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(71) Applicant: **NOKIA TECHNOLOGIES OY** [FI/FI];
Karaportti 3, Espoo 02610 (FI).

(71) Applicant (for LC only): **NOKIA TECHNOLOGIES
(BEIJING) CO., LTD.** [CN/CN]; Unit 18, Room 1001,
Level 10, East Tower, World Financial Center, No. 1,
East Third Ring Middle Road, Chaoyang District, Beijing
100020 (CN).

(72) Inventor: **MIAO, Deshan**; Room 903, Building 13, Lin-
heli, Tongzhou District, Beijing 101101 (CN).

(74) Agent: **KING & WOOD MALLESONS**; 20th Floor,
East Tower, World Financial Centre, No. 1 Dongsanhuan
Zhonglu, Chaoyang District, Beijing 100020 (CN).

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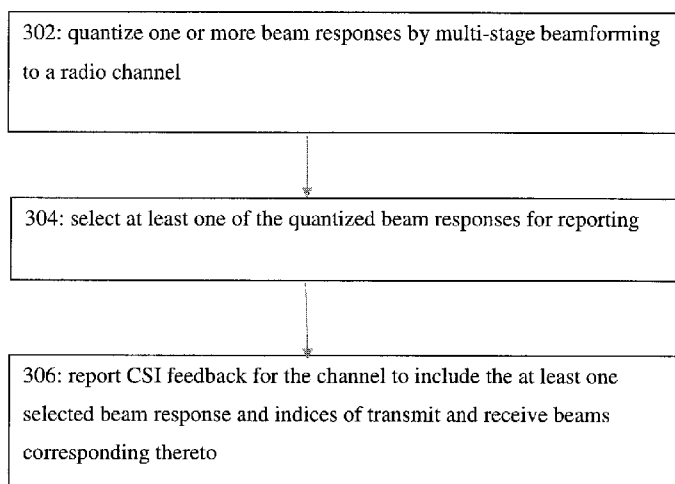


FIG. 3

(57) Abstract: Reporting channel state information (CSI) with reduced overhead is particularly valuable for 5G and similar systems with multiple antennas. For a downlink channel a user equipment quantizes one or more beam responses by multi-stage beamforming, selects at least one of the quantized beam responses for reporting; and reports CSI feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto. In a specific example this multi-stage beamforming includes a first stage transmit beamforming and a second stage receiving beamforming, such that each of the quantized beam responses is for one beam pair comprising one transmit beam and one receive beam; and the quantized beam responses that are selected and reported are only for beam pairs.

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EXPLICIT CHANNEL STATE INFORMATION FEEDBACK

TECHNOLOGICAL FIELD:

- 5 [0001] The described invention relates to wireless communications, and more particularly to the reporting of explicit channel state information concerning joint beam optimization, and the underlying computations for such reporting.

10 BACKGROUND:

- [0002] Wireless radio access technologies continue to be improved to handle increased data volumes and larger numbers of subscribers. The 3GPP organization is developing 5th Generation (5G) wireless networks to handle peak data rates of the order of ~10Gbps (gigabits per second) while still satisfying ultra-low latency requirements in existence for certain 4G applications. 5G intends to
15 utilize radio spectrum on the order of GHz or more in the millimeter-wave (mmWave) band; and also to support massive MIMO (m-MIMO). M-MIMO systems are characterized by a much larger number of antennas as compared to 4G systems, as well as finer beamforming resolution and a higher antenna gain.

- 20 [0003] Feedback of channel state information (CSI) is an important aspect to realize MIMO performance gain. In Rel-14 there is an ongoing study of advanced CSI feedback and in 5G (currently termed in 3GPP as ‘new radio’) there is ongoing discussions on how to implement a high resolution CSI feedback. In traditional explicit CSI feedback, channel coefficient or covariance matrix are quantized per antenna element/port and these coefficients are what is reported to the network base
25 station. Conventionally the explicit CSI feedback is most often either based on eigen-vectors or on a covariance matrix; both of these approaches utilize per antenna element quantization. But the overhead for these techniques becomes quite large as the number of antenna ports increases.

- [0004] Since Rel-14, the beam space reduced CSI feedback has been occasionally discussed in
30 3GPP, where typically the N strongest beams will be selected to approximate the eigen-vector of the channel matrix (or of the channel matrix itself). One problem with this approach is it considers only the transmit (TX) beam and not at all the receiving (RX) beam.

- [0005] Recent discussions within 3GPP concerning the 5G new radio system consider a beam-
35 based explicit feedback, and one option there concerns quantization based on the beam space. Specifically, the following different explicit CSI feedback schemes with a reduced beam space have been presented at 3GPP TSG RAN WG1 #86 in Gothenburg, Sweden on 22-26 August 2016:

- R1-167197 by Huawei and HiSilicon entitled *CSI acquisition mechanism for NR DL MIMO*;
- R1-167643 by Ericsson entitled *Explicit versus implicit feedback for advanced CSI reporting*; and
- R1-166784 by Samsung entitled *Simulation results for explicit CSI feedback for NR MIMO*.

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[0006] While these teachings are not limited only to the 5G/new radio effort at the 3GPP, the explicit feedback method based on TX beam and RX beam joint optimization described below is suitable for that purpose and for others.

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SUMMARY:

[0007] According to a first aspect of these teachings there is a method comprising: quantizing one or more beam responses by multi-stage beamforming to a radio channel; selecting at least one of the quantized beam responses for reporting; and reporting report channel state information (CSI) feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto.

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[0008] According to a second aspect of these teachings there is an apparatus such as a radio access node comprising at least one computer readable memory storing executable computer program instructions and at least one processor. The computer readable memory with the computer program instructions is configured, with the at least one processor, to cause the apparatus to at least quantize one or more beam responses by multi-stage beamforming to a radio channel; select at least one of the quantized beam responses for reporting; and report CSI feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto.

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[0009] According to a third aspect of these teachings there is a non-transitory computer readable memory tangibly storing program code that when executed by at least one processor causes a host apparatus to perform actions comprising: quantizing one or more beam responses by multi-stage beamforming to a radio channel; selecting at least one of the quantized beam responses for reporting; and reporting report CSI feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto.

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[0010] According to a fourth aspect of these teachings there is an apparatus such as a radio access node comprising means for quantizing one or more beam responses by multi-stage beamforming to a radio channel; means for selecting at least one of the quantized beam responses for reporting; and means for reporting CSI feedback for the channel to include the at least one selected

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beam response and indices of transmit and receive beams corresponding thereto. In an example embodiment the means for reporting is a radio transmitter while the means for quantizing and means for selecting are implemented as circuitry. In another embodiment the quantization and selection means are implemented as computer-executable software. In a further embodiment the quantization and selection means are implemented as a general purpose processor or a digital signal processing processor. In a still further embodiment the quantization and selection means are implemented as a combination of one or more processors in combination with computer executable software stored on one or more computer readable memories.

[0011] These and other aspects are detailed further below with particularity.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0012] FIG. 1 is a plan view of a base station and a user equipment depicting transmit beams of the base station in spatial relation to receive beams of the user equipment to illustrate joint transmit/receive beam quantization as described herein.

[0013] FIG. 2 is following the principle of FIG. 1 but illustrating the joint beam quantization more specifically from channel quantization prospective.

[0014] FIG. 3 is a process flow diagram summarizing certain aspects of the invention from the perspective of a user equipment/mobile device.

[0015] FIG. 4 is a diagram illustrating some components of a radio network access node/base station and a UE/mobile device, each of which are suitable for practicing various aspects of the invention.

DETAILED DESCRIPTION:

[0016] FIG. 1 is a conceptual diagram of the relevant radio environment between one base station (BS) 20 and one user equipment (UE) 10 showing a MIMO channel and beamforming relationship, particularly defined by a number of transmit beams and a number of receive beams.

[0017] FIG. 2 is a plan view to illustrate the channel quantization principle., more particularly showing four transmit (TX) beams A through D for the base station (BS) 20 and three receive (RX) beams 1 through 3 for the user equipment (UE) 10. Any one of the BS TX beams may be matched with any one of the UE RX beams. In practice the individual UE will typically 'sweep' its RX beams

across the BS's various TX beams to find a best match or the best matches, as generally known in the art. For one wireless channel, if using beamforming technique, after transmit beam in transmitter side and receive beam in receiver side, UE will get one beam response of joint transmit beam and receive beam to this wireless channel. Similarly, if UE gets one wireless channel firstly, no matter that this channel is beamformed or non-beamformed, UE can re-conduct transmit beamforming and receive beamforming in UE side to received channel information, still, one joint beam response can be gotten. Therefore, joint beamforming technique can be used to do channel quantization.

[0018] FIG. 2 illustrates one example channel beamforming structure. It means for one wireless channel, through TX beam and RX beam the UE can do two-fold beamforming, in order for the UE to get one joint beam response for each TX beam and RX pair. In another aspect, according to beam sampling theory, for one N*M wireless channel, the minimal TX sampling beam number is 2N, similarly, due to M RX antenna, the minimal RX sampling beam number is 2M. Based on beam sampling principle, it is possible to utilize the joint TX and RX beam pairing to quantize the channel coefficient and reconstruct the channel coefficient.

[0019] More specifically, these teachings focus on explicit reporting of CSI and the information that is reported is based on a joint optimization of TX beams with RX beams. In a specific but non-limiting embodiment there is a TX beam and RX beam joint quantization mechanism to implement CSI quantization and reporting.

[0020] First, the UE calculates the beam responses of TX beams and RX beams respectively, based on predefined beam vectors and estimated downlink channel coefficients. These pre-defined beam vectors may be orthogonal or non-orthogonal. It is well known in the art how the UE can estimate the downlink channel coefficients; in LTE the UE can use CSI reference signals and/or common reference signals depending on its time/frequency channel coherence which generally corresponds to whether the UE is fast or slow moving. In the current development of 5G there have been presented for consideration variations on the LTE approach as well as new approaches for reference signals the UE utilizes to estimate its channel and the relevant parameters that represent it.

[0021] More specifically, the UE can compute one by one each TX beam response based on the computation rule:

$$\alpha_i = \mathbf{H} * \mathbf{W}_i ;$$

where H is channel matrix, α_i is the respective TX beam response, and $\mathbf{W}_i$ is the predefined TX beam vector.

[0022] Next the UE selects the biggest K TX beams based on response power (that is, from among all the N TX beams select the K beams having the highest response power). This beam selection can easily impact the quantization accuracy; if more beams are reported that naturally means more overhead but enables the channel estimates to approach the true channel coefficient. In theory, infinite beam quantization will approach ideal channel information. So there is a trade-off. In this case the trade-off can be optimized by determining a suitable strength threshold; for example the K TX beams are the TX beam with the highest beam response strength and among these selected beams, the least beam response strength is not less than 10 dB than the beam response strength of the big beam. Only the beams exceeding that power threshold can be reported.

[0023] For each TX beam from among these K TX beams, the UE can then compute the RX beam response, for example based on the computation rule:

$$\beta_j = V_j * H * W_i;$$

where β_j is the RX beam response to each TX beam, and V_j is the predefined beam vector. To quantize this beam response coefficient β_j it is preferred to quantize both the beam response coefficient phase and amplitude information. In order to reduce signaling overhead, joint quantization for beam response could be used; for example by using quadrature amplitude modulation (QAM) constellation point to estimate/approach the beam response coefficients. In order to scale the beam response power, a relative power offset can be used for amplitude quantization and explicit CSI reporting.

[0024] Next the UE can select the biggest L RX beam responses for each selected TX beam (the L beams having the highest response power from among all the M RX beams), and quantize the beam response β_j for reporting. The end result is that the explicit CSI report sent by the UE 10 to the base station 20 includes the following information:

- the selected TX beam indexes and RX beam indexes; and
- the quantized beam responses.

[0025] More specifically, the total explicit CSI feedback content includes:

- K TX beam indices (optionally),
- K*L RX beam pair indices, and
- K*L quantized beam responses.

[0026] Assuming N=4 and M=3 as in FIG. 2, and further assuming that K=3 and L=2, the UE would make the following computations and decisions.

- compute α_i for each of TX beams A, B, C and D of FIG. 2 (total 4 computations)

- select $K=3$ highest α_i ; assume this selects TX beams A, B and C of FIG. 2.
- compute β_j for each of RX beams 1, 2 and 3 of FIG. 2 with respect to each of TX beams A, B and C (total 9 computations).
- select $L=2$ highest β_j for each of the K TX beams.

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[0027] For the example immediately above the UE's explicit CSI report would include the following information:

- Beam indices only for TX beams A, B and C.
- Beam pair indices only for the $L=2$ best RX beams for each of the $K=3$ TX beams.

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- Exactly six quantized beam responses of those beam pair indices

[0028] In another example $L=M$ meaning the number of RX beams being reported is not down-selected. Substituting $L=3$ in the above example, the total explicit CSI feedback content would then include:

- K TX beam indices (for TX beams A, B and C),
- $K*M$ RX beam pair indices (all of the $L=M=3$ RX beams for each of the $K=3$ TX beams), and
- $K*M$ quantized beam responses (exactly nine beam responses).

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[0029] Since each RX beam response β_j is for exactly one RX beam with respect to exactly one TX beam, the RX beam responses may be considered as a joint beam responses for a given RX and TX beam pair. Since only the best joint beam responses per selected TX beam are selected for reporting as explicit CSI these joint beam responses may be considered as the optimized ones. In above example two-step beam selection would can simplify the UE behavior, where beam selection is based on TX beam response strength in the first step, and based on RX beam strength in second step. In case of joint TX and RX beam pairing selection, it possibly tracks all possible beam combinations, and then it will cause more computation complexity, but likely give more accurate beam pair selection.

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[0030] The values for K and L may be set by the radio network/base station. For example, the BS 20 may broadcast system information that specifies specific values for K and L , or that specifies a threshold response power that the UE uses when selecting which ones of all the TX beams will be among the selected K TX beams and which ones of all the RX beams will be among the selected L RX beams if in fact L is less than M . This system information may specify one threshold response power for both TX and RX beams, or more preferably specifies different response powers for selecting the K TX beams (and the L RX beams if $L < M$). Alternatively, the values or thresholds may be published in a specification for the operative radio access technology.

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[0031] The above approach represents a substantial overhead reduction as compared to prior art explicit CSI reporting techniques such as reporting the channel coefficient or covariance matrix per antenna element. Signaling overhead can be further reduced by restricting the beam set so the UE's explicit CSI report would not need to include the beam indices at all. Restricting the beam set means the BS and UE will have one negotiation to determine a fixed TX and RX beam set, for example according to the UE's previous selection in a previous CSI report. That fixed TX and RX beam set will be operative until the channel environment changes and until then there is no need to re-report the beam indices.

[0032] The BS 20 receives the UE's explicit CSI report and can reconstruct the channel matrix according to the reported parameters. For example, using the explicitly reported joint beam responses β_j the BS 20 can reconstruct the downlink channel that the UE is reporting on using the following derivation:

$$\beta_j = V_j * H * W_i \quad \Rightarrow \quad H \approx \sum_{i=1 \dots K}^{j=1 \dots M} (V_j)^H * \beta_j * (W_i)^H / \Omega;$$

where Ω is a normalized factor. Thus the BS 20 can construct the channel coefficient using one set of beam responses and the related TX/RX beam weights. Preferably the UE 10 and BS 20 share these beam weights. In one example these beam weights could be predefined in a published specification for the operative radio access technology, or alternatively the BS will inform the UE and UE will down-select a useful beam set according to its channel status.

[0033] Certain embodiments of these teachings provide the technical effect of improving channel quantization accuracy according to TX beam and RX beam joint quantization. A further technical effect is a significant reduction in signaling overhead as compared to a per-antenna element reporting scheme, at least when there is a large number of TX and RX antenna ports as is true for the 5G new radio system currently under development.

[0034] FIG. 3 is a flow diagram from the perspective of the user equipment (UE) and summarizes some of the above features described more particularly above, where for a radio channel at block 302 the UE quantizes one or more beam responses by multi-stage beamforming to a radio channel (for example, a joint beam response for each a plurality of beam pairs, each beam pair comprising one transmit beam and one receive beam). Then at block 304 the UE selects at least one of the quantized beam responses for reporting; and at block 306 reports (explicit) CSI feedback for the channel to include the at least one selected beam response and indices of the corresponding transmit and receive beams.

[0035] In one particular embodiment the multi-stage beamforming of block 302 includes a first stage transmit beamforming and a second stage receiving beamforming, and each of the quantized beam responses is for one beam pair comprising one transmit beam and one receive beam. In this case the selecting at block 304 includes selecting from the quantized beam responses only one or more beam pairs for reporting. In a particular example of this above, the channel is defined by N transmit beams and M receive beams, and quantizing the one or more beam responses at block 302 comprises: selecting from among the N transmit beams a number K of the transmit beams that exhibit a best channel response (this is the first stage); and for each of the respective K transmit beams, selecting from among the M receive beams a number L of the receive beams that exhibit a best channel response for the respective transmit beam (this is the second stage. In this specific example N, M, K and L are each integers greater than one, K is less than N, and L is no more than M. In that example the quantizing at the second stage of block 302 was for each of the K transmit beams with respect to each of the correspondingly selected L receive beams; and the reported CSI feedback for the channel included:

- the quantized joint beam responses only for each of the K transmit beams with respect to each of the correspondingly selected L receive beams; and at least one of
 - indications identifying only the K transmit beams; and
 - indications identifying for only each of the K transmit beams only the corresponding L receive beams.

[0036] In another example detailed further below, a receiving beam vector corresponding to one receiver beam is equal to one vector comprising of one-zero element and M-1 zeros (as above, M is an integer greater than one corresponding to the number of receiver antennas). In this case each quantized beam response is for a transmit beam and a receiver beam pair, and further is equal to one receiver antenna channel coefficient with transmit beamforming.

[0037] Also as further detailed below, the multi-stage beamforming at block 302 comprises in a first stage using multiple wide beams and in a second stage using multiple narrow beams to quantize multiple beam responses. In this example the selecting at block 304 comprises selecting a beam group and from among only one beam group selecting for reporting at least one quantized beam response for one of the wide beams and one of the narrow beams. In this case the reported CSI feedback at block 306 includes the quantized beam responses that are selected only from among the (selected) one beam group.

[0038] In the above examples the channel for which the CSI is reported is a downlink channel. For the channel information to quantized, it could be equal to one channel information of one resource

element, or one average channel information of one subband, or any other transformation of measured channel information.

[0039] For the above TX beam and RX two-stage based beam quantization, it could be extended to other multi-staged beam quantization methods. As one alternative, it could be implemented as firstly using one wideband beam to quantize it, then after that first level beam quantization, we can use a narrow beam to further quantize it, then the multi-stage based beam quantization can reduce feedback overhead and improve accuracy. As one example:

- Channel information can be expressed as
 - $H(\text{quantized channel information}) = \beta_1 * W_1 + \beta_2 * W_2$,
 - W_1 is one wide beam vector, W_2 is one narrow beam vector, in other words, W_1 is one large granularity beam, and W_2 is one finer beam.
 - β_1, β_2 is the beam response respectively.
- In real application, selected wide beam is not limited to one, and selected narrow beam could be multiple. UE needs to select and report one beam group including one or multiple wide beams, and one or multiple narrow beams according to beam response strength. Normally UE will firstly select one few of wide beams, then according to quantization error with the real channel information, further select a few of narrow beams. These beam vectors of wide beam and narrow beam should be predefined and known by the UE and base station.
- In the above formula, it only describes the principle of multiple granularity beams constructing the channel information. When it combines with the transmission beam and receiver beam joint quantizing the channel information, no matter in TX beamforming or RX beamforming, a wide beam and narrow beam combination could be used.

[0040] When the UE antenna number is larger, the received beamforming can reduce the quantization overhead, not coupled with the RX antenna number. When the UE antenna number is small, we could simplify the beam vectors as $[1 \ 0]$ or $[1 \ 0]$ if two RX antennas are equipped, then it falls back to RX antenna coefficient quantization, so here we can provide one scalable CSI quantization solution. For transmit beam and receiver beam pairing used, receiver beamforming will lose its functionality, only transmit beam is effective. This is due to only one non-zero element in the RX beam vector, so it becomes the per antenna quantization. But these RX beam vectors are not needed to select, they can be just pre-defined.

[0041] For one 4 receiver antenna case, the beam vector could for example be expressed as

$[1 \ 0 \ 0 \ 0], [0 \ 1 \ 0 \ 0], [0 \ 0 \ 1 \ 0], [0 \ 0 \ 0 \ 1]$

[0042] Any or all of these aspects of the invention with respect to FIG. 3 can be embodied as a computer readable memory tangibly storing a computer program that when executed causes a mobile device/UE to perform the actions described above and in that figure.

5 [0043] These teachings can further be embodied as an apparatus, such as a mobile device/UE, or components thereof. Such apparatus can comprise at least one processor and at least one memory storing an executable computer program. In this embodiment the at least one processor is configured with the at least one memory and the computer program to cause the apparatus to perform the actions described above for FIG. 3.

10 [0044] FIG. 3 may further be considered as an algorithm, and more generally represents steps of a method, and/or certain code segments of software stored on a computer readable memory or memory device that embody the FIG. 3 algorithm for implementing these teachings from the perspective of that UE. In this regard the invention may be embodied as a non-transitory program
15 storage device readable by a machine such as for example one or more processors of a UE, where the storage device tangibly embodies a program of instructions executable by the machine for performing operations such as those shown at FIG. 3 and detailed above.

[0045] FIG 3 is a high level diagram illustrating some relevant components of various
20 communication entities that may implement various portions of these teachings, including a base station identified generally as a radio network access node 20, a mobility management entity (MME) which may also be co-located with a user-plane gateway (uGW) 40, and a user equipment (UE) 10. In the wireless system 330 of FIG. 3 a communications network 335 is adapted for communication over a wireless link 332 with an apparatus, such as a mobile communication device which may be
25 referred to as a UE 10, via a radio network access node 20. The network 335 may include a MME/Serving-GW 40 that provides connectivity with other and/or broader networks such as a publicly switched telephone network and/or a data communications network (e.g., the internet 338).

[0046] The UE 10 includes a controller, such as a computer or a data processor (DP) 314 (or
30 multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) 316 (or more generally a non-transitory program storage device) that stores a program of computer instructions (PROG) 318, and a suitable wireless interface, such as radio frequency (RF) transceiver or more generically a radio 312, for bidirectional wireless communications with the radio network access node 20 via one or more antennas. In general terms the UE 10 can be considered a machine
35 that reads the MEM/non-transitory program storage device and that executes the computer program code or executable program of instructions stored thereon. While each entity of FIG. 3 is shown as having one MEM, in practice each may have multiple discrete memory devices and the relevant

algorithm(s) and executable instructions/program code may be stored on one or across several such memories.

[0047] In general, the various embodiments of the UE 10 can include, but are not limited to, mobile user equipments or devices, cellular telephones, smartphones, wireless terminals, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, specific-function personal devices (such as digital cameras, gaming devices, music storage and playback appliances, etc.) having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, as well as portable units or terminals that incorporate combinations of such functions.

[0048] The radio network access node 20 also includes a controller, such as a computer or a data processor (DP) 324 (or multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) 326 that stores a program of computer instructions (PROG) 328, and a suitable wireless interface, such as a RF transceiver or radio 322, for communication with the UE 10 via one or more antennas. The radio network access node 20 is coupled via a data/control path 334 to the MME 40. The path 334 may be implemented as an S1 interface. The radio network access node 20 may also be coupled to other radio network access nodes via data/control path 336, which may be implemented as an X5 interface.

[0049] The MME 340 includes a controller, such as a computer or a data processor (DP) 344 (or multiple ones of them), a computer-readable memory medium embodied as a memory (MEM) 346 that stores a program of computer instructions (PROG) 348.

[0050] At least one of the PROGs 318, 328 is assumed to include program instructions that, when executed by the associated one or more DPs, enable the device to operate in accordance with exemplary embodiments of this invention. That is, various exemplary embodiments of this invention may be implemented at least in part by computer software executable by the DP 314 of the UE 10; and/or by the DP 324 of the radio network access node 20; and/or by hardware, or by a combination of software and hardware (and firmware).

[0051] For the purposes of describing various exemplary embodiments in accordance with this invention the UE 10 and the radio network access node 20 may also include dedicated processors 315 and 325 respectively.

[0052] The computer readable MEMs 316, 326 and 346 may be of any memory device type suitable to the local technical environment and may be implemented using any suitable data storage

technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The DPs 314, 324 and 344 may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on a multicore processor architecture, as non-limiting examples. The wireless interfaces (e.g., RF transceivers 312 and 322) may be of any type suitable to the local technical environment and may be implemented using any suitable communication technology such as individual transmitters, receivers, transceivers or a combination of such components.

[0053] A computer readable medium may be a computer readable signal medium or a non-transitory computer readable storage medium/memory. A non-transitory computer readable storage medium/memory does not include propagating signals and may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. Computer readable memory is non-transitory because propagating mediums such as carrier waves are memoryless. More specific examples (a non-exhaustive list) of the computer readable storage medium/memory would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing.

[0054] The UE 10 may be considered to include quantization means for quantizing one or more beam responses by multi-stage beamforming to a radio channel, selection means for selecting at least one of the quantized beam responses for reporting, and transmitting means for reporting CSI feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto, as set forth above with respect to FIG. 3. In an example embodiment the transmitting means is a radio as shown at FIG. 4 or more specifically a radio transmitter. The quantization and selection means may be implemented as circuitry; or in another embodiment they may be implemented as computer-executable software; or in a further embodiment they may be implemented as a general purpose processor or a digital signal processing processor. In a still further embodiment the quantization and selection means may be implemented as a combination of one or more processors in combination with computer executable software stored on one or more computer readable memories.

[0055] It should be understood that the foregoing description is only illustrative. Various alternatives and modifications can be devised by those skilled in the art. For example, features recited

in the various dependent claims could be combined with each other in any suitable combination(s). In addition, features from different embodiments described above could be selectively combined into a new embodiment. Accordingly, the description is intended to embrace all such alternatives, modifications and variances which fall within the scope of the appended claims.

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[0056] A communications system and/or a network node/base station may comprise a network node or other network elements implemented as a server, host or node operationally coupled to a remote radio head. At least some core functions may be carried out as software run in a server (which could be in the cloud) and implemented with network node functionalities in a similar fashion as much as possible (taking latency restrictions into consideration). This is called network virtualization. “Distribution of work” may be based on a division of operations to those which can be run in the cloud, and those which have to be run in the proximity for the sake of latency requirements. In macro cell/small cell networks, the “distribution of work” may also differ between a macro cell node and small cell nodes. Network virtualization may comprise the process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network. Network virtualization may involve platform virtualization, often combined with resource virtualization. Network virtualization may be categorized as either external, combining many networks, or parts of networks, into a virtual unit, or internal, providing network-like functionality to the software containers on a single system.

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[0057] Below are some acronyms used herein:

	3GPP	third generation partnership project
	BS	base station (including NodeB and enhanced NodeB=eNB)
	CSI	channel state information
25	DL	downlink
	MME	mobility management entity
	MIMO	multiple-input multiple output
	mmWave	millimeter wave
	OFDM	orthogonal frequency division multiplex
30	RF	radiofrequency
	RX	receive
	TX	transmit
	UE	user equipment
	UL	uplink

WHAT IS CLAIMED IS:

1. A method comprising:
quantizing one or more beam responses by multi-stage beamforming to a radio channel,
5 selecting at least one of the quantized beam responses for reporting; and
reporting channel state information (CSI) feedback for the channel to include the at least one
selected beam response and indices of transmit and receive beams corresponding thereto.
2. The method according claim 1, wherein the multi-stage beamforming includes a first stage
10 transmit beamforming and a second stage receiving beamforming; and wherein
each of the quantized beam responses is for one beam pair comprising one transmit beam and
one receive beam; and wherein the selecting includes selecting from the quantized beam responses
only one or more beam pairs for reporting.
3. The method according to claim 2, wherein the channel is defined by N transmit beams and M
15 receive beams, and quantizing the one or more beam responses comprises:
selecting from among the N transmit beams a number K of the transmit beams that exhibit a
best channel response; and
for each of the respective K transmit beams, selecting from among the M receive beams a
20 number L of the receive beams that exhibit a best channel response for the respective transmit beam;
wherein N, M, K and L are each integers greater than one, K is less than N, and L is no more than M.
4. The method according to claim 3, wherein the quantizing further comprises:
quantizing a joint beam response for each of the K transmit beams with respect to each of the
25 correspondingly selected L receive beams.
5. The method according to claim 4, wherein the reported CSI feedback for the channel includes:
the quantized joint beam responses only for each of the K transmit beams with
respect to each of the correspondingly selected L receive beams; and at least one of
30 indications identifying only the K transmit beams; and
indications identifying for only each of the K transmit beams only the corresponding
L receive beams.
6. The method according to claim 2, wherein a receiving beam vector corresponding to one
35 receiver beam is equal to one vector comprising of one-zero element and M-1 zeros, where M is an
integer greater than one corresponding to a number of receiver antennas, each quantized beam

response is for a transmit beam and a receiver beam pair and is equal to one receiver antenna channel coefficient with transmit beamforming.

7. The method according claim 1, wherein:

the multi-stage beamforming comprises in a first stage using multiple wide beams and in a second stage using multiple narrow beams to quantize multiple beam responses;

the selecting comprises selecting one group of beams and corresponding quantized beam responses, wherein this group of beam includes at least one wide beam and at least one narrow beam, for reporting; and

the reported CSI feedback for the channel includes selected group of beam indices and corresponding quantized beam responses.

8. The method according to any of claims 1-7, wherein the channel is a downlink channel and the method is executed by a user equipment.

9. An apparatus comprising:

at least one processor; and

at least one computer readable memory storing program code;

wherein the at least one processor is configured with the at least one memory and program code to cause the apparatus to at least:

quantize one or more beam responses by multi-stage beamforming to a radio channel,

select at least one of the quantized beam responses for reporting; and

report channel state information (CSI) feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto.

10. The apparatus according claim 9, wherein the multi-stage beamforming includes a first stage transmit beamforming and a second stage receiving beamforming; and wherein

each of the quantized beam responses is for one beam pair comprising one transmit beam and one receive beam; and wherein the selecting includes selecting from the quantized beam responses only one or more beam pairs for reporting.

11. The apparatus according to claim 10, wherein the channel is defined by N transmit beams and M receive beams, and quantizing the one or more beam responses comprises:

selecting from among the N transmit beams a number K of the transmit beams that exhibit a best channel response; and

for each of the respective K transmit beams, selecting from among the M receive beams a number L of the receive beams that exhibit a best channel response for the respective transmit beam;

wherein N, M, K and L are each integers greater than one, K is less than N, and L is no more than M.

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

quantizing a joint beam response for each of the K transmit beams with respect to each of the
5 correspondingly selected L receive beams.

13. The apparatus according to claim 12, wherein the reported CSI feedback for the channel includes:

the quantized joint beam responses only for each of the K transmit beams with
10 respect to each of the correspondingly selected L receive beams; and at least one of
indications identifying only the K transmit beams; and
indications identifying for only each of the K transmit beams only the corresponding
L receive beams.

14. The apparatus according to claim 10, wherein a receiving beam vector corresponding to one
15 receiver beam is equal to one vector comprising of one-zero element and M-1 zeros, where M is an
integer greater than one corresponding to a number of receiver antennas, each quantized beam
response is for a transmit beam and a receiver beam pair and is equal to one receiver antenna channel
coefficient with transmit beamforming.

15. The apparatus according claim 9, wherein:

the multi-stage beamforming comprises in a first stage using multiple wide beams and in a
second stage using multiple narrow beams to quantize multiple beam responses;

the selecting comprises selecting from among only one beam group at least one quantized
25 beam response for one of the wide beams and one of the narrow beams for reporting; and

the reported CSI feedback for the channel includes the quantized beam responses selected
only from among the one beam group.

16. The apparatus according to any of claims 9-16, wherein the channel is a downlink channel
30 and the apparatus is a user equipment or components thereof.

17. A non-transitory computer readable memory tangibly storing program code that when
executed by at least one processor causes a host apparatus to perform actions comprising:

quantizing one or more beam responses by multi-stage beamforming to a radio channel,

35 selecting at least one of the quantized beam responses for reporting; and

reporting channel state information (CSI) feedback for the channel to include the at least one
selected beam response and indices of transmit and receive beams corresponding thereto.

18. The non-transitory computer readable memory according claim 17, wherein the multi-stage beamforming includes a first stage transmit beamforming and a second stage receiving beamforming; and wherein

5 each of the quantized beam responses is for one beam pair comprising one transmit beam and one receive beam; and wherein the selecting includes selecting from the quantized beam responses only one or more beam pairs for reporting.

19. The non-transitory computer readable memory according to claim 18, wherein the channel is
10 defined by N transmit beams and M receive beams, and quantizing the one or more beam responses comprises:

selecting from among the N transmit beams a number K of the transmit beams that exhibit a best channel response; and

for each of the respective K transmit beams, selecting from among the M receive beams a
15 number L of the receive beams that exhibit a best channel response for the respective transmit beam; wherein N, M, K and L are each integers greater than one, K is less than N, and L is no more than M.

20. The non-transitory computer readable memory according claim 17, wherein:

the multi-stage beamforming comprises in a first stage using multiple wide beams and in a
20 second stage using multiple narrow beams to quantize multiple beam responses;

the selecting comprises selecting from among only one beam group at least one quantized beam response for one of the wide beams and one of the narrow beams for reporting; and

the reported CSI feedback for the channel includes the quantized beam responses selected
only from among the one beam group.

21. An apparatus comprising:

means for quantizing one or more beam responses by multi-stage beamforming to a radio
channel;

means for selecting at least one of the quantized beam responses for reporting; and

30 means for reporting CSI feedback for the channel to include the at least one selected beam response and indices of transmit and receive beams corresponding thereto.

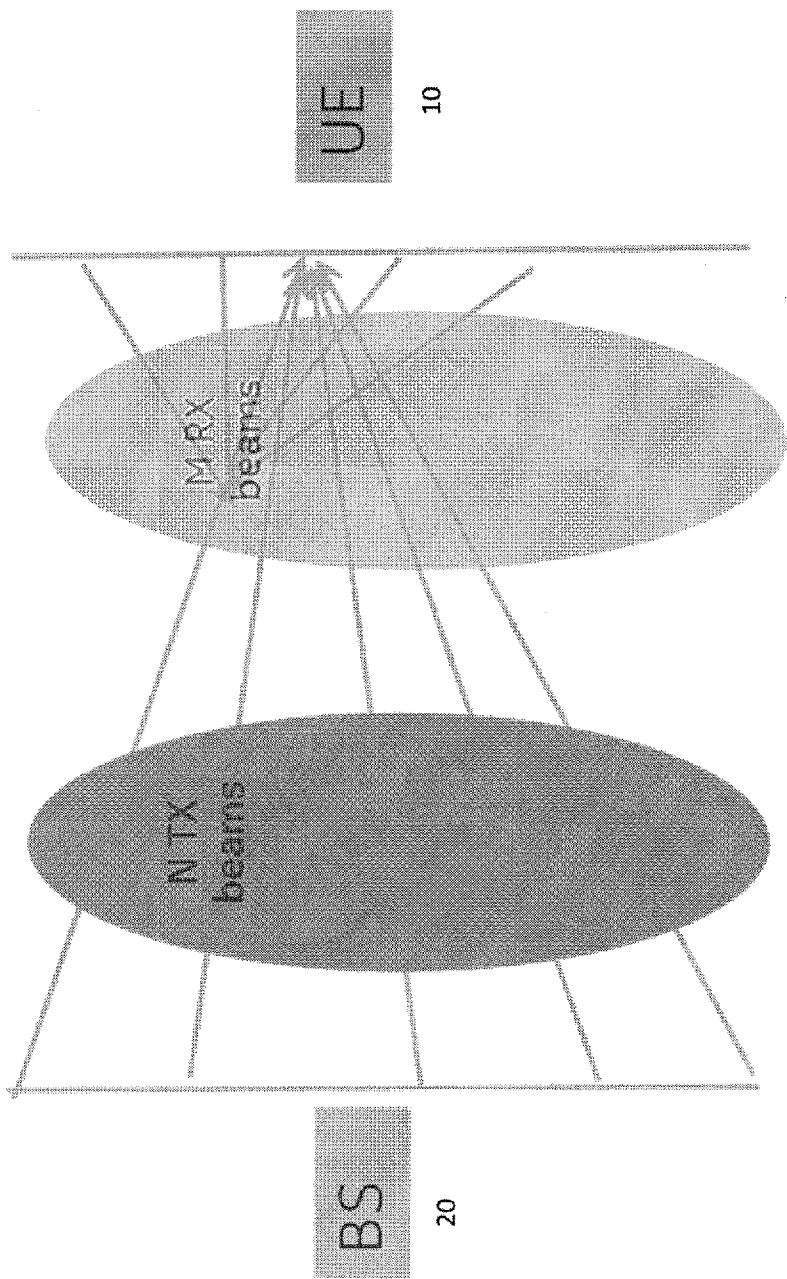


FIG. 1

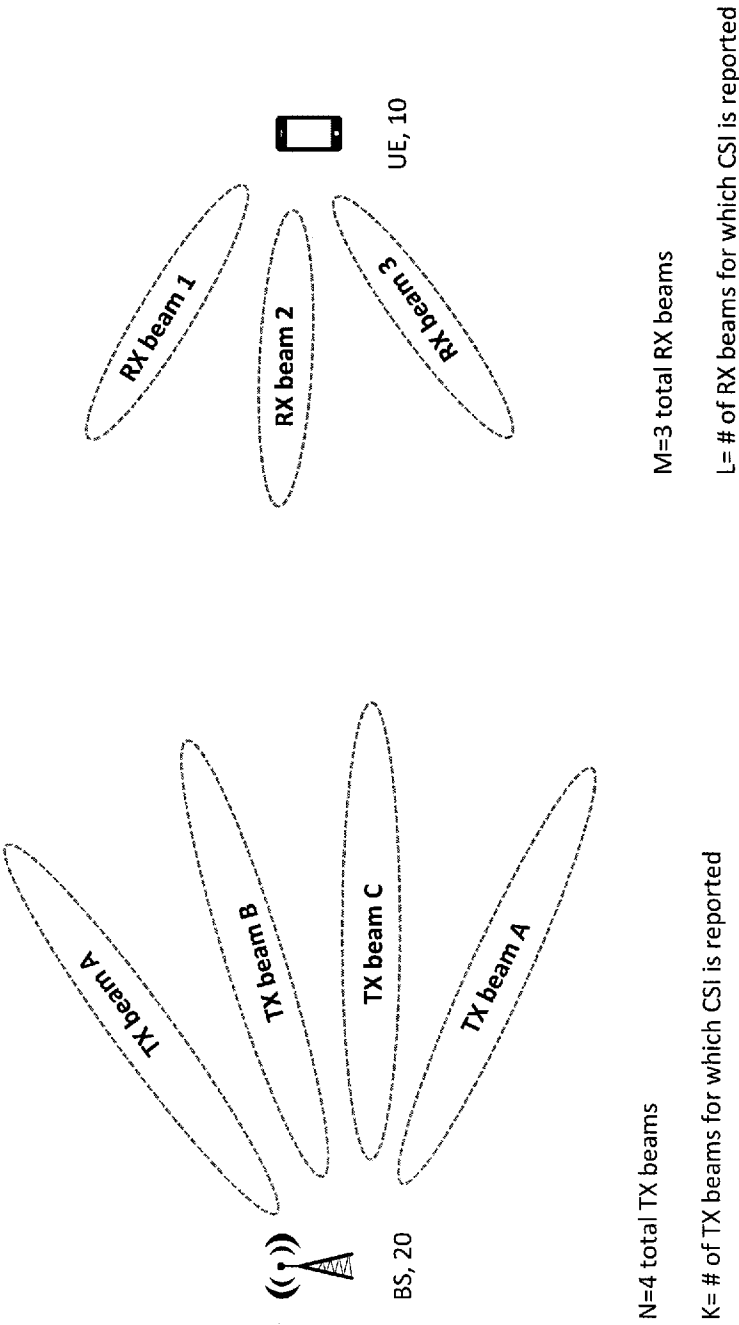
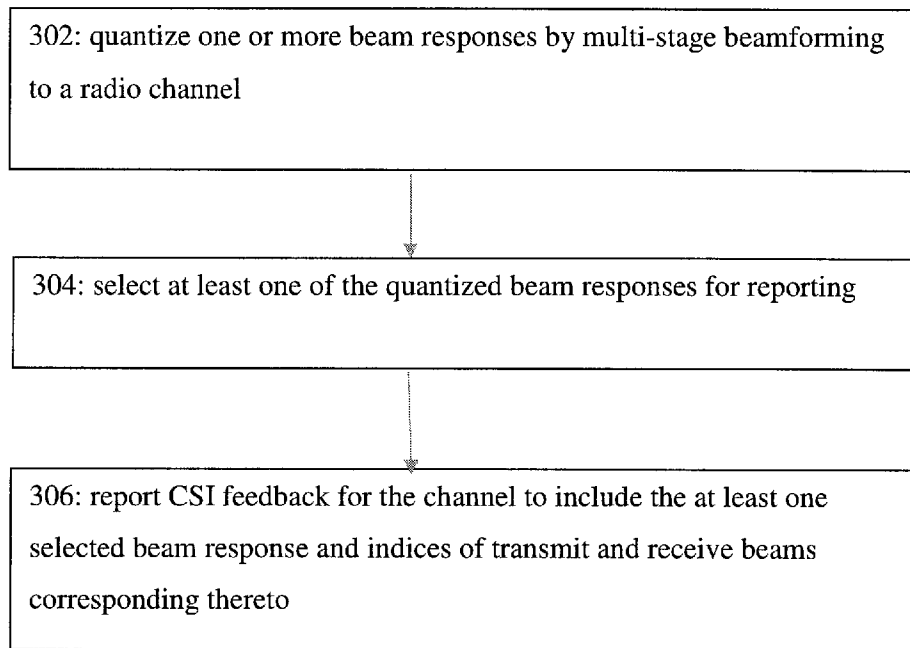


FIG. 2

**FIG. 3**

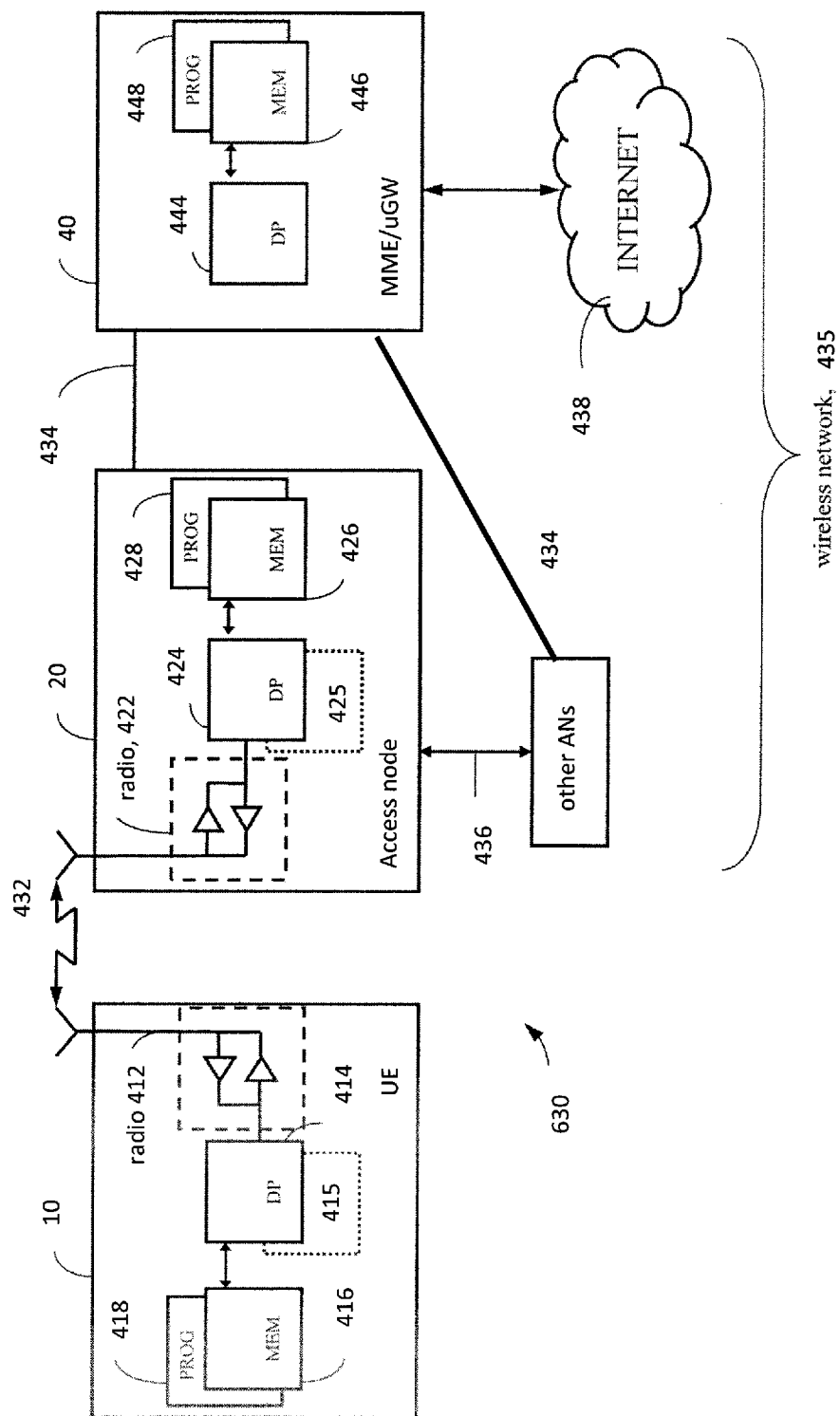


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/101458

A. CLASSIFICATION OF SUBJECT MATTER

H04B 17/24(2015.01)i

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)

H04B; H04J; 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)

CNPAT, CNKI, EPODOC, WPI, IEEE, 3GPP: MIMO, multiple input, multiple output, CSI, channel state information, quantiz
+, beam response, beamforming, multi-stage, feedback, report+, explicit feedback, transmit+, receive+, index, indices**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006155533 A1 (LIN, XINTIAN E.ET AL.) 13 July 2006 (2006-07-13) description, paragraph 3	1-21
A	US 2012082198 A1 (NECCHINA CO., LTD.) 05 April 2012 (2012-04-05) the whole document	1-21
A	EP 2134016 A1 (PANASONIC CORPORATION) 16 December 2009 (2009-12-16) the whole document	1-21
A	CN 103685093 A (BEIJING UNIVERSITY OF POSTS AND TELECOMMUNICATIONS) 26 March 2014 (2014-03-26) the whole document	1-21
A	CN 101207590 A (HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY) 25 June 2008 (2008-06-25) the whole document	1-21

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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

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

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

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

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search

02 June 2017

Date of mailing of the international search report

10 July 2017

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STATE INTELLECTUAL PROPERTY OFFICE OF THE
P.R.CHINA
6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088
China

Authorized officer

TIAN,Tao

Facsimile No. (86-10)62019451

Telephone No. (86-10)62413319

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2016/101458

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CN	101207590	A	25 June 2008	None			