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(54) Title: DIRECT CHANNEL FEEDBACK AND COMPRESSION ON RX ANTENNA DIMENSION

(57) Abstract: A method of reporting channel state information (CSI) by a user equipment (UE), the method is provided. The method comprises directly reporting a channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

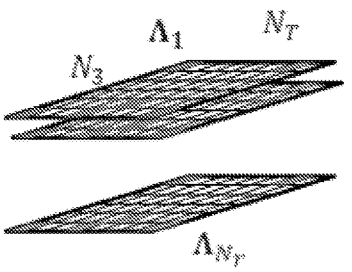

FIG. 3

DIRECT CHANNEL FEEDBACK AND COMPRESSION ON RX ANTENNA DIMENSION

CROSS-REFERENCE TO RELATED APPLICATIONS

The present Application claims priorities of Indian provisional patent applications Ser. No. 202321040991 filed on June 16, 2023 and titled "METHOD FOR DIRECT CHANNEL FEEDBACK AND COMPRESSION ON RX ANTENNA DIMENSION", and the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

This disclosure generally relates to mobility management for 5G or 6G communication system, and more particularly, to a method and device for reporting channel state information (CSI) for 5G or 6G communication system.

BACKGROUND

In a typical mobile communication environment, a User Equipment (UE) (also called as a Mobile Station (MS)), such as a mobile phone (also known as a cellular phone or cell phone), or a tablet Personal Computer (PC) with wireless communication capability may communicate voice and/or data signals with a wireless communication network. The wireless communication between the UE and the wireless communication network may be performed using various Radio Access Technologies (RATs), such as Global System for Mobile communications (GSM) technology, General Packet Radio Service (GPRS) technology, Enhanced Data rates for Global Evolution (EDGE) technology, Wideband Code Division Multiple Access (WCDMA) technology, Code Division Multiple Access 2000 (CDMA-2000) technology, Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) technology, Worldwide Interoperability for Microwave Access (WiMAX) technology, Long Term Evolution (LTE) technology, LTE-Advanced (LTE-A) technology, and New Radio (NR) technology etc. In particular, GSM/GPRS/EDGE technology is also called 2G technology; WCDMA/CDMA-2000/TD-SCDMA technology is also called 3G technology; LTE/LTE-A/TD-LTE technology is also called 4G technology; and NR technology is also called 5G technology.

In the conventional multiple-input and multiple-output (MIMO) system with N_T transmitter antennas deployed on a base station (e.g. gNodeB or gNB) and N_R receiver antennas deployed on a UE, the input-output relationship can be described as $y = HWx + n$, where y is the vector of the received symbols, x is the vector of transmitted symbols, and n is the noise, H is a $N_r \times N_t$ matrix of channel coefficients, and W is a precoding matrix, which is used on the transmitted symbols to enhance communication performance. The precoding matrix W is determined by UE feedback. Specifically, UE reports the Precoder Matrix Indication (PMI) as one of its Channel State Information (CSI) feedbacks, which are used by UE to inform the base station about the condition of the channel state. In order to create variety, it is considered to allow UE to report other pieces of information instead of PMI as its CSI feedback.

SUMMARY OF THE INVENTION

In one aspect of the present disclosure, a method of reporting channel state information (CSI) by a user equipment (UE), the method is provided. The method comprises directly reporting a channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

In another aspect of the present disclosure, the method further comprises a Radio Resource Control (RRC) signal is configured to enable the UE to directly report the channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

In yet another aspect of the present disclosure, the channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands can be decomposed as a Spatial Domain (SD) basis matrix W_{SD} containing a set of SD basis vectors, a Frequency Domain (FD) basis matrix W_{FD} containing a set of FD basis vectors, and a projection coefficient matrix Λ_r associated to the SD basis matrix W_{SD} and the FD basis matrix W_{FD}.

In yet another aspect of the present disclosure, the set of SD basis vectors is a set of orthogonal SD basis vectors or a set of non-orthogonal SD basis vectors.

In yet another aspect of the present disclosure, the set of FD basis vectors is a set of orthogonal FD basis vectors or a set of non-orthogonal FD basis vectors.

In yet another aspect of the present disclosure, a set of Discrete Fourier Transform (DFT) basis vectors with oversampling is used for the set of SD basis vectors.

In yet another aspect of the present disclosure, a set of Discrete Fourier Transform (DFT) basis vectors with oversampling is used for the set of FD basis vectors.

In yet another aspect of the present disclosure, the set of SD basis vectors is a set of SD basis vectors with reduced number of vectors.

In yet another aspect of the present disclosure, the set of FD basis vectors is a set of FD basis vectors with reduced number of vectors.

In yet another aspect of the present disclosure, the UE further reports a rotation phase indication.

In yet another aspect of the present disclosure, the UE further reports a basis selection indication.

In yet another aspect of the present disclosure, the UE selects non-zero coefficients (NZCs) based on a NZC selection ratio (β_1) controlling the number of coefficients of the projection coefficient matrix Λ_r to be reported.

In yet another aspect of the present disclosure, the NZC selection ratio (β_1) is a value configured in a Radio Resource Control (RRC) signal.

In yet another aspect of the present disclosure, the NZC selection ratio (β_1) is a value reported by the UE.

In yet another aspect of the present disclosure, the number of NZCs of the projection coefficient matrix Λ_r to be reported is equal for each receiver antenna.

In yet another aspect of the present disclosure, a sum of the number of NZCs of each projection coefficient matrix Λ_r to be reported is limited to a pre-determined value.

In yet another aspect of the present disclosure, the UE reports a bitmap of NZC locations for each projection coefficient matrix Λ_r.

In yet another aspect of the present disclosure, the bitmap of NZC locations is a receiver antenna specific bitmap or a receiver antenna common bitmap.

In yet another aspect of the present disclosure, the UE reshapes the projection coefficient matrix Λ_r as a coefficient matrix Λ across a receiver antenna domain.

In yet another aspect of the present disclosure, the UE applies a Discrete Fourier Transform (DFT) compression or a singular value decomposition (SVD) compression on the coefficient matrix Λ before selecting non-zero coefficients (NZCs) based on a NZC selection ratio (β_1).

In yet another aspect of the present disclosure, the UE applies a Discrete Fourier Transform (DFT) compression or a singular value decomposition (SVD) compression on the coefficient matrix Λ after selecting non-zero coefficients (NZCs) based on a NZC selection ratio (β_1).

In yet another aspect of the present disclosure, the UE applies the DFT compression on each row of the coefficient matrix Λ and selects non-zero coefficients (NZCs) based on a receiver-dimensional compression ratio (β_2) controlling the number of coefficients of the coefficient matrix Λ to be reported.

In yet another aspect of the present disclosure, the receiver-dimensional compression ratio (β_2) is a value configured in a Radio Resource Control (RRC) signal.

In yet another aspect of the present disclosure, the receiver-dimensional compression ratio (β_2) is a value reported by the UE.

In yet another aspect of the present disclosure, the UE applies the DFT compression on each row of the coefficient matrix Λ and then gets a matrix product $\Lambda'=\Lambda W_r$, where W_r is a DFT matrix with oversampling.

In yet another aspect of the present disclosure, the DFT matrix with oversampling can be in a normal DFT form, a polarization-common form, or a polarization-specific form depending on the receiver antennas.

In yet another aspect of the present disclosure, the UE applies the SVD compression on the coefficient matrix Λ which is decomposed as $\Lambda = V\Sigma W^H$.

In yet another aspect of the present disclosure, the UE trims singular values in the Σ and W^H as $\bar{\Sigma}$ and $\bar{W}^H$ to retain dominated coefficients for the coefficient matrix Λ.

In yet another aspect of the present disclosure, the UE trims the W^H into $\bar{W}^H$ can be constrained by limiting the frequency domain elements in a contiguous window of length-N.

In yet another aspect of the present disclosure, only $\bar{\Sigma}$ and $\bar{W}^H$are reported.

These and other features and advantages of the present disclosure can be more readily understood from the following preferred embodiments with reference to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to sufficiently understand the essence, advantages and the preferred embodiments, the following detailed description will be more clearly understood by referring to the accompanying drawings.

FIG. 1 illustrates a $N_r \times N_t$ channel matrix $H[n]$.

FIG. 2 illustrates a reshaped channel matrix F_r based on the $N_r \times N_t$ channel matrix $H[n]$.

FIG. 3 illustrates the locations of NZCs for each receiver antenna.

FIG. 4 illustrates taking DFT to each row of the coefficient matrix Λ before NZC selection.

FIG. 5 illustrates taking DFT to each row of the coefficient matrix Λ after NZC selection.

FIG. 6 illustrates performing SVD compression on the coefficient matrix Λ before NZC selection.

FIG. 7 illustrates performing SVD compression on the coefficient matrix Λ after NZC selection.

DETAILED DESCRIPTION OF THE DRAWINGS

The following description discloses the preferred embodiments. The present disclosure is described below by referring to the embodiments and the figures. Thus, the present disclosure is not intended to be limited to the embodiments shown, but is to be accorded the principles disclosed herein. Furthermore, that various modifications or changes in light thereof will be suggested to a person having ordinary skill in the art and are to be included within the spirit and purview of this application and scope of the appended claims.

Now please refer to a first embodiment of the present disclosure, which is a method of reporting channel state information (CSI) by a user equipment (UE). The method comprises the UE is allowed to directly report Direct Channel Feedback (DCF) information instead of Precoder Matrix Indication (PMI) as its CSI feedback to a base station (BS), such as a gNodeB (gNB). Specifically, a Radio Resource Control (RRC) signal is configured to enable the UE to directly report the channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

For a Multiple Input Multiple Output (MIMO) system having N_r receiving antennas and N_t transmitting antennas, the UE estimates a $N_r \times N_t$ channel matrix denoted as $H[n]$, $n = 0, 1, \ldots, N_3 - 1$ for N_3 subbands as shown in FIG. 1. Given the above, the UE can report the channel matrix of N_T transmitter antennas and N_R receiver antennas $H[n]$ for the N_3 subbands as DCF in accordance with the first embodiment of the present disclosure.

In addition, the UE can, in light of N_r receiving antennas, reshape the $N_r \times N_t$ channel matrix $H[n] \in \mathbb{C}^{N_r \times N_t}$ to $F_r \in \mathbb{C}^{N_t \times N_3}, r = 0, 1, \ldots, N_r - 1$ as shown in FIG. 2. F_r can be further decomposed as $F_r^* = W_{SD} \Lambda_r W_{FD}^H$, where W_{SD} is a Spatial Domain (SD) basis matrix containing a set of SD basis vectors, W_{FD} is a Frequency Domain (FD) basis matrix containing a set of FD basis vectors, and Λ_r is a projection coefficient matrix associated to the SD basis matrix W_{SD} and the FD basis matrix W_{FD}. Given the above, the UE can report W_{SD}, Λ_r and W_{FD} as DCF in accordance with the first embodiment of the present disclosure.

The SD basis matrix W_{SD} may contain a set of orthogonal SD basis vectors in one example. Specifically, there are N_t orthogonal Discrete Fourier Transform (DFT) basis vectors in $W_{SD} \in \mathbb{C}^{N_t \times N_t}$. In addition, the orthogonal DFT basis vectors with oversampling factor (O_1, O_2) can be considered to achieve a finer horizontal and vertical beam resolution. The $N_t \times N_t$ SD basis matrix $W_{SD}^{(k)}$ can be expressed as $\begin{bmatrix} s_0^k & s_1^k & \cdots & s_{N_1N_2-1}^k & & 0 & & \\ & 0 & & & s_0^k & s_1^k & \cdots & s_{N_1N_2-1}^k \end{bmatrix}$, where $N_t = 2N_1N_2$ and $k =$

$0, \ldots, O_1O_2-1$ is the rotation phase of the oversampling DFT beam and $[s_0^k \ s_1^k \ \cdots \ s_{N_1N_2-1}^k]$ is the $N_1N_2 \times N_1N_2$ DFT matrix per polarization, where s_n^k is a N_1N_2-length DFT vector with k-th oversampling phase, N$_1$ and N$_2$ are the numbers of antenna ports of the same polarization direction in horizontal and vertical domains and O$_1$ and O$_2$ are the oversampling factors in respective dimensions.

The SD basis matrix W_{SD} may contain a set of non-orthogonal SD basis vectors in another example. The non-orthogonal DFT basis vectors with oversampling factor $(O_1, \ O_2)$ can also be considered to achieve a finer horizontal and vertical beam resolution. Specifically, there are $N_tO_1O_2$ oversampled DFT basis vectors in $W_{SD} \in \mathbb{C}^{N_t \times N_tO_1O_2}$. The $N_t \times N_tO_1O_2$ SD basis matrix $W_{SD}^{(k)}$ can be expressed as

$$\begin{bmatrix} s_0^0 \cdots s_{N_1N_2-1}^0, \ s_0^1 \cdots s_{N_1N_2-1}^1, \ \cdots, s_0^{O_1O_2-1} \cdots s_{N_1N_2-1}^{O_1O_2-1} & \mathbf{0} \\ \mathbf{0} & s_0^0 \cdots s_{N_1N_2-1}^0, \ s_0^1 \cdots s_{N_1N_2-1}^1, \ \cdots, s_0^{O_1O_2-1} \cdots s_{N_1N_2-1}^{O_1O_2-1} \end{bmatrix},$$

where $N_t = 2N_1N_2$, s_n^k is a $N_1N_2O_1O_2$-length DFT vector with k-th oversampling phase, N$_1$ and N$_2$ are the numbers of antenna ports of the same polarization direction in horizontal and vertical domains and O$_1$ and O$_2$ are the oversampling factors in respective dimensions.

The FD basis matrix W_{FD} may contain a set of orthogonal FD basis vectors in one example. Specifically, there are N_3 orthogonal DFT basis vectors in $W_{FD} \in \mathbb{C}^{N_3 \times N_3}$. In addition, the orthogonal DFT basis vectors with oversampling factor (O_3) can be considered to ensure a proper phase rotation for frequency domain. The FD basis matrix $W_{FD}^{(k)}$ can be expressed as $[f_0^k \ f_1^k \ \cdots \ f_{N_3-1}^k]$, where $f_n^k = \left[1 \ e^{j\frac{2\pi(O_3n+k)}{O_3N_3}} \ldots e^{j\frac{2\pi(O_3n+k)(N_3-1)}{O_3N_3}}\right]^T$ is a N_3-length DFT vector with k-th oversampling phase, and N_3 is the number of subbands.

The FD basis matrix W_{FD} may contain a set of non-orthogonal FD basis vectors in another example. The non-orthogonal DFT basis vectors with oversampling factor (O_3) can be considered to ensure a proper phase rotation for frequency domain. There are N_3O_3 non-orthogonal DFT basis vectors in $W_{FD} \in \mathbb{C}^{N_3 \times N_3O_3}$. The FD basis matrix $W_{FD}^{(k)}$ can be expressed as $W_{FD} = [f_0^0 \ f_0^1 \ \ldots \ f_0^{O_3-1} \ \ldots \ f_{N_3-1}^0 \ f_{N_3-1}^1 \ \ldots \ f_{N_3-1}^{O_3-1}]$.

In order to mitigate the feedback overhead, it is also considered for the UE to report the SD basis matrix W_{SD} with reduced number of vectors and the FD basis matrix W_{FD} with reduced number of vectors in accordance with the first embodiment of the present disclosure. Specifically, the UE selects proper vectors from the original full space of the SD basis matrix W_{SD} containing aforementioned orthogonal SD basis vectors or non-orthogonal SD basis vectors and the FD basis matrix W_{FD} containing aforementioned orthogonal FD basis vectors or non-orthogonal FD basis vectors.

In the example that the SD basis matrix W_{SD} contains a set of orthogonal SD basis vectors, UE needs to report a proper rotation phase $\hat{k} \in \{0, \ldots, O_1O_2 - 1\}$ and thus needs $\lceil \log_2(O_1O_2) \rceil$ bits for reporting as a rotation phase indication. In addition, UE selects L beams (or vectors) from N_1N_2 beams for each polarization, and then the SD basis matrix $W_{SD}^{(\hat{k})}$ after selection can be expressed as $\begin{bmatrix} s_0^{\hat{k}} & s_1^{\hat{k}} & \cdots & s_{L-1}^{\hat{k}} & & 0 & \\ & 0 & & s_0^{\hat{k}} & s_1^{\hat{k}} & \cdots & s_{L-1}^{\hat{k}} \end{bmatrix} \in \mathbb{C}^{N_t \times 2L}$, and thus needs $\left\lceil log_2\binom{N_1N_2}{L} \right\rceil$ bits for reporting as a basis selection indication. In the condition that all beams are selected, i.e., $L = N_1N_2$, then it can be understood that only $\lceil \log_2(O_1O_2) \rceil$ bits of the rotation phase indication are needed for reporting the SD basis matrix W_{SD} contains a set of orthogonal SD basis vectors.

In the example that the SD basis matrix W_{SD} contains a set of non-orthogonal SD basis vectors, UE selects L beams (or vectors) from $N_1N_2O_1O_2$ beams for each polarization, and then the SD basis matrix W_{SD} after selection can be expressed as $\begin{bmatrix} s_0^{k} & s_1^{k} & \cdots & s_{L-1}^{k} & & 0 & \\ & 0 & & s_0^{k} & s_1^{k} & \cdots & s_{L-1}^{k} \end{bmatrix} \in \mathbb{C}^{N_t \times 2L}$, and thus needs $\left\lceil log_2\binom{N_1N_2O_1O_2}{L} \right\rceil$ bits for reporting as a basis selection indication. In the condition that all beams are selected, i.e., $L = N_1N_2O_1O_2$, then it can be understood that no bit is required for reporting the SD basis matrix W_{SD} contains a set of non-orthogonal SD basis vectors.

In the example that the FD basis matrix W_{FD} contains a set of orthogonal FD basis vectors, UE needs to report a proper rotation phase $\hat{k} \in \{0, \ldots, O_3 - 1\}$ and thus needs $\lceil \log_2(O_3) \rceil$ bits for reporting as a rotation phase indication. In addition, UE selects M taps (or vectors) from N_3 taps, and then the FD basis matrix $W_{FD}^{(\hat{k})}$ after selection can be expressed as $\begin{bmatrix} f_0^{\hat{k}} & f_1^{\hat{k}} & \cdots & f_{M-1}^{\hat{k}} \end{bmatrix} \in \mathbb{C}^{N_3 \times M}$, and thus needs $\left\lceil log_2\binom{N_3}{M} \right\rceil$ bits for reporting as a basis selection indication. In the condition that all taps are selected, i.e., $M = N_3$, then it can be understood that only $\lceil \log_2(O_3) \rceil$ bits of the rotation phase indication are needed for reporting the FD basis matrix W_{FD} contains a set of orthogonal FD basis vectors.

In the example that the FD basis matrix W_{FD} contains a set of non-orthogonal FD basis vectors, UE selects M taps (or vectors) from N_3O_3 taps, and then the FD basis matrix W_{FD} after selection can be expressed as $\begin{bmatrix} f_0^{\hat{k}_0} & f_1^{\hat{k}_1} & \cdots & f_{M-1}^{\hat{k}_{M-1}} \end{bmatrix} \in \mathbb{C}^{N_3 \times M}$, and thus needs

$\left\lceil log_2(\binom{N_3O_3}{M})\right\rceil$ bits for reporting as a basis selection indication. In the condition that all beams are selected, i.e., $M = N_3O_3$, then it can be understood that no bit is required for reporting the FD basis matrix W_{FD} contains a set of non-orthogonal FD basis vectors.

With proper selections of W_{SD} and W_{FD}, the UE can derive the projection coefficient matrix Λ_r to be reported by

$$\Lambda_r = W_{SD}^H F_r^* W_{FD} = \begin{bmatrix} \boxed{\lambda_{1,1}^r} & \cdots & \lambda_{1,M}^r \\ \vdots & \ddots & \vdots \\ \lambda_{2L,1}^r & \cdots & \boxed{\lambda_{2L,M}^r} \end{bmatrix}, \ r = 0,1,\ldots, N_r - 1.$$

$\Lambda_r \in \mathbb{C}^{2L\times M}$ is a sparse matrix and thus can be further trimmed as $\widetilde{\Lambda}_r$ by retaining the relatively significant P_r coefficients and setting relatively insignificant coefficients to zero without reporting. The number of non-zero coefficients (NZCs) for each r-th Rx antenna to be reported by the UE is $P_r \leq \beta_1 \cdot 2LM$, where β_1 is a NZC selection ratio used to the number of coefficients of the projection coefficient matrix Λ_r to be reported.

In one example, the NZC selection ratio (β_1) is a value configured in a Radio Resource Control (RRC) signal. In another example, the NZC selection ratio (β_1) is a value reported by the UE. For example, assume $2LM$ is equal to 20 and the NZC selection ratio (β_1) is 0.5 provided by the RRC signal, and then the number of NZCs to be reported is less than or equal to 10.

Besides, in one example, the number of NZCs of the projection coefficient matrix Λ_r to be reported is equal for each receiver antenna, i.e., $P_r \leq \beta_1 2LM$. In another example, a sum of the number of NZCs of each projection coefficient matrix Λ_r to be reported is limited to a pre-determined value P, i.e., $P = \sum_{r=0}^{N_r-1} P_r$.

The locations of NZCs, i.e. a bitmap, for each receiver antenna is required to be reported as shown in FIG. 3. In one example, the locations of NZCs on a bitmap for each projection coefficient matrix Λ_r, where $r = 0,1,\ldots, N_r - 1$, could be receiver antenna specific, which means the bitmap for each receiver antenna is specific. The UE is required to report N_r bitmaps and thus $2LMN_r$ bits are needed for reporting, where N_r is the number of the receiver antennas. In another example, the locations of NZCs on a bitmap for each projection coefficient matrix Λ_r, where $r = 0,1,\ldots, N_r - 1$, could be receiver antenna common, which means the bitmap for each receiver antenna is the same. The UE is required to only one bitmap, and thus $2LM$ bits are needed for reporting.

The UE is required to report not only the locations of NZCs (bitmap) but also values of NZCs in accordance with the first embodiment of the present disclosure. Specifically, NZCs are complex numbers represented by magnitude and phase angle. 3 bits are needed for reporting magnitude of a complex number and 4 bits are needed for reporting phase angle of a complex number, and thus (3+4) $\cdot \beta_1 2LM \cdot N_r$ bits are required for reporting for NZCs.

Still refer to FIG. 3, if the receiver antennas are correlated, the projection coefficient matrix Λ_r could be further compressed across a receiver antenna domain. Depending on the deployment of the receiver antennas, the projection coefficient matrix Λ_r could be compressed by different approaches. In one example, the receiver antennas are spaced uniformly, the DFT basis can be used to compress the projection coefficient matrix Λ_r across receiver dimension. In another example, the receiver antennas are irregularly spaced but cross-polarized, the projection coefficient matrix Λ_r can be compressed by a singular value decomposition (SVD) approach.

In the example that the DFT basis is used to compress the projection coefficient matrix Λ_r across receiver dimension, the DFT compression can be performed before NZC selection based on the aforementioned NZC selection ratio (β_1). Specifically, the DFT compression is performed by the following steps. The UE reshapes the projection coefficient matrix $\Lambda_r \in \mathbb{C}^{2L\times M}$, $r = 0, \ldots, N_r - 1$ as a coefficient matrix $\Lambda \in \mathbb{C}^{2LM\times N_r}$ across a receiver antenna domain (STEP 1). The UE takes DFT to each row of the coefficient matrix Λ and get $\Lambda' = \Lambda W_r$, where W_r is a DFT matrix (STEP 2). Select the $P' = \beta_2 \cdot 2LMN_r$ NZCs from $\boldsymbol{\Lambda}'$ for reporting, where β_2 is a receiver-dimensional compression ratio controlling the number of coefficients of the coefficient matrix Λ to be reported (STEP 3).

In one example, the receiver-dimensional compression ratio (β_2) is a value configured in a Radio Resource Control (RRC) signal. In another example, the receiver-dimensional compression ratio (β_2) is a value reported by the UE. For example, assume $2LM$ is equal to 8, the number of the receiver antennas is 4, and the receiver-dimensional compression ratio (β_2) is 0.4 provided by the RRC signal, and then the UE takes DFT to each row of the coefficient matrix Λ and get $\Lambda' = \Lambda W_r$ as shown in FIG. 4. Please note that the 4 receiver antennas (Rx = 1, 2, 3 and 4) are assumed to be similar and thus the NZCs would locate near columns at the left-hand side, which achieves compression effect.

In the example that the DFT basis is used to compress the projection coefficient matrix Λ_r across receiver dimension, the DFT compression can be performed after NZC selection based on the aforementioned NZC selection ratio (β_1). Specifically, the DFT compression is performed by the following steps. The UE reshapes the selected P_r NZCs in the trimmed projection coefficient matrix $\widetilde{\Lambda}_r \in \mathbb{C}^{2L\times M}$, $r = 0, \ldots, N_r - 1$ as a coefficient matrix $\Lambda \in \mathbb{C}^{P_r\times N_r}$ (STEP 1). The UE takes DFT to each row of the coefficient matrix Λ and get $\Lambda' = \Lambda W_r$, where W_r is a DFT matrix (STEP 2). Select the $P' = \beta_2 \cdot P_r N_r$ NZCs from Λ' for reporting, where $\beta_2$is a receiver-dimensional compression ratio controlling the number of coefficients of the coefficient matrix Λ to be reported (STEP 3).

In one example, the receiver-dimensional compression ratio (β_2) is a value configured in a Radio Resource Control (RRC) signal. In another example, the receiver-dimensional compression ratio (β_2) is a value reported by the UE. For example, assume $P_r = \beta_1 \cdot 2LM$ is equal to 4, the number of the receiver antennas is 4, and the receiver-dimensional compression ratio (β_2) is 0.8 provided by the RRC signal, and then the UE takes DFT to each row of the coefficient matrix Λ and get $\Lambda'= \Lambda W_r$ as shown in FIG. 5. Please note that the number of coefficients to be reported is reduced, which achieves compression effect.

The aforementioned DFT matrix $W_r \in \mathbb{C}^{N_r \times N_r}$ could be a DFT matrix with oversampling factor O_r , and could further be in a normal DFT form, a polarization-common form, or a polarization-specific form depending on the receiver antennas. In the normal DFT form, DFT matrix W_r could be $[W_r]_{m,n} = e^{j\frac{2\pi(O_r n+k)m}{O_r N_r}}$, where $m, n = 0, \dots, N_r - 1$ and $k = 0, \dots, O_r - 1$ is the oversampling phase. In the polarization common form, DFT matrix W_r could be $W_r = \begin{bmatrix} W_{r1} & 0 \\ 0 & W_{r1} \end{bmatrix}$, where W_{r1} is $\frac{N_r}{2} \times \frac{N_r}{2}$ DFT matrix. In the polarization specific form, DFT matrix W_r could be $W_r = \begin{bmatrix} W_{r1} & 0 \\ 0 & W_{r2} \end{bmatrix}$.

In the example that the projection coefficient matrix Λ_r is compressed by the singular value decomposition (SVD) approach, the SVD compression can be performed before NZC selection based on the aforementioned NZC selection ratio (β_1) as shown in FIG. 6. Specifically, the SVD compression is performed by the following steps. The UE reshapes the projection coefficient matrix $\Lambda_r \in \mathbb{C}^{2L \times M}$, $r = 0, \dots, N_r - 1$ as a coefficient matrix $\Lambda \in \mathbb{C}^{N_r \times 2LM}$ (STEP 1). In order to explore dependency across receiver antennas, the UE utilizes the SVD approach to decompose the coefficient matrix Λ as follows.

$$\Lambda = V\Sigma W^H = [v_0 \quad \cdots \quad v_{N_r-1}] \begin{bmatrix} \sigma_0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_{N_r-1} \end{bmatrix} \begin{bmatrix} w_0^H \\ \vdots \\ w_{N_r-1}^H \end{bmatrix} \text{(STEP 2).}$$

The UE trims the coefficient matrix Λ to retain dominated coefficients for the coefficient matrix Λ as follows.

$\bar{\Lambda} = \bar{V}\bar{\Sigma}\bar{W}^H = [\bar{v}_0 \quad \cdots \quad \bar{v}_{\rho-1}]\begin{bmatrix}\sigma_0 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \sigma_{\rho-1}\end{bmatrix}\begin{bmatrix}\bar{w}_0^H\\ \vdots\\ \bar{w}_{\rho-1}^H\end{bmatrix}$, where $\rho \le N_r$ (STEP 3). The singular values of σ_i, $i > \rho$ is trimmed if σ_ρ is smaller than σ_0 by a pre-defined dB, such as 10 dB. The w_i^H, $i = 0, \ldots, \rho - 1$ can further be trimmed as $\bar{w}_i^H$ by keeping enough of elements in w_i^H to preserve $95\%, 90\%, 85\%, \cdots$ of the channel's energy. Trimming w_i^H as $\bar{w}_i^H$ can be constrained by limiting the frequency domain elements in a contiguous window of length-N, where N is a positive integer. For example, N is equal to 4 in FIG. 6. Please note that the number of coefficients to be reported is reduced, which achieves compression effect.

In the example that the projection coefficient matrix Λ_r is compressed by the singular value decomposition (SVD) approach, the SVD compression can be performed after NZC selection based on the aforementioned NZC selection ratio (β_1) as shown in FIG. 7. Specifically, the SVD compression is performed by the following steps. The UE reshapes the selected P_r NZCs in the trimmed projection coefficient matrix $\tilde{\Lambda}_r \in \mathbb{C}^{2L\times M}$, $r = 0, \ldots, N_r - 1$ as a coefficient matrix $\Lambda \in \mathbb{C}^{N_r \times P_r}$ (STEP 1). In order to explore dependency across receiver antennas, the UE utilizes the SVD approach to decompose the coefficient matrix Λ as follows.

$$\Lambda = V\Sigma W^H = [v_0 \quad \cdots \quad v_{N_r-1}]\begin{bmatrix}\sigma_0 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \sigma_{N_r-1}\end{bmatrix}\begin{bmatrix}w_0^H\\ \vdots\\ w_{N_r-1}^H\end{bmatrix} \text{ (STEP 2).}$$

The UE trims the coefficient matrix Λ to retain dominated coefficients for the coefficient matrix Λ as follows.

$\bar{\Lambda} = \bar{V}\bar{\Sigma}\bar{W}^H = [\bar{v}_0 \quad \cdots \quad \bar{v}_{\rho-1}]\begin{bmatrix}\sigma_0 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \sigma_{\rho-1}\end{bmatrix}\begin{bmatrix}\bar{w}_0^H\\ \vdots\\ \bar{w}_{\rho-1}^H\end{bmatrix}$, where $\rho \le N_r$ (STEP 3). The singular values of σ_i, $i > \rho$ is trimmed if σ_ρ is smaller than σ_0 by a pre-defined dB, such as 10 dB. The w_i^H, $i = 0, \ldots, \rho - 1$ can further be trimmed as $\bar{w}_i^H$ by keeping enough of elements in w_i^H to preserve $95\%, 90\%, 85\%, \cdots$ of the channel's energy. Trimming w_i^H as $\bar{w}_i^H$ can be constrained by limiting the frequency domain elements in a contiguous window of length-N, where N is a positive integer. For example, N is equal to 4 in FIG. 7. Please note that the number of coefficients to be reported is reduced, which achieves compression effect.

For the purpose of precoder derivation by the base station (BS), there is no need to feedback the aforementioned left eigenvectors $[\bar{v}_0 \quad \cdots \quad \bar{v}_{\rho-1}]$ because the precoder can be determined by $\Lambda^H\Lambda$, which is not a function of $[\bar{v}_0 \quad \cdots \quad \bar{v}_{\rho-1}]$. In other words, the UE only reports $\bar{\Sigma}$ and $\bar{W}^H$and the feedback quantity can only be $\{\sigma_0\bar{w}_0^H, \cdots, \sigma_{\rho-1}\bar{w}_{\rho-1}^H\}$, which is the set of the linear combination coefficients of $\begin{bmatrix} \sigma_0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_{\rho-1} \end{bmatrix} \begin{bmatrix} \bar{w}_0^H \\ \vdots \\ \bar{w}_{\rho-1}^H \end{bmatrix}$.

The preferred embodiments of the present invention have been described above. However, those having ordinary skill in the art readily recognize that the disclosure described above can be utilized in a variety of devices, environments, and situations. Although the present invention is written with respect to specific embodiments and implementations, various changes and modifications may be suggested to a person having ordinary skill in the art. It is intended that the present disclosure encompass such changes and modifications that fall within the scope of the appended claims.

For example, those having ordinary skill in the art would understand that the method can apply not only to 5GS but also to other system with different generation.

For example, those having ordinary skill in the art would understand that a device, such as a UE, may include a processor, memory in electronic communication with the processor, and instructions stored in the memory. The instructions are used to perform the methods in accordance with the embodiments above.

What is claimed is:

1. A method of reporting channel state information (CSI) by a user equipment (UE), the method comprising:

   directly reporting a channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

2. The method of claim 1, the method further comprising:

   a Radio Resource Control (RRC) signal is configured to enable the UE to directly report the channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands.

3. The method of claim 1, wherein the channel matrix of N_T transmitter antennas and N_R receiver antennas for subbands can be decomposed as a Spatial Domain (SD) basis matrix W_{SD} containing a set of SD basis vectors, a Frequency Domain (FD) basis matrix W_{FD} containing a set of FD basis vectors, and a projection coefficient matrix Λ_r associated to the SD basis matrix W_{SD} and the FD basis matrix W_{FD}.

4. The method of claim 3, a set of Discrete Fourier Transform (DFT) basis vectors with oversampling is used for the set of SD basis vectors.

5. The method of claim 3, a set of Discrete Fourier Transform (DFT) basis vectors with oversampling is used for the set of FD basis vectors.

6. The method of claim 3, wherein the set of SD basis vectors is a set of SD basis vectors with reduced number of vectors.

7. The method of claim 3, wherein the set of FD basis vectors is a set of FD basis vectors with reduced number of vectors.

8. The method of claim 6, wherein the UE further reports a rotation phase indication.

9. The method of claim 6, wherein the UE further reports a basis selection indication.

10. The method of claim 7, wherein the UE further reports a rotation phase indication.

11. The method of claim 7, wherein the UE further reports a basis selection indication.

12. The method of claim 3, wherein the UE selects non-zero coefficients (NZCs) based on a NZC selection ratio (β_1) controlling the number of coefficients of the projection coefficient matrix Λ_r to be reported.

13. The method of claim 12, wherein the NZC selection ratio (β_1) is a value configured in a Radio Resource Control (RRC) signal.

14. The method of claim 12, wherein the NZC selection ratio (β_1) is a value reported by the UE.

15. The method of claim 12, wherein the number of NZCs of the projection coefficient matrix Λ_r to be reported is equal for each receiver antenna.

16. The method of claim 12, wherein a sum of the number of NZCs of each projection coefficient matrix Λ_r to be reported is limited to a pre-determined value.

17. The method of claim 12, wherein the UE reports a bitmap of NZC locations for each projection coefficient matrix Λ_r.

18. The method of claim 17, wherein the bitmap of NZC locations is a receiver antenna specific bitmap or a receiver antenna common bitmap.

19. The method of claim 12, wherein the UE reshapes the projection coefficient matrix Λ_r as a coefficient matrix Λ across a receiver antenna domain.

20. The method of claim 19, wherein the UE applies a Discrete Fourier Transform (DFT) compression or a singular value decomposition (SVD) compression on the coefficient matrix Λ before selecting non-zero coefficients (NZCs) based on a NZC selection ratio (β_1).

21. The method of claim 19, wherein the UE applies a Discrete Fourier Transform (DFT) compression or a singular value decomposition (SVD) compression on the coefficient

matrix Λ after selecting non-zero coefficients (NZCs) based on a NZC selection ratio (β_1).

22. The method of claim 20, wherein the UE applies the DFT compression on each row of the coefficient matrix Λ and selects non-zero coefficients (NZCs) based on a receiver-dimensional compression ratio (β_2) controlling the number of coefficients of the coefficient matrix Λ to be reported.

23. The method of claim 21, wherein the UE applies the DFT compression on each row of the coefficient matrix Λ and selects non-zero coefficients (NZCs) based on a receiver-dimensional compression ratio (β_2) controlling the number of coefficients of the coefficient matrix Λ to be reported.

24. The method of claim 22, wherein the receiver-dimensional compression ratio (β_2) is a value configured in a Radio Resource Control (RRC) signal.

25. The method of claim 22, wherein the receiver-dimensional compression ratio (β_2) is a value reported by the UE.

26. The method of claim 23, wherein the receiver-dimensional compression ratio (β_2) is a value configured in a Radio Resource Control (RRC) signal.

27. The method of claim 23, wherein the receiver-dimensional compression ratio (β_2) is a value reported by the UE.

28. The method of claim 20, wherein the UE applies the DFT compression on each row of the coefficient matrix Λ and then gets a matrix product $\Lambda'=\Lambda W_r$, where W_r is a DFT matrix with oversampling.

29. The method of claim 28, wherein the DFT matrix with oversampling can be in a normal DFT form, a polarization-common form, or a polarization-specific form depending on the receiver antennas.

30. The method of claim 20, wherein the UE applies the SVD compression on the coefficient matrix Λ which is decomposed as $\Lambda = V\Sigma W^H$.

31. The method of claim 30, wherein the UE trims singular values in the Σ and W^H as $\bar{\Sigma}$ and $\bar{W}^H$ to retain dominated coefficients for the coefficient matrix Λ.

32. The method of claim 31, wherein the UE trims the W^H into $\bar{W}^H$ can be constrained by limiting the frequency domain elements in a contiguous window of length-N.

33. The method of claim 30, wherein only $\bar{\Sigma}$ and $\bar{W}^H$are reported.

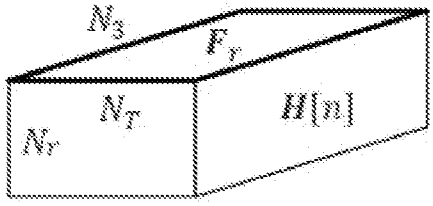

FIG. 1

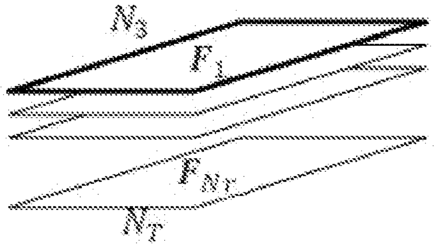

FIG. 2

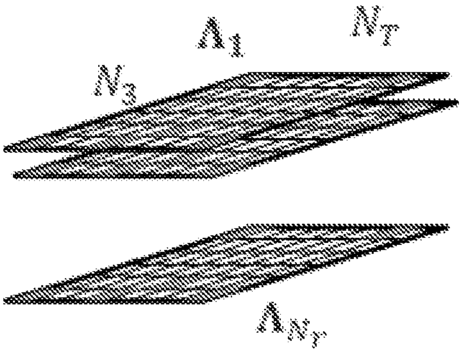

FIG. 3

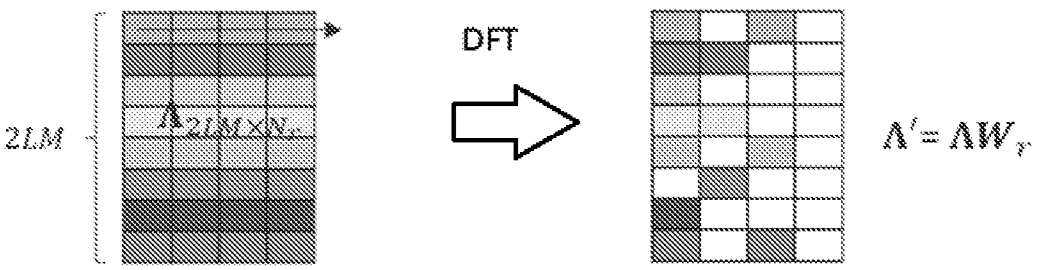

FIG. 4

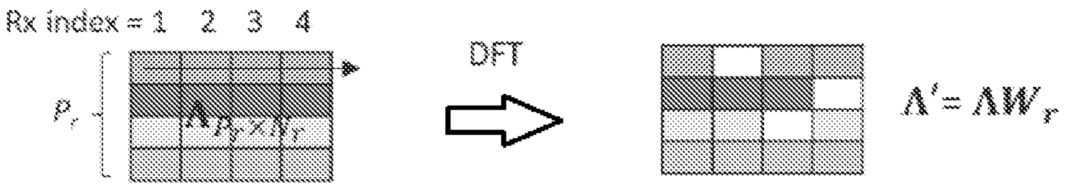

FIG. 5

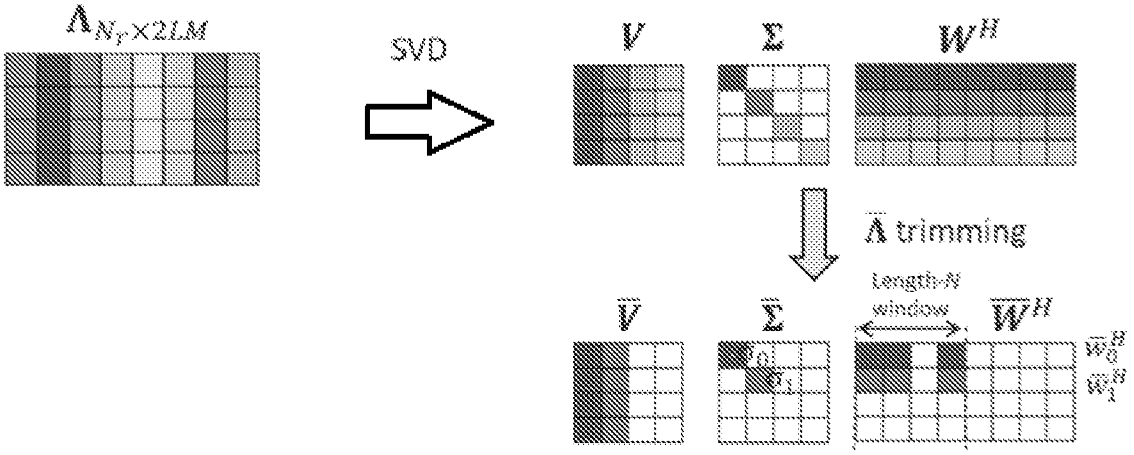

FIG. 6

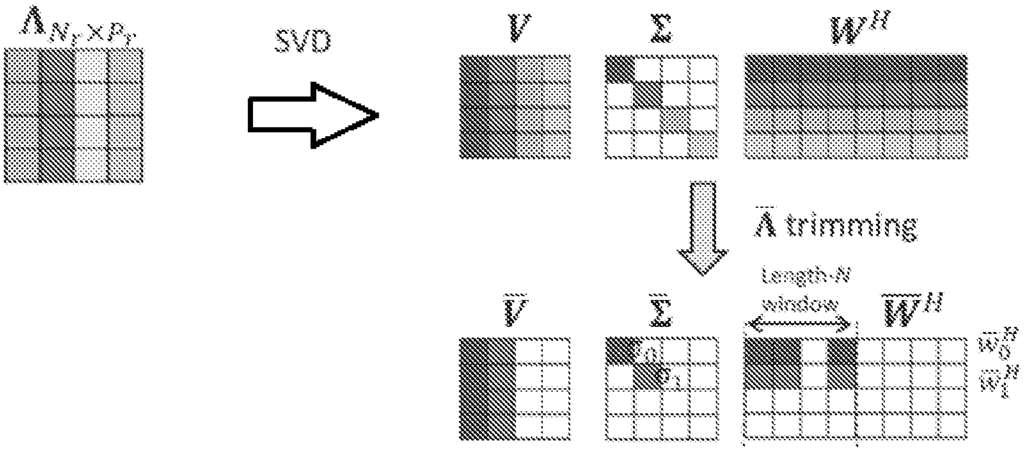

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2024/099143

A. CLASSIFICATION OF SUBJECT MATTER

H04B7/0413(2017.01)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)

IPC: H04B H04M H04L H04W

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)

CNTXT,CNKI,ENTXT,ENTXTC,3GPP,IEEE: CSI,channel state information, report, UE, terminal, matrix, antenna, transmit+, receiv+, subband

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2018262253 A1 (SAMSUNG ELECTRONICS CO LTD) 13 September 2018 (2018-09-13) description, paragraphs 0038-0145	1-33
A	CN 114128161 A (FRAUNHOFER APPL RES PROMOTION ASSOC) 01 March 2022 (2022-03-01) the whole document	1-33
A	EP 3734853 A1 (FRAUNHOFER GES FORSCHUNG) 04 November 2020 (2020-11-04) the whole document	1-33
A	US 2022038159 A1 (QUALCOMM INC) 03 February 2022 (2022-02-03) the whole document	1-33

☐ 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
"D"	document cited by the applicant in the international application
"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 **22 September 2024**	Date of mailing of the international search report **23 September 2024**
Name and mailing address of the ISA/CN **CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION** **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	Authorized officer **WU,JiangXia** Telephone No. **(+86) 01062412034**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2024/099143

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