least one of:
- a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
- a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

According to an exemplary embodiment of the fourth exemplary aspect, wherein the second method further comprises:

- receiving (e.g. from the first apparatus) a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

According to an exemplary embodiment of the fourth exemplary aspect, the second method further comprises:

- receiving (e.g. from the first apparatus) one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus (e.g. the user equipment memory) and tailored to the radio channel (e.g. during past communication sessions between the first and second apparatuses).

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprises: receiving, e.g. from a second apparatus, a configuration for tailored DMRS patterns comprising at least one of: at least one default DMRS pattern (that e.g. may be utilized for training a machine learning algorithm or for future transmissions), and a past demodulation reference signal pattern (that may e.g. be utilized for training a machine learning algorithm or for future transmissions), wherein the past DMRS pattern may e.g. be retrieved from a memory of the apparatus and may be tailored to the radio channel during past communication sessions between the apparatus and a second apparatus.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprise: receiving, e.g. from a second apparatus, at least one default DMRS pattern; Causing the apparatus to generate at least one (e.g. a plurality of) demodulation reference signal pattern over the resource grid based on channel measurements, e.g. performed by the apparatus, e.g. by means of a trained machine learning algorithm fed with the channel measurements. The channel measurements may be obtained or performed based on the received default (or pre-determined or legacy) demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the default or pre-determined demodulation reference signal pattern (e.g. data-aided channel estimation). A machine learning algorithm may be utilized to generate tailored (or specific) DMRS patterns, which are tailored to the radio channel.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprises: transmitting, e.g. to a second apparatus, at least one (generated) demodulation reference signal pattern or a plurality of generated demodulation reference signal patterns, wherein the plurality of demodulation reference signal patterns correspond to at least one of: different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion, and to different channel recovery performances associated with the respective demodulation reference signal patterns.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprises: transmitting, e.g. to a second apparatus, e.g. together (e.g. in the same transmission) with a plurality of (generated, tailored) DMRS patterns, a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns. The plurality of demodulation reference signal patterns may e.g. be a plurality of nested demodulation reference signal patterns.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprises: receiving, e.g. from a second apparatus, a reconfiguration information element indicative of or comprising e.g. at least one (tailored) DMRS pattern, e.g. to be utilized for future transmissions, from the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the first exemplary aspect) further comprising means for or the method further comprises: receiving, e.g. from a second apparatus, a control information element (e.g. DCI) indicative of or comprising (the) at least one selected DMRS pattern, e.g. to be utilized for future (scheduled) transmissions, from the plurality of demodulation reference signal patterns.

According to an exemplary embodiment of all exemplary aspects, the apparatus (e.g. an apparatus according to the second exemplary aspect) further comprising means for or the method further comprises: (dynamically) transmitting, e.g. to a first apparatus, a control information element (e.g. DCI) indicative of or comprising (the) at least one selected DMRS pattern, e.g. to be utilized for future (scheduled) transmissions at least partly depending on detecting a change in the radio channel, e.g. a switch to a different channel.

According to another exemplary embodiment an apparatus (e.g. UE or gNB) comprising means for obtaining a demodulation reference signal (DMRS) pattern specific for a radio channel using a machine learning algorithm is disclosed, wherein the machine learning algorithm utilizes a resource grid (e.g. a full resource grid) of the radio channel and a channel frequency response of the radio channel measured over the resource grid or part thereof.

According to an exemplary embodiment of all exemplary aspects, the apparatus further comprising means for or the method further comprises at least one of: applying (e.g. for channel estimation or data demodulation) the demodulation reference signal pattern according to a user equipment bit-error rate requirement; obtaining a user equipment bit-error rate requirement; and selecting the demodulation reference signal pattern according to the user equipment bit-error rate requirement. According to an exemplary embodiment of all exemplary aspects, the apparatus further comprising means for or the method further comprises at least one of: deriving a (nested) plurality of demodulation reference signal patterns based on an iterative approach, transmitting (e.g. to a gNB) an indication of a capability to obtain the demodulation reference signal pattern specific for a radio channel; receiving (e.g. from a gNB) a set of parameters for obtaining the demodulation reference signal pattern specific for the radio channel (e.g. a number of demodulation reference signal patterns to obtain, a number of resource elements to be used for insertion of demodulation reference signals); transmitting (e.g. to a gNB) a suggested demodulation reference signal pattern from historical record based on the received set of parameters and in particular a value indicative of a channel recovery performance (e.g. mean square error) associated with the suggested demodulation reference signal pattern; obtaining a plurality of demodulation reference signal patterns based on the received set of parameters and optionally transmitting the obtained plurality of demodulation reference signal patterns (e.g. to the gNB); receiving (e.g. from UE) a plurality of demodulation reference signal patterns; selecting the demodulation reference signal pattern from the plurality of demodulation reference signals patterns based on a bit-error rate requirement; and transmitting (e.g. to a UE) the demodulation reference signal pattern from the plurality of demodulation reference signals patterns to be applied for communication over the radio channel. According to an exemplary embodiment of all exemplary aspects, the apparatus further comprising means for or the method further comprises at least one of: determining a switch from the radio channel to a second radio channel; upon determining that the switch from the radio channel to a second radio channel is present, obtaining a second demodulation reference signal pattern specific for the second radio channel using the machine learning algorithm.

The features and example embodiments described above may be described for DMRS pattern, however the technique described for DMRS pattern (generation) may also be used to for (e.g. to derive) CSI-RS or SRS patterns using similar signaling and techniques.

The features and example embodiments described above may equally pertain to the different aspects, a demodulation reference signal pattern is associated with at least one of: a number indicative of a number of resource elements used for demodulation reference signals in the demodulation reference signal pattern (per slot); and a value indicative of a channel recovery performance (e.g. mean square error) associated with the demodulation reference signal pattern.

It is to be understood that the presentation in this section is merely by way of examples and non-limiting.

Other features will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for purposes of illustration and not as a definition of the limits, for which reference should be made to the appended claims. It should be further understood that the drawings are not drawn to scale and that they are merely intended to conceptually illustrate the structures and procedures described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The figures show:

Fig. 1	a schematic drawing showing an example system;
Fig. 2	a flowchart showing an example embodiment of a method according to the third exemplary aspect;
Fig. 3	a flowchart showing an example embodiment of a method according to the fourth exemplary aspect;
Fig. 4a	a figure showing examples of DMRS patterns;
Fig. 4b	a figure showing examples of DMRS patterns;
Fig. 5	a flowchart showing an example embodiment of a method according to at least one of the third and fourth exemplary aspect;
Fig. 6	a figure showing an exemplary embodiment of a method according to at least one of the third and fourth exemplary aspect;
Fig. 7	a flowchart showing an example embodiment of a method according to at least one of the third and fourth exemplary aspect;
Fig. 8a	a figure showing examples of DMRS patterns according to any exemplary aspect.
Fig. 8b	a table with properties associated with the exemplary DMRS patterns of Fig. 8a, in particular a number of resource elements in the resource grid used for insertion of demodulation reference signals and a channel recovery performance.
Fig. 9a	a figure showing an exemplary DMRS pattern with DMRS inserted in 12 resource elements;

Fig. 9b a figure showing an exemplary DMRS pattern according to any exemplary aspect with DMRS inserted in 12 resource elements;

Fig. 10 a schematic block diagram of an example embodiment of an apparatus according to the first aspect and/or an example embodiment of an apparatus configured to perform the method according to the second exemplary aspect.

DETAILED DESCRIPTION OF SOME EXEMPLARY EMBODIMENTS

The following description serves to deepen the understanding and shall be understood to complement and be read together with the description as provided in the above summary section of this specification. Some aspects may have a different terminology than e.g. provided in the description above. The skilled person will nevertheless understand that those terms refer to the same subject-matter, e.g. by being more specific. For instance, generating a DMRS pattern may be referred to as derivation of DMRS patterns, a tailored or specific DMRS pattern may be referred to as a flexible DMRS pattern, a channel frequency response over the resource grid may be referred to as a channel grid, and a plurality of DMRS patterns may be referred to as a set of DMRS patterns.

Fig. 1 is a schematic drawing showing an example system. Therein, a RAN node (for instance a gNB) 101 or base station 101 transmits via a DL channel 103 to a mobile entity 102, e.g. a user equipment 102, and receives via an UL channel 104. For instance, DL transmissions may utilize a default DMRS pattern or a tailored DMRS pattern e.g. for demodulation or decoding of a data channel. The exemplary system may e.g. be a system according to the sixth exemplary aspect. The exemplary system may e.g. perform a method of at least one of the third and fourth exemplary aspect. The exemplary system may comprise an exemplary embodiment of an apparatus according to the first aspect and an exemplary embodiment of an apparatus according to the second aspect.

Fig. 2 is a flowchart showing an example embodiment of a method according to the third exemplary aspect. This flowchart 200 may for instance be performed by at least one of apparatus according to the first exemplary aspect, e.g. a mobile entity or UE 102.

In a first step 201, channel measurements of a radio channel between a first apparatus (e.g. a UE 102) and a second apparatus (e.g. a gNB 101 or base station 101) are obtained or measured over a resource grid, for instance over the full or whole resource grid or a subset of the full resource grid.

In a second step 202, a demodulation reference signal pattern is generated or derived over the resource grid based on the channel measurements.

In a third step 203, the generated demodulation reference signal pattern is transmitted to the second apparatus.

Fig. 3 is a flowchart showing an example embodiment of a method according to the fourth exemplary aspect. This flowchart 300 may for instance be performed by at least one of apparatus according to the second exemplary aspect, e.g. a base station 101 or gNB 101.

In step 301, a demodulation reference signal pattern over a resource grid is received, for instance from a first apparatus (e.g. a UE 102), wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between a first and a second apparatus measured over the resource grid.

Fig. 4a and Fig. 4b show exemplary pre-determined or legacy DMRS patterns for different antenna ports. A resource grid having 14 OFDM symbols and 12 subcarriers is shown in each case with resource elements 402 carrying DMRS or used for insertion of DMRS, resource elements 403 carrying a payload, e.g. data, and resource elements 401 being empty. In Fig. 4a DRMS has been inserted at OFDM symbols 2 and 3. In Fig. 4b additionally DRMS has been inserted at OFDM symbols 10 and 11.

Fig. 5 is a flowchart showing an example embodiment of a method according to at least one of the third and fourth exemplary aspect. The exemplary method may be performed by a system, in particular together by a gNB 101 and a UE 102.

During RRC setup 501 UE 102 may transmit 502, to gNB 101, a fourth information element indicative of a capability of the first apparatus (e.g UE 102) to generate a demodulation reference signal pattern tailored to the radio channel, the fourth information element may further e.g. be indicative of a capability of the first apparatus (e.g UE 102) to transmit one or more past demodulation reference signal patterns, and in particular transmits one or more past demodulation reference signal patterns retrieved from a memory of the UE 102 (e,g, a user equipment memory) and tailored to the radio channel during past communication sessions between UE 102 and gNB 102. One or more past demodulation reference signal patterns may be retrieved from a memory based on at least one of an information element indicative of a number of DMRS patterns to derive, an information element indicative of a minimum number of resource elements to be used for insertion of DMRS, an information element indicative of a maximum number of resource elements to be used for insertion of DMRS, an information element indicative of the location of a tailored DMRS pattern within a plurality of DMRS patterns, wherein said information elements may be received from gNB 102. The one or more past demodulation reference signal patterns may e.g. have been generated when UE 102 or another (e.g. similar) mobile entity was, in the past, located at the same (e.g. geographical) position, e.g. in a fixed wireless access use case. UE 102 may transmit, e.g. together with the one or more past demodulation reference signal patterns, to gNB 101 an information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns.

UE 102 may receive 503, from gNB 101, a configuration for tailored DMRS patterns comprising at least one of: at least one default DMRS pattern that may be utilized for training a machine learning algorithm or for future transmissions 504(e.g. as a fallback option), and a past demodulation reference signal pattern that may be utilized for training a machine learning algorithm or for future transmissions 504, wherein the past DMRS pattern may be retrieved from a memory of the UE or the gNB and e.g was tailored to the radio channel during past communication sessions between UE 102 and gNB 101 (e.g. a DMRS pattern transmitted 502 by the UE 102 to gNB 101). Receiving 503 at least one default DMRS pattern may cause UE 102 to generate at least one (e.g. a plurality of) demodulation reference signal pattern over the resource grid based on channel measurements, e.g. performed by the UE 102, e.g. by means of a trained machine learning algorithm fed with the channel measurements. The channel measurements may be obtained or performed based on the received default (or pre-determined or legacy) demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the default or pre-determined demodulation reference signal pattern (e.g. data-aided channel estimation 505). A machine learning algorithm may be utilized 506 to generate tailored DMRS patterns (cf. e.g. Fig. 6 and Fig. 7). A gNB 101 may signal the UE 102 the default DMRS patterns for the training stage, e.g. by predefining the DMRS patterns in the specification and configuring a few to the UE. At the ML model training phase, gNB may transmit with the default DMRS patterns, UE may apply data aided channel estimation to obtain a channel frequency response over the resource grid and may use the channel frequency response over the resource grid as the training data to train the ML model. Alternatively or additionally, when UE channel changes due to a relocation or beam update, the DMRS patterns may be updated accordingly, i.e. gNB may fallback to default DMRS patterns and trigger the UE to retrain the model and feedback a new set of generated or tailored DMRS patterns. Further, a gNB may configure a UE to use only a few or all of these patterns signaled by the UE based on DMRS pattern derivation parameters, determined or configured at the gNB. Alternatively or additionally, a gNB may configure a UE to use the default patterns for future transmissions 504, which may implicitly trigger the training of the ML model.

During RRC reconfiguration 507, UE 102 may transmit 508 to gNB 101 the at least one generated demodulation reference signal pattern or the plurality of generated demodulation reference signal patterns, wherein the plurality of demodulation reference signal patterns correspond to at least one of: different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion, and to different channel recovery performances associated with the respective demodulation reference signal patterns. UE 102 may transmit, e.g. together with a plurality of (generated, tailored) DMRS patterns, to gNB 101 a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns. The plurality of demodulation reference signal patterns may e.g. be a plurality of nested demodulation reference signal patterns. UE 102 may receive 509 a reconfiguration information from gNB 101 indicative of or comprising e.g. at least one (tailored) DMRS pattern, e.g. to be utilized for future transmissions, from the plurality of demodulation reference signal patterns.

gNB 101 may select 510 at least demodulation reference signal pattern from the plurality of demodulation reference signal patterns to achieve a given error performance metric (e.g. a bit error rate) and e.g. to minimize RS overhead, wherein the error performance metric may e.g. be determined based on at least one of: an effective number of resource elements used for insertion of demodulation reference signals in the selected demodulation reference signal pattern; a channel recovery performance for the selected demodulation reference signal pattern; and channel measurements of the radio channel. UE 102 may receive 511 a control information (e.g. DCI) from gNB 101 indicative of or comprising the at least one selected DMRS pattern, e.g. to be utilized for future (scheduled) transmissions, from the plurality of demodulation reference signal patterns. gNB 101 may (dynamically) transmit 511 to the UE 102 a control information (e.g. DCI) indicative of or comprising the at least one selected DMRS pattern, e.g. to be utilized for future (scheduled) transmissions 512 at least partly depending on detecting a change in the radio channel, e.g. a switch to a different channel. A gNB may indicate UE to switch between generated DMRS patterns (e.g. from a generated plurality of demodulation reference signal patterns). The gNB may dynamically schedule the (generated) DMRS patterns and may indicate in DCI the selected DMRS pattern for a scheduled transmission. As an exemplary embodiment, this may be done by creating a new field in the DCI format for the (flexible) DMRS pattern indication. The bitwidth of the field may accord to the number of the generated (flexible) DMRS patterns and when a bit in the field is set as "1", it may indicate the associated DMRS pattern is selected for the transmission. Alternatively, the gNB may encode a (logical) identifier of the selected (flexible) DMRS pattern in the DCI, or use a spare identifier that is not used by the default DMRS patterns. Additionally or alternatively, UE may signal gNB in UCI its preferred DMRS pattern (e.g. from the generated plurality of demodulation reference signal patterns) for the next DL transmission. (e.g. UE assisted (flexible) DMRS pattern transmission). This may be done by creating a new field in the UCI format for the flexible DMRS pattern report. Then gNB may select for later DL transmission the DMRS pattern, e.g. taking into consideration the preferred pattern signaled by UE.

A gNB may indicate UE to fallback to default DMRS patterns, e.g. gNB may collect UE ACK/NACK feedback and may monitor the BER statistics of the UE. When the BER statistics deviates from expectation, gNB may signal UE using DCI to switch to default DMRS patterns, this may implicitly trigger the retraining of the ML model. As one exemplary embodiment, if all flexible DMRS patterns are disabled with the according index signaled as "0", fallback to default DMRS patterns may implicitly be indicated. Note, the proposed method may allow to use of number of the DMRS REs and the associated channel recovery MSE to tag the DMRS patterns or an arbitrary loss function (and accordingly the threshold to associate with the patterns) to run and tag the DMRS patterns. Another note, the DMRS patterns may be non-uniformly configured across the bandwidth so to achieve a specific BER/MSE target in between the BER/MSE values in the DMRS pattern set. Therefore, e.g. more bits may be used to indicate the DMRS pattern in DCI format (e.g. PRB specific DMRS pattern scheduling)

A DMRS patterns may be selected to meet the target channel recovery MSE requirement and may be scheduled for transmission to minimize the RS overhead. The derived DMRS pattern may be scheduled directly to meet the bit error rate (BER) requirement of the UE. A BER may be calculated using DMRS RE number, channel recovery MSE, UE measurements (e.g. UE channel attenuation, noise power, etc.) For each of a plurality of (generated) DMRS patterns, the BER may be calculated and then one pattern with least RS overhead may be selected to meet the BER requirement and may be used for transmission.

The BER may be a BER performance after equalizer, which may be a function of the SNR after equalizer, which may be calculated as a function of the MSE of the equalizer output as below:

$$\mathrm{BER} = Q(\sqrt{SNR_{eqz}})$$

$$SNR_{eqz} = \frac{1-J}{J}$$

where $Q(x)$ may be defined as $Q(x) = \frac{1}{2\pi}\int_x^{\infty} e^{-t^2/2}dt$ and may depend on the modulation scheme, J may represent the MSE of equalizer output. The MSE of the equalizer output may consist of two parts, the MSE of the equalizer assuming perfect channel knowledge and the MSE of the channel recovery MSE,

$$J = \frac{\sigma^2}{M}\sum_{l=0}^{M-1}\frac{1}{|H_l|^2+\sigma^2} + \frac{J_{\mathrm{ch}}}{M}\sum_{l=0}^{M-1}\frac{|H_l|^2}{|H_l|^2+\sigma^2}$$

Where, J_{ch} may stand for the channel recovery MSE, σ^2 for the noise power, H_l, $l = 1 \dots M$ for the channel attenuation at l^{th} allocated PRB. Channel attenuation may be derived using UE CSI report, e.g. Per PRB CQI, noise power may be derived using UE measurement report, e.g. RSSI and RSRQ. Therefore, gNB may calculate the BER performance for each of the derived DMRS pattern before scheduling them for transmission. To meet the BER performance requirement for a particular UE, gNB may select the

DMRS pattern with maximum available MSE under the bound for the BER requirement, thus e.g. to minimize the DMRS overhead for the transmission. In a further way, since UE may be aware of all the measurements it has performed, UE may directly calculate the BER performance for each of the configured DMRS patterns, and may indicate in UL UCI its preferred DMRS pattern to assist gNB on flexible DMRS pattern scheduling.

For instance, the UE may first report its capability to support generating a demodulation reference signal pattern tailored to the radio channel. The gNB may control the generation or derivation of the DMRS patterns by the UE (e.g. according to number of DMRS patterns to be determined, and respective maximum number of DMRS REs for thresholding). Next the UE may report a plurality of DMRS patterns tailored to the actual UE radio channel with the least DMRS overhead. Each reported DMRS pattern may be associated with a different MSE threshold. A legacy or default DMRS pattern may be used during the training stage: the UE may apply data-aided channel estimation to estimate, recover or derive the channel frequency response over the (e.g. full) resource grid, and may use the derived channel frequency response over the resource grid as training data to train the ML model. Then, the gNB may dynamically select one of the reported DMRS patterns for DL communications with the UE to meet a given BER target. BER may be estimated from the reported MSE, the number of DMRS REs in the DMRS pattern and the UE measurements. The (optimal) DMRS patterns may also be derived or learned at gNB side for UL communications, and also for DL communications if UL/DL channel reciprocity applies (e.g., TDD communications), in which case e.g. some of the proposed signaling may still apply (e.g. new UE capability reporting, sending the plurality of (optimal) DMRS patterns to the UE).

Once configured during a RRC connection setup, a DMRS patterns may e.g. be fixed for the UE. That is the configured DMRS patterns may be used throughout the lifetime of the RRC connection even though e.g. the UE channel may change during the time. Alternatively (e.g. instead of fixing one set of DMRS patterns throughout the lifetime of RRC connection or instead of predefining a set of DMRS patterns and e.g. applying them to all UEs), the DMRS patterns may e.g. be generated or derived as described and dynamically applied, e.g. upon detection of a change in the radio channel, e.g. to meet a BER requirement of the UE and/or to minimize the DMRS overhead. The (flexible) DMRS pattern may be adaptively changed based on e.g. BER/MSE performance requirement of the UE. As the DMRS pattern may achieve or achieves maximum available MSE to meet the BER performance requirement, the DMRS overhead for DL transmission may be minimized.

For a set of DMRS RE number thresholds (e.g. indicated by a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals), the proposed ML model may output, according to the DMRS RE number thresholds, a set of nested DMRS patterns, each of which may be with different channel recovery MSE performance. Note that the same ML model may be used to recover (estimate or predict) the channel. For each of the derived DMRS patterns, the BER of the UE channel may be estimated using the DMRS RE number, the correspondent channel recovery MSE, together with the UE measurements. Therefore, the generated (optimal) DMRS pattern with least RS overhead from the pattern set may be selected to meet the target BER requirement and used for transmission.

The DMRS transmission framework may be updated to accommodate the proposed DMRS patterns derivation and (flexible) DMRS scheduling method. As the DMRS patterns generated or derived over the resource grid based on the channel measurements (e.g. from real UE channel) may reflect the real correlation between REs (in time and frequency domain) within the channel frequency response, the patterns may appear to be random. Therefore, the derived patterns may be nested and signaling the nested random patterns may minimize signaling overhead.

For the proposed ML model based method, the use cases may e.g. include both DL and UL DMRS patterns derivation and (flexible) DMRS scheduling. The proposed method may be implemented either at RAN node (e.g. gNB) or UE side.

Fig. 6 is a figure showing an exemplary embodiment of a method according to at least one of the third and fourth exemplary aspect, in particular showing a generation of DMRS patterns by means of a trained machine learning algorithm 602, and generating a plurality 601, 602, 607 of nested demodulation reference signal patterns. REs 604 in which a DMRS is inserted are indicated by a cross, e.g. RS REs 604. REs 605 without a DMRS inserted, e.g. data REs 605, are indicated by diagonal lines. A channel frequency response over the resource grid (e.g. a channel grid) has e.g. been obtained by means of data-aided channel estimation. As all resource elements may have been measured or estimated they may all be considered to carry or have inserted a DMRS (because they can all be recovered e.g. by a machine learning algorithm). In a first step, a first DMRS pattern 601 may be generated by choosing one RE and removing DMRS from it. The ML algorithm 602 may then recover or estimate the chosen RE in channel frequency response 603 over the resource grid . This may be done consecutively for all REs. For each of the generated DMRS patterns having one RE without DMRS a channel recovery performance associated with the respective demodulation reference signal pattern may be determined, e.g. by determining the MSE (value) between a training channel frequency response over the resource grid (e.g. a training channel grid) and the respective recovered channel frequency response over the resource grid (e.g. recovered channel grid), which may be recovered based on the generated DMRS pattern, e.g. is recovered using the (trained) ML algorithm. The DMRS pattern 601 having the RE 605 without DMRS exhibiting the best channel recovery performance may be chosen as a basis for, in a next step, consecutively removing DMRS from a second RE to generate a DMRS pattern 606 having two REs without DMRS, e.g. two data REs 605. The process can then iteratively repeated (e.g. via a loop) e.g. until all REs are data REs or a predetermined number of REs in the resource grid are used for data or DMRS or until a pre-determined channel recovery performance (threshold) cannot be reached anymore (e.g. because too many REs are data REs). An example of such a process is shown in Fig. 7, which is a flowchart showing an example embodiment of a method according to at least one of the third and fourth exemplary aspect, in particular showing a generation of DMRS patterns by means of a trained machine learning algorithm, and generating a plurality of nested demodulation reference signal patterns. A plurality of (generated) DMRS patterns may be a serial of nested patterns and may e.g. be represented in a nested way, which may allow e.g. to minimize signaling overhead.

A plurality of (nested) DMRS patterns may be generated by a method with an ML model looped in, e.g. based on channel measurements (e.g. from UE channel), for instance under different DMRS RE number thresholds. The derived DMRS patterns may have different channel recovery MSE performance, e.g. according to the different DMRS RE number thresholds.

As a channel frequency response over the resource grid (e.g. a channel PRB-TTI grid) may be seen as an image, e.g. with 14 (number of the symbols in time domain) x 12 (number of the subcarrier in frequency domain) pixels, a machine learning algorithm such as a convolutional neural network (CNN) may be used for image processing. For instance an extended convolution neural network model may be used to derive from channel (measurements) the DMRS patterns for different overhead parameters (e.g. different number of DMRS REs inserted in the resource grid).

Training the proposed ML model may e.g. utilize a channel frequency response over the (full) resource grid (e.g. a full channel grid) for e.g. the 14 x 12 pixels, as the training data. This data may be collected using data aided channel estimation, which may be used to improve channel estimation performance. When a transmission block is successfully decoded, the decoded data REs may be seen as pilot. Using the decoded data REs together with the reference signal REs, the channel frequency response may be acquired for the whole transmission block, therefore the full channel frequency response over the resource grid.

As e.g. shown in Fig. 6, it may be started from a pattern in which all REs are DMRS REs, so the full channel frequency response over the resource grid may be available and the channel could be recovered. Then one RE is picked out, e.g. suppressed from DMRS transmission (e.g. set the channel at the corresponding RE as 0), and e.g. train the CNN to recover the channel using the remaining DMRS REs with the loss function defined as the MSE between the recovered channel.

Training the machine learning algorithm to recover the radio channel may be based on a loss function defined as the MSE between the recovered channel frequency response $\widehat{H} = \{\hat{h}_{i,j}\}$ (e.g. the recovered channel) and the original (or real) channel frequency response $H = \{h_{i,j}\}$ (e.g. the original channel),

$$MSE = \frac{1}{12 \times 14} \sum_{i \le 12, j \le 14} \left|\hat{h}_{i,j} - h_{i,j}\right|^2$$

Given a channel frequency response H over the resource grid, $h_{i,j} = 0$ may be assigned to imitate the suppression of DMRS transmission on RE at row i column j and get H'. The channel dataset of H' (H with $h_{i,j} = 0$) may be fed to the machine learning algorithm and the machine learning algorithm may be trained to recover the channel frequency response $\widehat{H}$ over the resource grid, using the MSE as the loss function. When the training is done, the machine learning algorithm may be tested with a test dataset H'' (another batch of channel samples H with $h_{i,j} = 0$) and the MSE for the RE (i,j) may be recorded. This step may be repeated for all REs, and then the one with smallest MSE may be selected, it may be labeled as the data RE and the RE may be recorded as e.g. an (index, MSE) pair as the DMRS pattern with 12 x 14 – 1 DMRS REs with the corresponding channel recovery MSE value. The whole procedure may be repeated for the rest of DMRS REs (with the selected RE labeled as data RE, wherein the labeling of the data RE is e.g. incremental), the model may be repeatedly trained, the MSE values may be recorded and one RE with the smallest MSE may be found, labeled and recorded, e.g. until all the REs are suppressed. A serial of 12 x 14 DMRS patterns with increasing channel recovery MSEs may be arrived at. The trained model for each of the selected DMRS patterns may be recorded and may be used to predict/estimate the channel e.g. when the corresponding DMRS pattern is scheduled.

Note that since the channel frequency response “image” may have (only) 12 x 14 pixels, the CNN utilized in a proposed method may be very simple, thus the training process may be light. The trained model for each of the selected DMRS patterns may be recorded and may be used to predict/estimate the channel e.g. when the corresponding DMRS pattern is used.

Also, machine learning algorithm may comprise or utilize deep learning techniques to e.g. perform channel estimation or recovery. For example, by viewing the resource grid as a 2-D image, the problem of channel estimation may be turned into an image processing problem, similar to denoising or super-resolution, where CNNs may be effective. Standard-compliant waveforms and channel models to use for training data may be customized and generated. Using Deep Learning, this training data may be used to train a channel estimation CNN. This example may show how to generate such training data and how to train a channel estimation CNN. The example may also show how to use the channel estimation CNN to process images that contain obtained channel frequency response using (e.g. linearly interpolated) received pilot symbols.

Fig. 8a and Fig. 8b show examples of (generated) DMRS patterns 801, 802, 803, 804, 805 according to any exemplary aspect. The exemplary DMRS patterns 801, 802, 803, 804, 805 may be nested, in that e.g. REs without DMRS in pattern 801 are also REs without DMRS in the (nested) patterns 802, 803, 804, 805; REs without DMRS in pattern 802 are also REs without DMRS in the (nested) patterns 803, 804, 805; REs without DMRS in pattern 803 are also REs without DMRS in the in the (nested) patterns 804, 805; and REs without DMRS in pattern 804 are also REs without DMRS in the (nested) pattern 805.

Alternatively to nesting the patterns based on REs without DMRS or data REs, patterns may be nested with respect to REs having DMRS (e.g. by reversing the order of the DMRS patterns in Fig. 8a) or any other nesting criterion. The rows in the table in Fig. 8b correspond to the exemplary DMRS patterns 801, 802, 803, 804, 805. For instance, for DMRS pattern 801 having 159 REs with DMRS a MSE value of 0.06 may be determined and for DMRS pattern 805 having 35 REs with DMRS a (higher) MSE value of 0.1 may be determined.

The proposed method may be tested with aligned channel modeling with a mixture of scenarios and UE speeds to evaluate the performance gain in generalized case, specifically e.g. channel dataset parameters as shown below:

```
Channel: 612 subcarrier x 256 TTI for SISO channel
delayProfiles = {'TDL-A', 'TDL-B', 'TDL-C', 'TDL-D', 'TDL-E'};
channel.DelayProfile = string(delayProfiles(randi([1 numel(delayProfiles)])));
channel.DelaySpread = randi([1 300])*1e-9;
channel.MaximumDopplerShift = randi([5 400]);
```

The derived patterns may be shown in Fig. 8a, the striped pixels may represent those REs labelled as data REs and the crossed pixels may represent DMRS REs. It may be seen that the derived DMRS patterns are quite different from those predefined e.g. in the 3GPP standard, the positions of the DMRS REs may be seemingly random. With more REs are labelled as data REs and the REs reserved for DMRS transmission decreasing, the channel recovery MSE may be increasing (e.g. Fig. 8b).

Fig. 9a is a figure showing an exemplary pre-determined (or default) DMRS pattern with DMRS inserted in12 resource elements, which may be compared to Fig. 9b showing an exemplary (generated) DMRS pattern according to any exemplary aspect with DMRS inserted in12 resource elements 902. Both DMRS patterns have the same number of REs with DMRS, i.e. 12 DMRS REs 602 (with the rest e.g. being data REs 901). However, in this example the MSE of the generated DMRS pattern is 0.0068, compared to 0.018 for the pre-determined pattern .The generated DMRS pattern, hence, may be regarded as performing better than the pre-determined DMRS pattern. Note, these test results are for a generalized case, for a UE specific cases, the performance gain may be even bigger.

As the generated or derived DMRS patterns may e.g. be a serial of nested patterns, they may be represented in a nested way to e.g. minimize the signaling overhead. E.g. if UE is to send 5 of the derived patterns based on the parameters configured by gNB, and they are with 35, 50, 67, 109, 159 DMRS REs respectively. The first DMRS pattern with 35 DMRS REs may be represented and signaled with 12 x 14 bits with “1” representing the DMRS REs and “0” the data REs (or the other way around). The second DMRS pattern may only need 12 x 14 – 35 bits to be represented and signaled, as the derived patterns may be nested and only those data REs in the first pattern will be labelled further as DMRS for the second pattern. Therefore, this nested property of the derived DMRS patterns may be used to reduce the pattern signaling overhead. Note, that it may depend on the flexible DMRS patterns selected, there may be other ways to further compress the signaling overhead.

Fig. 10 is a schematic block diagram of an apparatus 1000 according to an exemplary aspect, which may for instance represent one of the apparatus according to the first or second exemplary aspect.

Apparatus 600 comprises a processor 1001, program memory 1002, working or main memory 1003, data memory, communication interface(s) 1004, and an optional user interface 1005.

Apparatus 1000 may for instance be configured to perform and/or control or comprise respective means (at least one of 1001 to 1005) for performing and/or controlling the method according to the third and/or fourth exemplary aspect. Apparatus 1000 may as well constitute an apparatus comprising at least one processor (1001) and at least one memory (1002) storing instructions that, when executed by the at least one processor,, cause an apparatus, e.g. apparatus 1000 at least to perform and/or control the method according to all exemplary aspects.

Processor 1001 may for instance further control the memories 1002 to 1003, the communication interface(s) 1004, the optional user interface 1005.

Processor 1001 may for instance execute program code stored in program memory 1002, which may for instance represent a readable storage medium comprising program code that, when executed by processor 1001, causes the processor 1001 to perform the method according to the third or fourth exemplary aspect.

Processor 1001 (and also any other processor mentioned in this specification) may be a processor of any suitable type. Processor 1001 may comprise but is not limited to one or more microprocessor(s), one or more processor(s) with accompanying one or more digital signal processor(s), one or more processor(s) without accompanying digital signal processor(s), one or more special-purpose computer chips, one or more field-programmable gate array(s) (FPGA(s)), one or more controller(s), one or more application-specific integrated circuit(s) (ASIC(s)), or one or more computer(s)/server(s). The relevant structure/hardware has been programmed in such a way to carry out the described function. Processor 1001 may for instance be an application processor that runs an operating system.

Program memory 1002 may also be included into processor 1001. This memory may for instance be fixedly connected to processor 1001, or be at least partially removable from processor 1001, for instance in the form of a memory card or stick. Program memory 1002 may for instance be non-volatile memory. It may for instance be a FLASH memory (or a part thereof), any of a ROM, PROM, EPROM and EEPROM memory (or a part thereof) or a hard disc (or a part thereof), to name but a few examples.

Program memory 1002 may also comprise an operating system for processor 1001. Program memory 1002 may also comprise a firmware for apparatus 1000.

Apparatus 1000 comprises a working memory 1003, for instance in the form of a volatile memory. It may for instance be a Random Access Memory (RAM) or Dynamic RAM (DRAM), to give but a few non-limiting examples. It may for instance be used by processor 1001 when executing an operating system and/or computer program.

Data memory may for instance be a non-volatile memory. It may for instance be a FLASH memory (or a part thereof), any of a ROM, PROM, EPROM and EEPROM memory (or a part thereof) or a hard disc (or a part thereof), to name but a few examples. Data memory may for instance store one or more pieces of information, e.g. a measurement of a first signal, information on a first subspace, additional information.

Communication interface(s) 1004 enable apparatus 1000 to communicate with other entities, e.g. another apparatus. The communication interface(s) 1004 may for instance comprise a wireless interface, e.g. a cellular radio communication interface and/or a WLAN interface) and/or wire-bound interface, e.g. an IP-based interface, for instance to communicate with entities via the Internet. Communication interface(s) may enable apparatus 1000 to communicate with other entities, for instance one or more entities as comprised by a mobile communication network

User interface 1005 is optional and may comprise a display for displaying information to a user and/or an input device (e.g. a keyboard, keypad, touchpad, mouse, etc.) for receiving information from a user.

Some or all of the components of the apparatus 1000 may for instance be connected via a bus. Some or all of the components of the apparatus 1000 may for instance be combined into one or more modules.

The disclosed exemplary aspects may allow for enhanced signaling, efficient resource reservation and interworking. Generated or derived DMRS patterns may allow reducing overhead e.g. for signaling the patterns and/or to achieve the tradeoff between DMRS overhead and channel recovery MSE. Exemplary aspects and exemplary embodiments provided below may enable adaptively scheduling of DMRS patterns, e.g. based on the BER/MSE performance requirement of a UE.

The method (or apparatus) according to any aspect, in particular generating a demodulation reference signal pattern over the resource grid based on the channel measurements may be utilized for or extended to multiple layers, multiple users, and multiple antenna panels by e.g. conversing a 2-D CNN network into an 3-D CNN network (the additional dimension represents for the multiple layers, the multiple users, or the multiple antenna panels). Instead of using a 2D picture of a channel frequency response over the resource grid, the machine learning algorithm may use or learn from a cube of the channel matrix to derive or generate DMRS pattern(s) for multiple layer, multiple user, or multiple panel cases. Note that the non-uniformity of the derived patterns across the layers, the users or the panels may bring about interference; nevertheless, the interference may be mitigated using beam domain multiplexing similar to what may be done for the case, so the performance can be kept. On the other hand, applying constraints to formulate the derived patterns techniques, such as combing and OCC, may be used to multiplex DMRS for the multiple layers, the multiple users and multiple panels may be beneficial if the overhead reduction for signaling the patterns is considered.

The derivation algorithm may be ready to be applied in general to all reference signals for overhead reduction purpose, e.g. CSI-RS, and it can be (e.g. jointly) considered with CSI feedback compression.

In the method (or apparatus) according to any aspect, UE may e.g. report its capability on deriving the patterns from channel and the (suggested) patterns, gNB may e.g. configure UE the pattern derivation parameters and the selected DMRS pattern set. In addition, for the flexible pattern scheduling, gNB may indicate UE in DCI the selected DMRS pattern for the DL transmission, and optionally UE may report/indicate in UL UCI its preferred DMRS pattern for the next transmission.

In the present specification, any presented connection in the described embodiments is to be understood in a way that the involved components are operationally coupled. Thus, the connections can be direct or indirect with any number or combination of intervening elements, and there may be merely a functional relationship between the components.

Moreover, any of the methods, processes and actions described or illustrated herein may be implemented using executable instructions in a general-purpose or special-purpose processor and stored on a computer-readable storage medium (e.g., disk, memory, or the like) to be executed by such a processor. References to a 'computer-readable storage medium' should be understood to encompass specialized circuits such as FPGAs, ASICs, signal processing devices, and other devices.

The expression "A and/or B" is considered to comprise any one of the following three scenarios: (i) A, (ii) B, (iii) A and B. Furthermore, the article "a" is not to be understood as "one", i.e. use of the expression "an element" does not preclude that also further elements are present. The term "comprising" is to be understood in an open sense, i.e. in a way that an object that "comprises an element A" may also comprise further elements in addition to element A. Further, the term "comprising" may be limited to "consisting of", i.e. consisting of only the specified elements.

The expression "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.

It will be understood that all presented embodiments are only exemplary, and that any feature presented for a particular example embodiment may be used with any aspect on its own or in combination with any feature presented for the same or another particular example embodiment and/or in combination with any other feature not mentioned. In particular, the example embodiments presented in this specification shall also be understood to be disclosed in all possible combinations with each other, as far as it is technically reasonable and the example embodiments are not alternatives with respect to each other. It will further be understood that any feature presented for an example embodiment in a particular category (method/apparatus/computer program/system) may also be used in a corresponding manner in an example embodiment of any other category. It should also be understood that presence of a feature in the presented example embodiments shall not necessarily mean that this feature forms an essential feature and cannot be omitted or substituted.

The statement of a feature comprises at least one of the subsequently enumerated features is not mandatory in the way that the feature comprises all subsequently enumerated features, or at least one feature of the plurality of the subsequently enumerated features. Also, a selection of the enumerated features in any combination or a selection of only one of the enumerated features is possible. The specific combination of all subsequently enumerated features may as well be considered. Also, a plurality of only one of the enumerated features may be possible.

The sequence of all method steps presented above is not mandatory, also alternative sequences may be possible. Nevertheless, the specific sequence of method steps exemplarily shown in the figures shall be considered as one possible sequence of method steps for the respective embodiment described by the respective figure.

The subject-matter has been described above by means of example embodiments. It should be noted that there are alternative ways and variations which are obvious to a skilled person in the art and can be implemented without deviating from the scope of the appended claims.

List of abbreviations:

3GPP	Third Generation Partnership Project
5G	5-th Generation
AI	Artificial intelligence
BER	Bit Error Rate
CNN	Convolutional Neural Network
CSI	Channel State Information
CSI-RS	Channel State Information Reference Signals
CQI	Channel Quality Indicator
CRI	CSI-RS Resource Indicator

CNN	Convolutional Neural Network
DCI	Downlink Control Information
DMRS	Demodulation Reference Signals
DL	Downlink
FDD	Frequency Division Duplex
gNB	next generation NodeB
IE	Information Element
L1-RSRP	Layer 1 RSRP
MAC CE	MAC Control Element
MCS	Modulation Coding Scheme
ML	Machine Learning
MSE	Mean Square Error
MU	Multi User
NN	Neural Networks
NR	New Radio
PMI	Precoding Matrix Indicator
RAN	Radio Access Network
RB	Residual Block
RRC	Radio Resource Control
RS	Reference Signal
RSRQ	Reference Signal Received Quality
RSRP	Reference Signal Received Power
RSSI	Received Signal Strength Indicator
SU	Single User
SRS	Sounding Reference Signals
UCI	Uplink Control Indication
UE	User Equipment
UL	Uplink

Claims

1) A first apparatus comprising:
- means for obtaining channel measurements of a radio channel between the first apparatus and a second apparatus measured over a resource grid;
- means for generating a demodulation reference signal pattern over the resource grid based on the channel measurements; and
- means for transmitting, to the second apparatus, the generated demodulation reference signal pattern.

2. The first apparatus according to claim 1, wherein the demodulation reference signal pattern is generated by means of a trained machine learning algorithm fed with the channel measurements.

3. The first apparatus according to claim 1 or 2, wherein the first apparatus further comprises:
- means for receiving, from the second apparatus, at least one of:
  - a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
  - a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

4. The first apparatus according to any of claims 1 to 3, wherein the first apparatus further comprises:
- means for generating a plurality of demodulation reference signal patterns over the resource grid based on the channel measurements; and
- means for transmitting, to the second apparatus, the plurality of demodulation reference signal patterns,

wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion or to different channel recovery performances associated with the respective demodulation reference signal patterns.

5. The first apparatus according to claim 4, wherein the first apparatus further comprises:

- means for transmitting, to the second apparatus, a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

6. The first apparatus according to claim 4 or 5, wherein the first apparatus further comprises:
- means for transmitting the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns.

7. The first apparatus according to any of claims 1 to 6, wherein the channel measurements are performed based on a pre-determined demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the pre-determined demodulation reference signal pattern.

8. The first apparatus according to any of claims 1 to 7, wherein the first apparatus further comprises:
- means for transmitting, to the second apparatus, a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

9. The first apparatus according to any of claims 1 to 8, wherein the first apparatus further comprises:
- means for detecting a change in the radio channel;
- means for triggering a fallback onto a pre-determined demodulation reference signal pattern;
- means for generating a new demodulation reference signal pattern over the resource grid based on new channel measurements performed following the detection of the change in the radio channel, the new channel measurements being based on the pre-determined demodulation reference signal pattern..

10. The first apparatus according to any of claims 1 to 9, wherein the first apparatus further comprises:
- means for transmitting, to the second apparatus, one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus and tailored to the radio channel during past communication sessions between the first and second apparatuses.

11. A second apparatus comprising:
- means for receiving, from a first apparatus, a demodulation reference signal pattern over a resource grid, wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between the first and second apparatuses measured over the resource grid.

12. The second apparatus according to claim 11, wherein the second apparatus further comprises:

- means for receiving, from the first apparatus, a plurality of demodulation reference signal patterns,

wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for insertion of demodulation reference signals or to different channel recovery performances associated with the respective demodulation reference signal patterns.

13. The second apparatus according to claim 12, wherein the second apparatus further comprises:

- means for receiving, from the first apparatus, a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

14. The second apparatus according to claim 12 or 13, wherein the second apparatus further comprises:

- means for selecting a demodulation reference signal pattern from the plurality of demodulation reference signal patterns to achieve a given error performance metric,

wherein the error performance metric is determined based on at least one of:

- an effective number of resource elements used for insertion of demodulation reference signals in the selected demodulation reference signal pattern;
- a channel recovery performance for the selected demodulation reference signal pattern; and
- channel measurements of the radio channel.

15. The second apparatus according to any one of claims 12 to 14, wherein the second apparatus further comprises:

- means for receiving the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns.

16. The second apparatus according to any one of claims 11 to 15, wherein the second apparatus further comprises:

- means for transmitting, to the first apparatus, at least one of:
- a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
- a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

17. The second apparatus according to any one of claims 11 to 16, wherein the second apparatus further comprises:
- means for receiving, from the first apparatus, a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

18. The second apparatus according to any one of claims 11 to 17, wherein the second apparatus further comprises:
- means for receiving, from the first apparatus, one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus and tailored to the radio channel during past communication sessions between the first and second apparatuses.

19. A first method comprising:
- obtaining channel measurements of a radio channel between a first apparatus and a second apparatus measured over a resource grid;
- generating a demodulation reference signal pattern over the resource grid based on the channel measurements; and
- transmitting the generated demodulation reference signal pattern.

20. The first method according to claim 19, wherein the demodulation reference signal pattern is generated by means of a trained machine learning algorithm fed with the channel measurements.

21. The first method according to claim 19 or 20, wherein the first method further comprises:
- receiving at least one of:
  - a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
  - a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,

and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

22. The first method according to any of claims 19 to 21, wherein the first method further comprises:
- generating a plurality of demodulation reference signal patterns over the resource grid based on the channel measurements; and
- transmitting the plurality of demodulation reference signal patterns,

wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for demodulation reference signal insertion or to different channel recovery performances associated with the respective demodulation reference signal patterns.

23. The first method according to claim 22, wherein the first method further comprises:
- transmitting a third information element indicative of the channel recovery performances associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

24. The first method according to claim 22 or 23, wherein the first method further comprises:
- transmitting the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns.

25. The first method according to any of claims 19 to 24, wherein the channel measurements are performed based on a pre-determined demodulation reference signal pattern, and on successful decoding of data conveyed over the resource grid along with demodulation reference signals inserted following the pre-determined demodulation reference signal pattern.

26. The first method according to any of claims 19 to 25, wherein the first method further comprises:
- transmitting a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

27. The first method according to any of claims 19 to 26, wherein the first method further comprises:
- detecting a change in the radio channel;
- triggering a fallback onto a pre-determined demodulation reference signal pattern;
- generating a new demodulation reference signal pattern over the resource grid based on new channel measurements performed following the detection of the change in the radio channel, the new channel measurements being based on the pre-determined demodulation reference signal pattern..

28. The first method according to any of claims 19 to 27, wherein the first method further comprises:
- transmitting one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus and tailored to the radio channel during past communication sessions between the first and second apparatuses.

29. A second method comprising:
- receiving a demodulation reference signal pattern over a resource grid, wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between the first and second apparatuses measured over the resource grid.

30. The second method according to claim 29, wherein the second method further comprises:

- receiving a plurality of demodulation reference signal patterns,
wherein the plurality of demodulation reference signal patterns correspond to different maximum numbers of resource elements in the resource grid to be used for insertion of demodulation reference signals or to different channel recovery performances associated with the respective demodulation reference signal patterns.

31. The second method according to claim 30, wherein the second method further comprises:
- receiving a third information element indicative of the channel recovery performance associated with the respective demodulation reference signal patterns of the plurality of demodulation reference signal patterns.

32. The second method according to claim 30 or 31, wherein the second method further comprises:
- selecting a demodulation reference signal pattern from the plurality of demodulation reference signal patterns to achieve a given error performance metric,
wherein the error performance metric is determined based on at least one of:
- an effective number of resource elements used for insertion of demodulation reference signals in the selected demodulation reference signal pattern;
- a channel recovery performance for the selected demodulation reference signal pattern; and
- channel measurements of the radio channel.

33. The second method according to any one of claims 30 to 32, wherein the second method further comprises:
- receiving the plurality of demodulation reference signal patterns as nested demodulation reference signal patterns.

34. The second method according to any one of claims 29 to 33, wherein the second method further comprises:
- transmitting at least one of:
- a first information element indicative of a maximum number of resource elements in the resource grid to be used for insertion of demodulation reference signals; and
- a second information element indicative of a channel recovery performance associated with the demodulation reference signal pattern,
and wherein the demodulation reference signal pattern is generated further based on at least one of the first and second information elements.

35. The second method according to any one of claims 29 to 34, wherein the second method further comprises:

- receiving a fourth information element indicative of a capability of the first apparatus to generate a demodulation reference signal pattern tailored to the radio channel.

36. The second method according to any one of claims 29 to 35, wherein the second method further comprises:
- receiving one or more past demodulation reference signal patterns retrieved from a memory of the first apparatus and tailored to the radio channel during past communication sessions between the first and second apparatuses.

37. A system comprising a mobile entity or a part thereof and a server or a part thereof together performing the method according to any of the claims 19 to 36.

38. A computer program product, the computer program product when executed by a processor of an apparatus causing said apparatus to perform a method according to any of claims 19 to 36.

39. A computer program, the computer program when executed by a processor causing an apparatus to perform or control the actions of the method according any of claims 19 to 36.

40. A tangible and non-transitory storage medium comprising the computer program product according to claim 38.

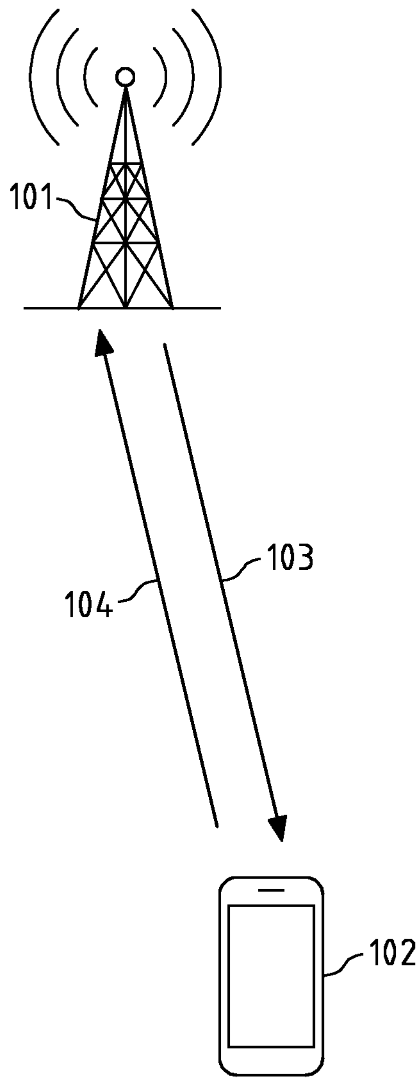


Fig.1

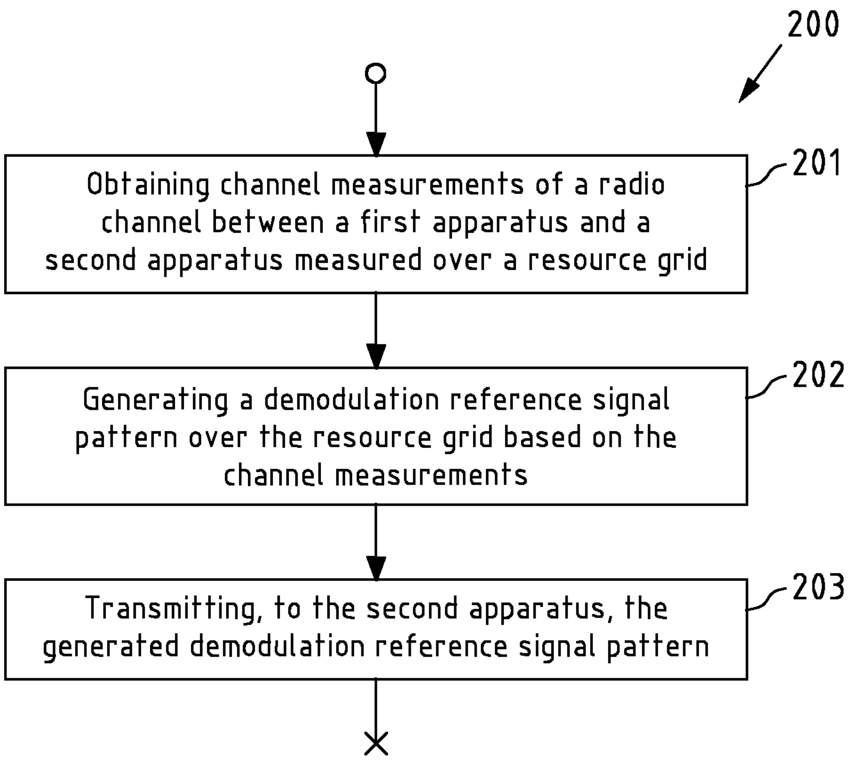

200
Obtaining channel measurements of a radio channel between a first apparatus and a second apparatus measured over a resource grid
201
Generating a demodulation reference signal pattern over the resource grid based on the channel measurements
202
Transmitting, to the second apparatus, the generated demodulation reference signal pattern
203

Fig.2

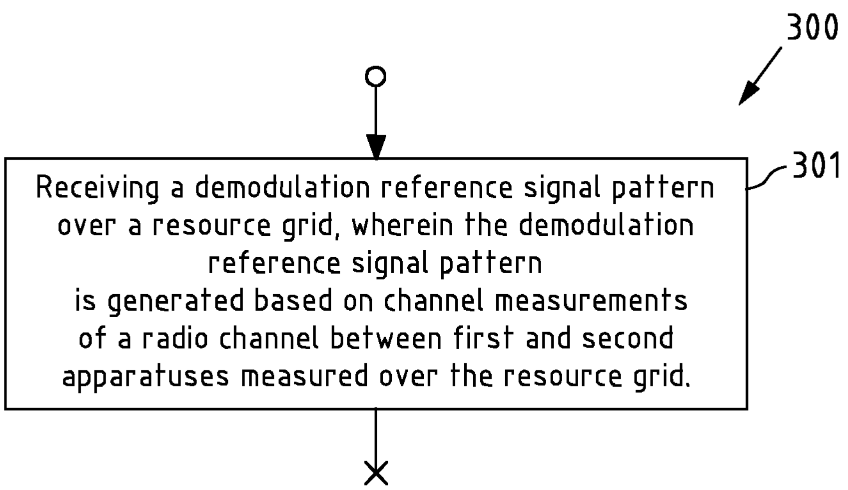

300
Receiving a demodulation reference signal pattern over a resource grid, wherein the demodulation reference signal pattern is generated based on channel measurements of a radio channel between first and second apparatuses measured over the resource grid.
301

Fig.3

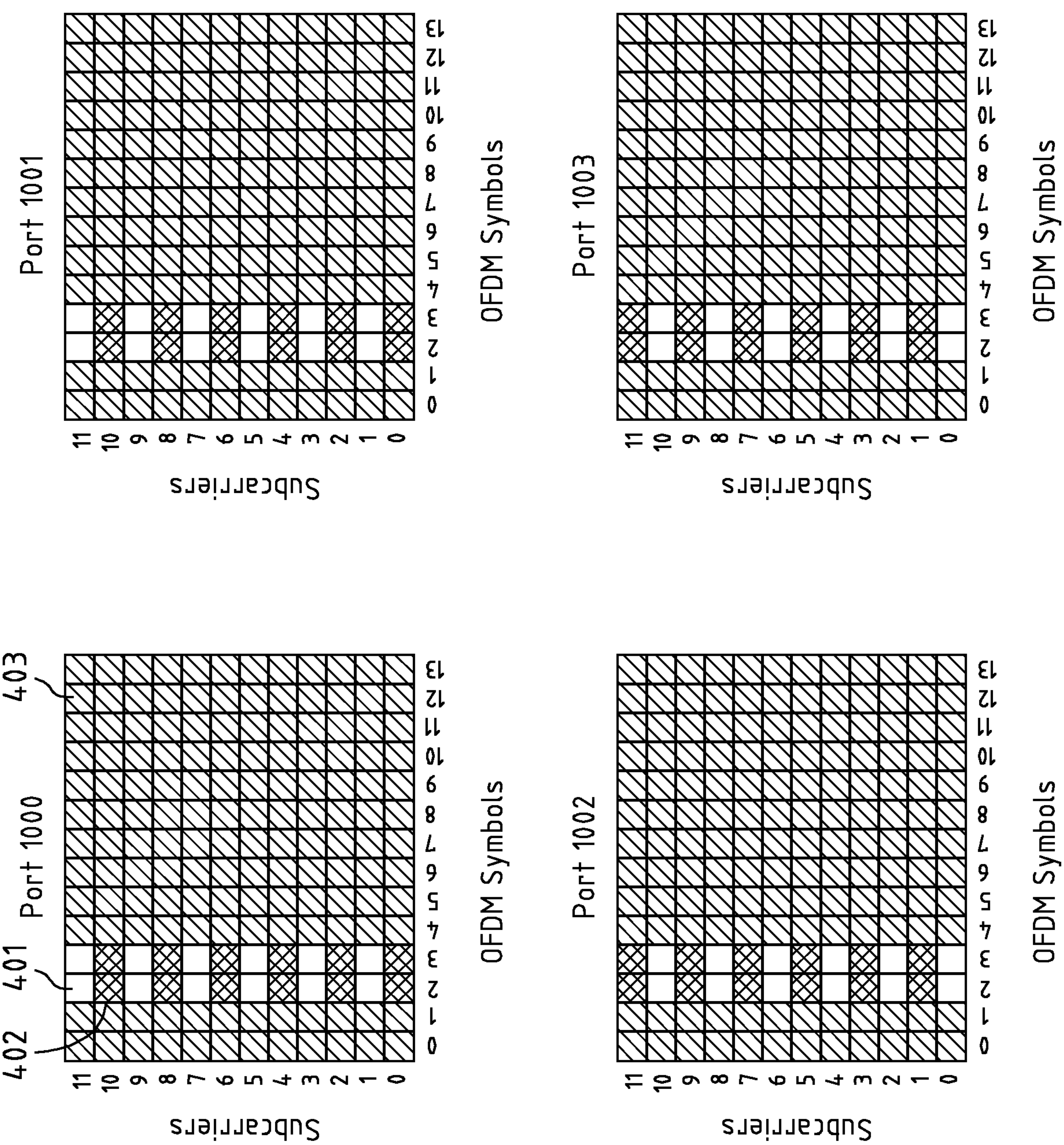

Port 1000
Port 1001
Port 1002
Port 1003
401
402
403
OFDM Symbols
Subcarriers
0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 1 2 3 4 5 6 7 8 9 10 11

Fig.4a

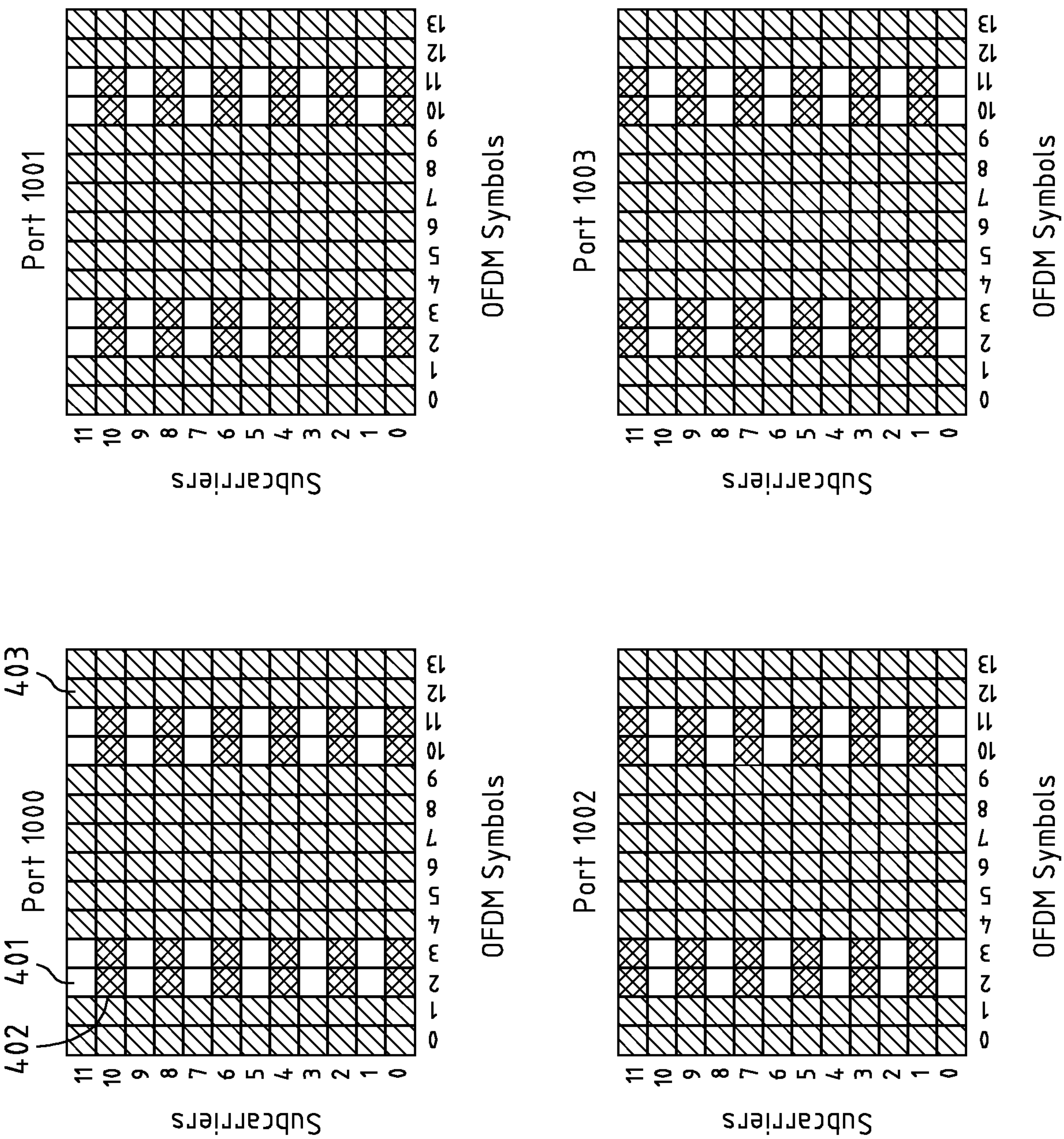
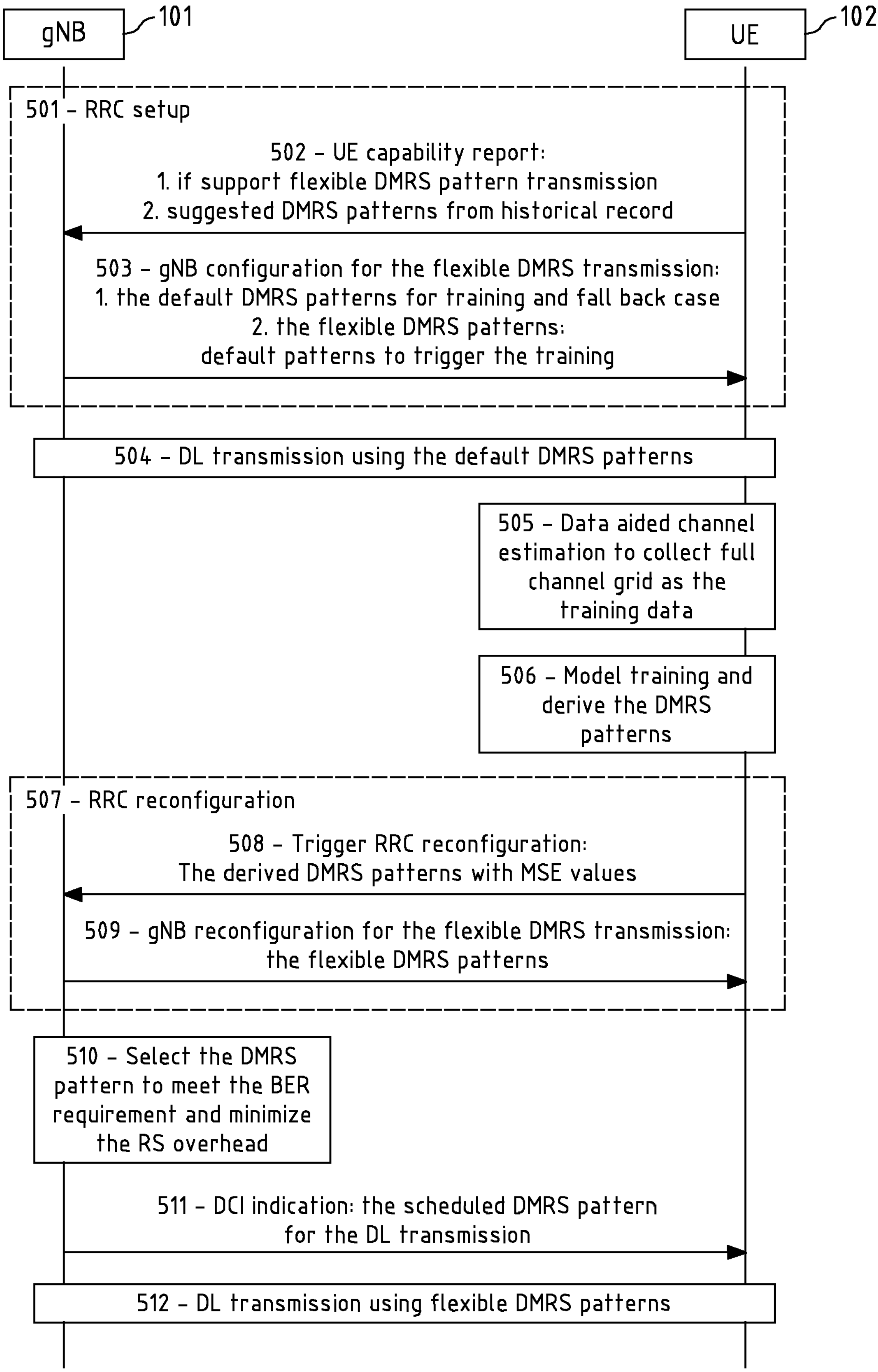

Port 1000
Port 1001
Port 1002
Port 1003
401
402
403
Subcarriers
OFDM Symbols
0 1 2 3 4 5 6 7 8 9 10 11 12 13
0 1 2 3 4 5 6 7 8 9 10 11

Fig.4b



gNB
101
UE
102
501 – RRC setup
502 – UE capability report:
1. if support flexible DMRS pattern transmission
2. suggested DMRS patterns from historical record
503 – gNB configuration for the flexible DMRS transmission:
1. the default DMRS patterns for training and fall back case
2. the flexible DMRS patterns:
default patterns to trigger the training
504 – DL transmission using the default DMRS patterns
505 – Data aided channel estimation to collect full channel grid as the training data
506 – Model training and derive the DMRS patterns
507 – RRC reconfiguration
508 – Trigger RRC reconfiguration:
The derived DMRS patterns with MSE values
509 – gNB reconfiguration for the flexible DMRS transmission:
the flexible DMRS patterns
510 – Select the DMRS pattern to meet the BER requirement and minimize the RS overhead
511 – DCI indication: the scheduled DMRS pattern for the DL transmission
512 – DL transmission using flexible DMRS patterns

Fig.5

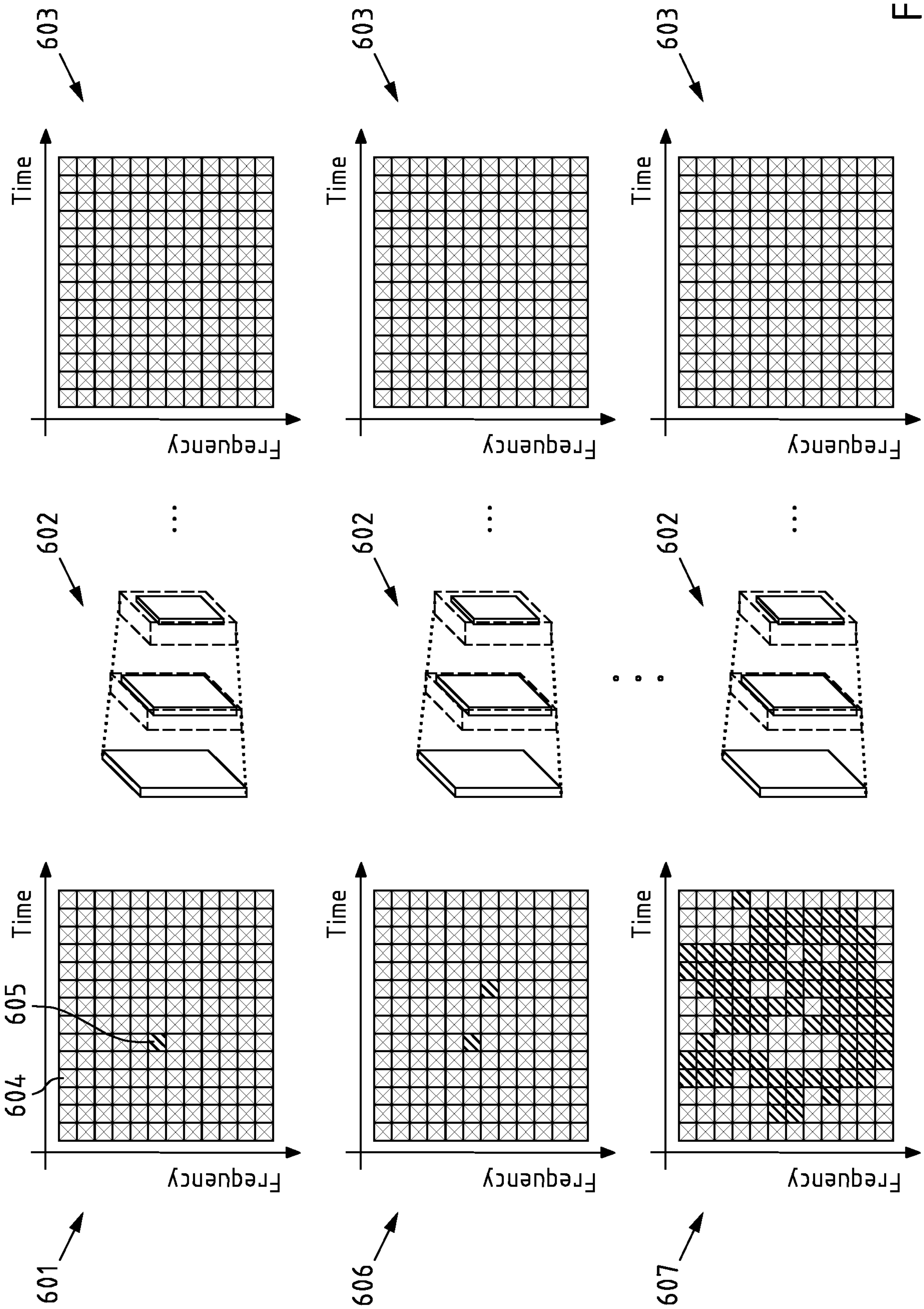


Fig.6

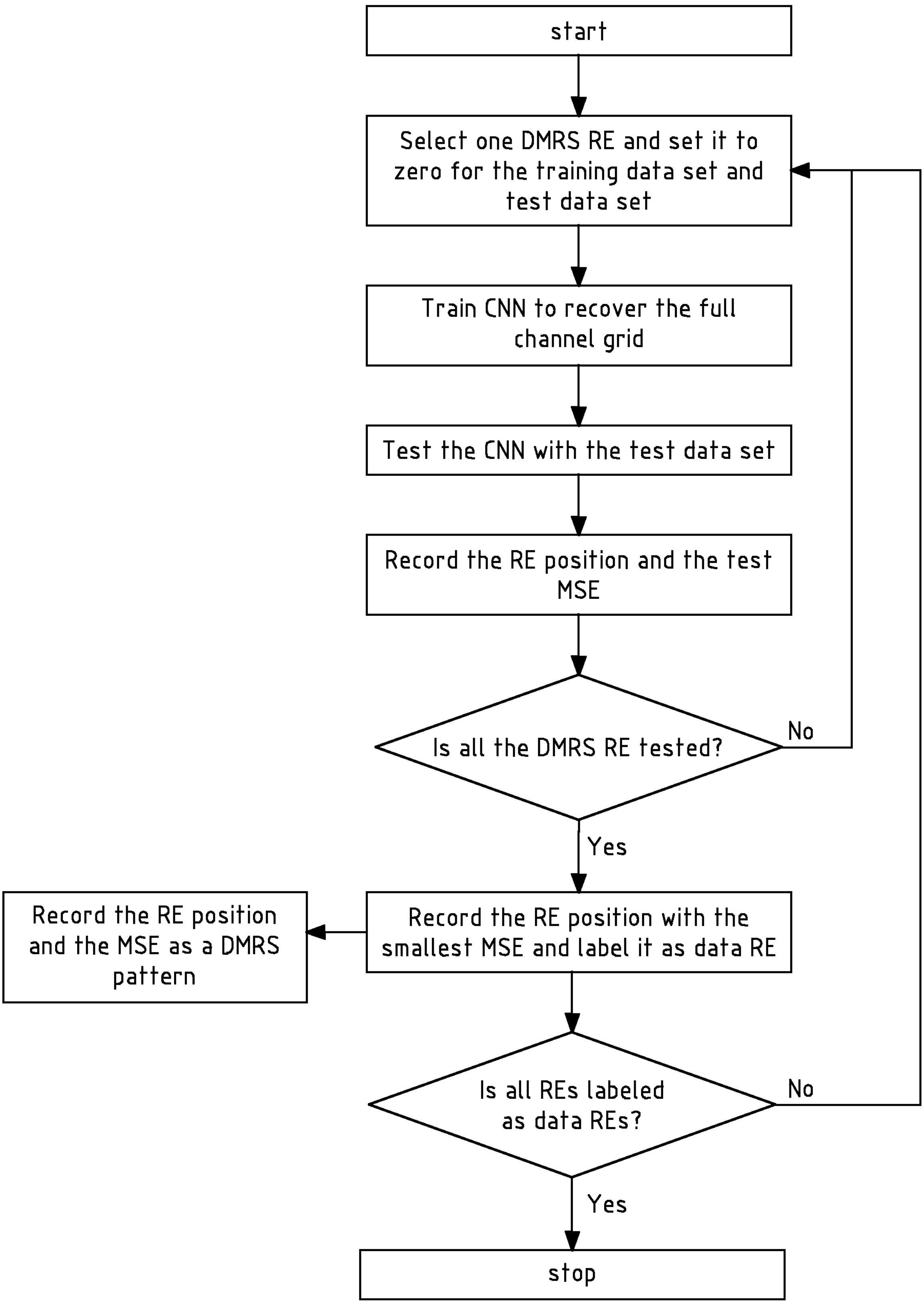

start
Select one DMRS RE and set it to zero for the training data set and test data set
Train CNN to recover the full channel grid
Test the CNN with the test data set
Record the RE position and the test MSE
Is all the DMRS RE tested?
No
Yes
Record the RE position with the smallest MSE and label it as data RE
Record the RE position and the MSE as a DMRS pattern
Is all REs labeled as data REs?
No
Yes
stop

Fig.7

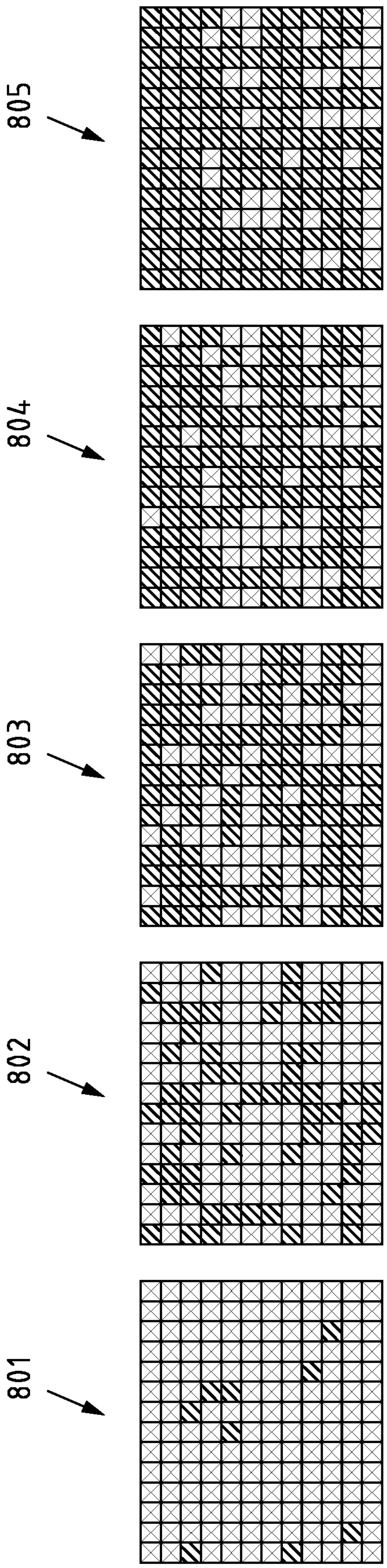


Fig.8a

MSE values	0,06	0,07	0,08	0,09	0,1
numbers of DMRS REs	159	109	67	50	35

Fig.8b

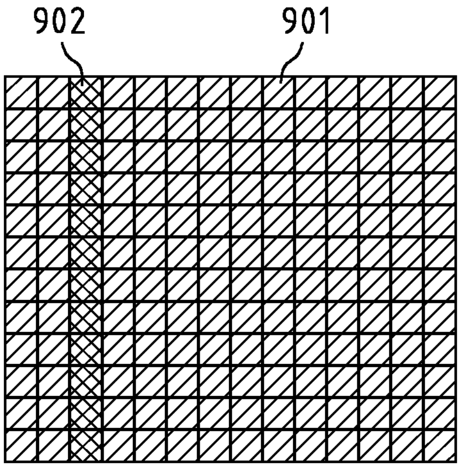


Fig.9a

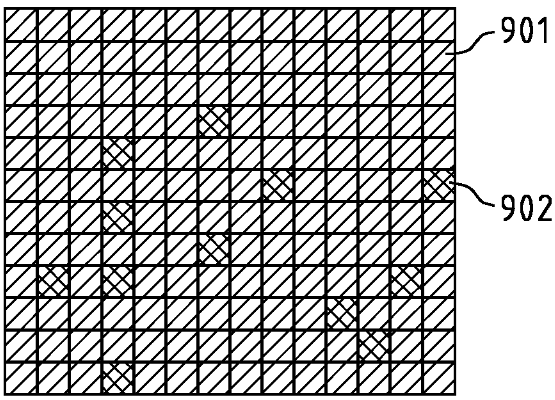


Fig.9b

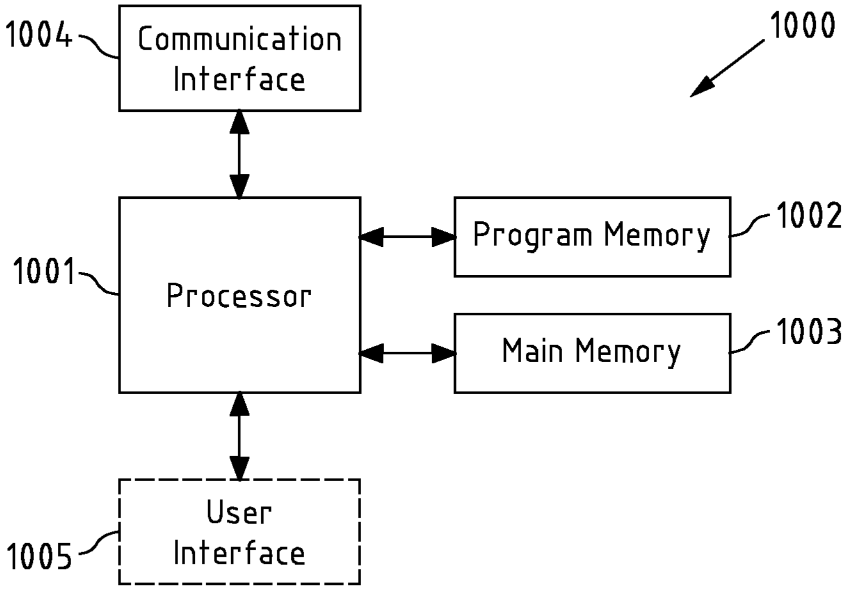

1000
1004
Communication Interface
1001
Processor
Program Memory
1002
Main Memory
1003
User Interface
1005

Fig.10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/080852

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L5/00 H04L25/02 H04L27/26
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, INSPEC, 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 2021/067290 A1 (CHEN TAO [CN] ET AL) 4 March 2021 (2021-03-04)	1,2, 9-11, 18-20, 27-29, 36-40
A	paragraph [0047] - paragraph [0048] paragraph [0051] - paragraph [0052] paragraph [0076] paragraph [0082]	3-8, 12-17, 21-26, 30-35

X	WO 2015/148041 A1 (INTEL IP CORP [US]) 1 October 2015 (2015-10-01)	1,11,19, 29,37-40
A	paragraph [0013] - paragraph [0014] paragraph [0022] - paragraph [0028]	2-10, 12-18, 20-28, 30-36

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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
5 June 2023	15/06/2023

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2022/080852

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2021067290 A1	04-03-2021	NONE	
WO 2015148041 A1	01-10-2015	CN 106063180 A	26-10-2016
		EP 3123654 A1	01-02-2017
		JP 6372724 B2	15-08-2018
		JP 2017515323 A	08-06-2017
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		US 2015282123 A1	01-10-2015
		WO 2015148041 A1	01-10-2015