(54) Title: PRECODING METHOD, FEEDBACK CHANNEL INFORMATION METHOD, MOBILE TERMINAL AND BASE STATION IN WIRELESS COMMUNICATION SYSTEM

[Fig. 8]

(57) Abstract: The present invention relates to precoding and feedback channel information in wireless communication system.
ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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

Title of Invention: PRECODING METHOD, FEEDBACK CHANNEL INFORMATION METHOD, MOBILE TERMINAL AND BASE STATION IN WIRELESS COMMUNICATION SYSTEM

Technical Field
[1] The present invention relates to precoding and feedback channel information in wireless communication system.

Background Art
[2] There are a number of multi-antenna transmission schemes or transmission such as transit diversity, closed-loop spatial multiplexing or open-loop spatial multiplexing. Closed-loop MIMO(CL-MIMO) relies on more extensive feedback from the mobile terminal.

Disclosure of Invention

Solution to Problem
[3] In accordance with an aspect, there is provided a method for feedbacking channel information, the method comprising: selecting a short term precoding matrix from short term codebook based on the estimated downlink channel; estimating a statistic property; transforming the statistic property to get a long term transform matrix; and feedbacking a short term feedback information for the short term precoding matrix and a long term feedback information for the long term transform matrix from long term codebook.

[4] In accordance with the other aspect, there is provided a method, the method comprising: receiving a short term feedback information for the short term precoding matrix based on the estimated downlink channel and a long term feedback information for the long term precoding matrix based on a statistic property of the estimated downlink respectively; find the short term precoding matrix and the long term precoding matrix by searching the short term feedback information and the long term feedback information from the corresponding codebook respectively; transforming the long term precoding matrix to get the long term transform precoding matrix; and perform the multilevel precoding using the short term precoding matrix and the long term transform precoding matrix.

[5] In accordance with another aspect, there is provided a method, the method comprising: mapping a codeword to a layer; precoding a mapped set of symbols using at least two precoding matrices in turn where one of them is the precoding matrix.
transformed from a downlink channel correlation matrix and transmitting a signal that comprises the precoded set of symbols.

In accordance with another aspect, there is provided a mobile terminal, the mobile terminal comprising: an estimator configured to select a short term precoding matrix from short term codebook based on the estimated downlink channel, estimate a statistic property, and feedback a short term feedback information for the short term precoding matrix; a transformer configured to transform the statistic property to get a long term transform matrix and feedback a long term feedback information from long term codebook for the long term transform matrix; and a post-decoder configured to decode the received signal to recover the set of data symbols.

In accordance with another aspect, there is provided a base station, the base station comprising: a layer mapper configured to map one or two codewords to the layers; a precoder configured to receive a short term feedback information for the short term precoding matrix based on the estimated downlink channel and a long term feedback information for the long term precoding matrix based on a statistic property of the estimated downlink respectively, find the short term precoding matrix and the long term precoding matrix using the short term feedback information and the long term feedback information respectively, and perform the multilevel precoding using the short term precoding matrix and the long term transform precoding matrix and a transformer configured to transform the long term precoding matrix to get the long term transform precoding matrix.

**Brief Description of Drawings**

FIG. 1 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to one embodiment.

FIG. 2 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to the other embodiment.

FIG. 3 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

FIG. 4 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

FIG. 5 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

FIG. 6 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

FIG. 7 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

FIG. 8 is the flowchart of the CL-MIMO system according to further another em-
FIG. 9 is the flowchart of the CL-MIMO system according to further another embodiment.

It will be appreciated that for simplicity and clarity of illustration, elements illustrated in the drawings have not necessarily been drawn to scale. For example, the dimensions of some of the elements are exaggerated relative to other elements for purposes of promoting and improving clarity and understanding. Further, where considered appropriate, reference numerals have been repeated among the drawings to represent corresponding or analogous elements.

**Mode for the Invention**

Hereinafter, embodiments of the present invention will be described in detail with reference to the attached drawings.

A unitary precoding is employed for Single User CL-MIMO (SU CL-MIMO), and unitary codebooks for different antenna configuration are defined. In LTE advance, it can be non-unitary also. Moreover, rank adaptation is also considered in LTE to enhance the performance.

In this exemplary embodiment, a multilevel precoding scheme is proposed for CL-MIMO. In the proposed scheme, we consider use at least two level precodings. With the proposed scheme, we can get optimal solution for CL-MIMO. So it can increase the CL-MIMO performance. Moreover, by using multilevel precoding, we can separately feedback the PMI for each level. The first PMI is feedbacked less frequently than the second one. So the feed back overhead is further reduced.

FIG. 1 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to an embodiment.

Referring to FIG. 1, the communication system may be any type of wireless communication system, including but not limited to a MIMO system, SDMA system, CDMA system, OFDMA system, OFDM system, etc. In the communication system, the wireless communication system 100 using closed-loop spatial multiplexing according to an embodiment comprises a transmitter 110 and a receiver 120. The transmitter 110 may act as a base station, while the receiver 120 may act as a subscriber station, which can be virtually any type of wireless one-way or two-way communication device such as a cellular telephone, wireless equipped computer system, and wireless personal digital assistant. Of course, the receiver/subscriber station 120 can also transmits signals which are received by the transmitter/base station 110. The signals communicated between the transmitter 110 and the receiver 120 can include voice, data, electronic mail, video, and other data, voice, and video signals.

In operation, the transmitter 110 transmits a signal data stream through one or more
antennas and over a channel to a receiver 120, which combines the received signal from one or more receive antennas to reconstruct the transmitted data. To transmit the signal, the transmitter 110 prepares a transmission signal represented by the vector for the signal.

[24] The transmitter 110 comprises a layer mapper 130 and a precoder 140.

[25] The layer mapper 130 of the transmitter 110 maps one or two codewords, corresponding to one or two transport, to the layers $N_L$ which may range from a minimum of one layer up to a maximum number of layers equal to the number of antenna ports. In case of multi-antenna transmission, there can be up to two transport blocks of dynamic size for each TTI (Transmission Time Interval), where each transport block corresponds to one codeword in case of downlink spatial multiplexing. In other words, the block of modulation symbols (one block per each transport block) refers to as a codeword. If there is only one codeword, we call it single codeword (SCW). Otherwise, we call it multiple codeword (MCW).

[26] After layer mapping by the layer mapper 130, a set of $N_L$ symbols (one symbol from each layer) is linearly combined and mapped to the $N_A$ antenna port by the precoder 140. This combining/mapping can be described by means of a precoding matrix $P$ of size $N_L \times N_A$.

[27] In various example embodiments, the precoding matrix $P$ is implemented with the matrix $P=WR$, where $R$ is, for example, the first matrix for the channel correlation, and $W$ is, for example, a second matrix without correlation. It may be unitary or non-unitary. In another example embodiments, the precoding matrix $P$ is implemented with the matrix $P=RW$, where $W$ is, for example, a first matrix without the channel correlation and $R$ is, for example, the second matrix for the channel correlation. As to the above embodiments, the first and the second precoding matrices may be transformed by several methods such EVD based transformation or square root transformation in order to enhance performance. For example, the precoding matrix $P$ is implemented with the matrix $P=WT$ or $TW$, which $T$ is the transformed matrix.

[28] The precoder 140 has its own codebook, which is accessed to obtain a transmission profile and/or precoding information to be used to process the input data signal to make best use of the existing channel conditions for individual receiver stations. In addition, the receiver 120 includes the same codebook for use in efficiently transferring information in either the feedback or feedforward channel, as described herein below.

[29] In various embodiments, the codebook is constructed as a composite product codebook from separable sections, where the codebook index may be used to access the different sections of the codebook. For example, one or more predetermined bits from the codebook index are allocated for accessing the first matrix, while a second set of predetermined bits from the second index is allocated to indicate the values for the
second matrix.

In various embodiments, instead of having a single codebook at each of the transmitter 110 and the receiver 120, separate codebooks can be stored so that there is, for example, a codebook for the first precoding matrix W, a codebook for the second matrix R. In such a case, separate indices may be generated wherein each index points to a codeword in its corresponding codebook, and each of these indices may be transmitted over a feedback channel to the transmitter, so that the transmitter uses these indices to access the corresponding codewords from the corresponding codebooks and determine a transmission profile or precoding information.

To assist the base station in selecting a suitable precoding matrix for transmission by the transmitter 110, the receiver/mobile terminal 120 may report channel information such as a recommended number of layers (expressed as a Rank Indication, RI) or a recommended precoding matrix (Precoding Matrix Index, PMI) corresponding to that number of layers, depending on estimates of the downlink channel conditions.

The receiver 120 may comprise a channel estimator 150 and a post-decoder 160. The receiver 120 estimates the channel by the channel estimator 150. The transmitter 110 receives PMI feedback for the first precoding by long term and PMI feedback for the second precoding by short term. The transmitter 110 precodes the set of symbols by means of the precoding matrix P=W*R based on the two feedback PMIs as shown in FIG.1, where R is the first matrix for the channel correlation and W is the second matrix without the channel correlation.

The receiver 120 recovers the original data symbols by post-decoder 160 with the previous feedback precoding matrices combination. The post-decoder 160 processes the received signal and decodes the precoded symbols.

FIG.2 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to the other embodiment.

Referring to FIG.2, in the communication system, the wireless communication system 200 using closed-loop spatial multiplexing according to one embodiment comprises a transmitter 210 and a receiver 220. The transmitter 210 comprises a layer mapper 230 and a precoder 240.

After layer mapping by the layer mapper 230, a set of N_L symbols (one symbol from each layer) is linearly combined and mapped to the N_A antenna port by the precoder 240.

The precoder 240 comprises two precoders 242 and 244 to optimize the performance. The first precoder 242 may be for the channel correlation. The second one 244 may be without the channel correlation. In other words, the first precoder 242 may be for a long term feedback information such as a long term PMI. The second one 244 may be for a short term feedback information such as a short term PMI.
In various example embodiments, the first precoder 242 may precode a set of symbols from the layer mapper 230 by means of a precoding matrix $R$ of size $N_{LX} N_L$. The second precoder 244 may also precode a set of symbols from the first precoder 242 by means of a precoding matrix $W$ of size $N_{LX} N_A$. The precoding matrix $R$ is a first matrix for the channel correlation and the precoding matrix $W$ is a second matrix without the channel correlation. As a result, the first and the second precoder 242 and 244 precode a set of symbols by means of the matrix $P=WR$.

In various embodiments, separate codebooks of the transmitter 210 and the receiver 220 may be stored so that there are, for example, a codebook for the first precoding matrix $R$ and a codebook for the second matrix $W$. In such a case, separate indices may be generated wherein each index points to a codeword in its corresponding codebook, and each of these indices may be transmitted over a feedback channel to the transmitter, so that the transmitter uses these indices to access the corresponding codewords from the corresponding codebooks and determine a transmission profile or precoding information.

The receiver 220 may comprise a channel estimator 250 and a post-decoder 260.

The channel estimator 250 of the receiver 220 estimates the downlink channel condition. The channel estimator 250 feedbacks at least one of RI and PMI to the transmitter 210. The channel estimator 250 may perform many kinds of codebook based PMI feedback.

The receiver 220 estimates the channel by the channel estimator 250. Based on the estimated channel information, then the receiver 220 selects the precoding matrix for each level from the corresponding codebooks. Once the precoding matrix for each level is decided, the receiver/mobile terminal 220 separately feedback the PMIs of both level to the transmitter 210.

There may be codebook based PMI feedback where the receiver/mobile terminal 220 feedbacks the precoding matrix index(PMI) of the favorite matrix in the codebook to the transmitter/base station 210 to support CL-MIMO(closed MIMO) operation in wireless communication system.

The feedback frequency of the receiver 220 is different for different level precoding. The first precoding is for the channel correlation, which is decided by the channel amplitude. The second precoding may be without the channel correlation. The first precoding is by long term feedback and the second one is byshort term feedback. So multilevel precoding may reduce the feedback overhead.

The transmitter 210 receives PMI feedback for the first precoding by long term and PMI feedback for the second precoding by short term. In the other embodiment as shown in FIG.2, the transmitter 210 precodes the set of data symbols by means of the two level precoders 242 and 244 based on the two feedback PMIs. For example, the
first precoder 242 and the second precoder 244 in turn precodes the set of data symbols by means of each of matrices W and R based on the long and the short term feedback PMIs.

Then the transmitter 210 transmits the precoded data symbols by different antennas.

The receiver 220 recovers the original data symbols by post-decoder 260 with the previous feedback precoding matrices combination. The post-decoder 260 processes the received signal and decodes the precoded symbols.

FIG.3 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

Referring to FIG.3, in the communication system, the wireless communication system 300 using closed-loop spatial multiplexing according to one embodiment comprises a transmitter 310 and a receiver 320. The transmitter 310 comprises a layer mapper 330 and a precoder 340.

After layer mapping by the layer mapper 330, a set of symbols(one symbol from each layer) is linearly combined and mapped to the antenna port by the precoder 340.

The precoder 340 comprises two level precoders 342 and 344 to enhance or substantially optimize the performance. The first precorder 342 may be without the channel correlation. The second precoder 344 is for channel correlation. In other words, the first precoder 342 may be for the short term feedback information such as the short term PMI. The second one 344 may be the long term feedback information such as the long term PMI.

In various example embodiments, the first precoder 342 may precode a set of symbols from the layer mapper 330 by means of a precoding matrix W of size $N_{LX}N_A$. The second precoder 344 may also precode a set of symbols from the first precoder 342 by means of a precoding matrix R of size $N_{AX}N_A$.

The precoding matrix W is a first matrix without the channel correlation and the precoding matrix R is a second matrix for the channel correlation. As a result, the first and the second precoders 342 and 344 precode a set of symbols by means of the matrix $P=RW$.

The receiver 320 may comprise a channel estimator 350 and a post-decoder 360.

The receiver 320 estimates the channel by the channel estimator 350. Based on the estimated channel information, then the receiver 320 selects the precoding matrix for each level from the corresponding codebooks. Once the precoding matrix for each level is decided, the receiver/mobile terminal 320 separately feedback the PMIs of both level to the transmitter 310.

The transmitter 10 receives PMI feedback for the first precoding by the short term and PMI feedback for the second precoding by the long term.
The receiver 320 recovers the original data symbols by post-decoder 360 with the previous feedback precoding matrices combination. The post-decoder 360 processes the received signal and decodes the precoded symbols.

FIG. 4 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

Referring to FIG. 4, in the communication system, the wireless communication system 400 using closed-loop spatial multiplexing according to one embodiment comprises a transmitter 410 and a receiver 420.

The receiver 420 may comprise the precoder 440 which comprise the first precoder 442 and second precoder 230. Since operation of the first precoder 442 and the second precoder 444 has been described above, a more detailed description of the first precoder 442 and the second precoder 444 will be omitted.

For example, the first precoder 442 may precode a set of symbols from the layer mapper by means of the first precoding matrix derived from the short term feedback information such as the short term PMI. The second precoder 444 may also precode a set of symbols from the first precoder 442 by means of the second precoding matrix derived from the long term feedback information such as the long term PMI.

The receiver 420 may comprise a channel estimator 450, a post-decoder 460 and a transformer 470.

The receiver 420 estimates the channel by the channel estimator 450. Based on the estimated channel information such as a short term channel information, then the receiver 420 selects the precoding matrix for the first level from the corresponding codebook 455 such as the unitary codebook. The receiver 420 may feedback the PMI(Precoding Matrix Indication) for the first precoding matrix to the precoder 440, for example the first precoder 442. The PMI is the index of the selected precoding matrix in the corresponding codebook 455.

The receiver 420 also estimates the long term/wideband statistic property such as the channel correlation matrix $R$ in time or frequency domain as follows.

$$R = E \left[ \sum_{m=1}^{N} h_m h_m^H \right]$$

Here, $R$ is the channel correlation matrix, $E$ is a expectation of the product of the
downlink channel matrix and its Hermitian transpose and N is the number of the considered downlink channel matrices.

As to the channel correlation matrix, the correlation matrix may be Hermitian matrix as follows.

\[ R = R^H \]

The receiver 420 may transform this correlation matrix R to get the transform matrix T. If the MIMO channel has some correlation, the MIMO performance will be getting worse. The correlation of MIMO channel depends on the distance between antennas. The larger distance, the lower correlation. The performance is shown as follows.

However, if the channel correlation matrix can be known at the transmitter 410, we can do some transform for the precoding. In this case, the channel correlation can be compensated at the transmitter 410. The correlated channel

\[ H = H_{i.i.d} \]

Where

\[ H_{i.i.d} \]

is the independent and identically distributed (i.i.d) channel matrix, and R is a correlation matrix. If we do the transform, the transformed channel will be as

\[ H = HR^{-1/2} \]

After the transform, It will have the similar performance as i.i.d channel.

As to the transform operation, there are several methods for the transformation with different complexity and performance. For example, several methods for the trans-
formation may be one of a EVD(eigenvalue decomposition) based transform, a square
root transform and a direct precoding, but it isn't limited thereto.

[78] The EVD(eigenvalue decomposition) based transform may be as follows.

[79] [Formula 3]

[80] \[ T = \text{EVD}(R) = \text{exev}(R) \]

[81] Here, R is the channel correlation matrix, T is the transform matrix with
EVD(eigenvalue decomposition) based transform and exev means the function of the
EVD.

[82] The square root of the channel correlation matrix is as follow.

[83] [Formula 4]

[84] \[ T = R^{\frac{1}{2}} \]

[85] The simpler transform is direct precoding, that is direct use the channel correlation
matrix as precoding matrix.

[86] [Formula 5]

[87] \[ T = R \]

[88] The receiver 420 selects the second precoding matrix from corresponding codebook
475 which has nearer or the nearest distance with the transform matrix T. This corre-
sponding codebook 475 for the long term feedback may be equal to or different from
the above codebook 455 for the short term feedback.

[89] As to the codebook for the transform at the receiver 420, the corresponding
codebook475 for the long term feedback may be one of several codebooks such as a
DFT codebook, a FFT codebook and a Hermitian codebook. The DFT codebook may
be a good choice for the EVD based transform. The FFT codebook for Eigen vector
feedback is as follows.

[90] [Formula 6]

[91] \[
\begin{bmatrix}
1 \\
1 \\
1 \\
1 \\
1 \\
1 \\
1 \\
1
\end{bmatrix}
\begin{bmatrix}
1 & j\pi & j2\pi & j3\pi & j4\pi & j5\pi & j6\pi & j7\pi \\
e^\frac{\pi}{4} & e^\frac{2\pi}{4} & e^\frac{3\pi}{4} & e^\frac{4\pi}{4} & e^\frac{5\pi}{4} & e^\frac{6\pi}{4} & e^\frac{7\pi}{4} & e^\frac{8\pi}{4}
\end{bmatrix}
\]

[92] Since the correlation matrix may be Hermitian matrix, the matrix for its codebook is
also Hermitian matrix as follows.

[93] [Formula 7]

[94] \[ C = C^H \]

[95] For example, the Hermitian codebook for correlation matrix is as follows.

[96] [Formula 8]
In other words, the transformed matrix may have the same feature of the channel correlation matrix for other transforms except for EVD based transform. So Hermitian codebook will be used as an example.

As to the PMI search from the corresponding codebook 475, a chordal distance may be employed but it isn't limited thereto. For example, the chordal distance still may be one choice for the transform at the receiver 420, for example, if EVD is used for transform. The chordal distance between two matrices U and V is defined as follows.

\[ d(U, V) = \frac{1}{\sqrt{2}} \|UU^H - VV^H\|_F \]

where

\[ \|U\|_F = \|V\|_F = 1 \]

In case of other transform which direct relate to the channel correlation matrix, the original chordal distance may be not optimal. This is because the property of different elements has different importance in channel correlation matrix. The diagonal elements which decide the average power usual have higher importance. So we proposed the weighted distance. That is the diagonal element has higher weight, others have lower weight.

The proposed weighted distance can be expressed as follow.

\[ d(U, V) = \frac{1}{\sqrt{2}} \|\Lambda \cdot U(\Lambda \cdot U)^H - \Lambda \cdot V(\Lambda \cdot V)^H\|_F \]

Where
Moreover are a real number and in addition, is the inner product between matrices as an follow example,

\[ \begin{bmatrix} \lambda_1 & \lambda_2 & \ldots & \lambda_2 \\ \lambda_2 & \lambda_1 & \ldots & \lambda_2 \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_2 & \lambda_2 & \ldots & \lambda_1 \end{bmatrix} \]

and

\[ \| \Lambda \|_F = 1 \]

Moreover

\( \lambda_1, \lambda_2 \)

are a real number and

\( \lambda_1 > \lambda_2 \)

In addition,

is the inner product between matrices as an follow example,

\[ [108] \quad \text{[Formula 11]} \]
The receiver 420 may feedback the PMI (Precoding Matrix Indication) for the second precoding matrix from the codebook such as

\[ \mathbf{C}_{i}^{(2)} \]

to the precoder 440 of the transmitter 410, for example the second precoder 444.

As a result, the receiver/mobile terminal 420 separately feedback the PMIs of both level to the transmitter 410.

The transmitted 10 receives PMI feedback for the first precoding by the short term and PMI feedback for the second precoding by the long term.

If the input date symbol is

\[
\begin{bmatrix}
S_1 \\
S_2 \\
\end{bmatrix}
\]

, the output signal of the transmitter 410 is

\[
\mathbf{C}_j^{(1)} \mathbf{C}_i^{(2)} \begin{bmatrix}
S_1 \\
S_2 \\
\end{bmatrix}
\]

where
$C_{j}^{(1)}$

is the short term precoding matrix and

$C_{j}^{(2)}$

is the long term precoding matrix.

[114] FIG.5 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

[115] Referring to FIG.5, in the communication system, the wireless communication system 500 using closed-loop spatial multiplexing according to another embodiment comprises a transmitter 510 and a receiver 520.

[116] The transmitter 510 may comprise the precoder 540 which comprises the first precoder 542 and second precoder 530. All elements of the transmitter 510 are substantially equal to them of the transmitter 410 in FIG.4. Except that the first precoder 542 may precode a set of symbols from the layer mapper by means of the first precoding matrix derived from the long term feedback information such as the long term PMI. These second precoder 544 may also precode a set of symbols from the first precoder 542 by means of the second precoding matrix derived from the short term feedback information such as the short term PMI.

[117] As mentioned above, the short term PMI is the index of the selected precoding matrix from the corresponding codebook 555 based on the estimated channel information or matrix. The long term PMI is the index of the second precoding matrix from corresponding codebook 575 which has nearer or the nearest distance with the transform matrix T.

[118] FIG.6 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

[119] Referring to FIG.6, in the communication system, the wireless communication system 600 using closed-loop spatial multiplexing according to one embodiment comprises a transmitter 610 and a receiver 620.
The transmitter 610 may comprise the precoder 640 which comprise the first precoder 642 and second precoder 644. Since operation of the first precoder 642 and the second precoder 644 has been described above, a more detailed description of the first precoder 642 and the second precoder 644 will be omitted.

The transmitter 610 may also comprise the transformer 670. The detailed operation of the transformer 670 will be described later.

The receiver 620 may comprise a channel estimator 650 and a post-decoder 660.

The receiver 620 estimates the channel by the channel estimator 650. The receiver 620 may feedback the short term feedback information such as the short term PMI to the first precoder 642 and the long term feedback information such as the long term PMI to the second precoder 644.

Since operation of the short term feedback to the first precoder 642 has been described above, a more detailed description of its operation will be omitted.

The receiver 620 also estimates the long term/wideband statistic property such as the channel correlation matrix R in time or frequency domain as described referring to FIGs.4 and 5.

Although the above described is that the receiver may transform this correlation matrix R to get the transform matrix T, select the long term precoding matrix from corresponding codebook 675 which has nearer or the nearest distance with the transform matrix T using several methods for the transformation, and then feedback the PMI(Precoding Matrix Indication) for the long term precoding matrix from the codebook 675 such as

\[ C_{i}^{(2)} \]

The receiver 620 may select the long term precoding matrix from corresponding codebook 675 which has nearer or the nearest distance with its own correlation matrix R, not the transform matrix T and then feedback the PMI(Precoding Matrix Indication) for the selected long term precoding matrix from the codebook 675.

As a result, the receiver/mobile terminal 620 separately feedback the PMIs of both level to the transmitter 610.

The transmitter 610 receives PMI feedback for the first precoding by the short term and PMI feedback for the second precoding by the long term.

The precoder 640 of the transmitter 610 precodes the data symbols by using two
level precoders based on the feedback PMIs. For the first level precoding, it is directly used feedback PMI for precoding (PMI based precoding). For the second level precoding, it is transform based precoding. The transmitter 610 may directly use a long term feedback PMI to select the matrix from the codebook equal to the codebook 675 of the transmitter 610 and transform the selected matrix using several methods such the EVD based transform, the square root transform and the direct precoding to get the transform matrix by the transformer 670. In other words, the precoding matrix for this level is got by transform of the matrix searched from its own codebook.

For transform at the transmitter 610, weighted distance and Hermitian codebook may also be used. If the selected precoding matrix from the codebook is

\[ C_{i}^{(2)} \]

the transform matrix T using several methodssuch the EVD based transform, the square root transform and the direct precoding is as follows.

\[ T = \text{EVD}(C_{i}^{(2)}) = \text{exev}(C_{i}^{(2)}) \]

\[ T = (C_{i}^{(2)})^{\frac{1}{2}} \]

\[ T = C_{i}^{(2)} \]
After two level precoding, the transmitter 610 transmits the precoded data symbols by different antennas. At the receiver 620, it recovers the original data symbols by post decoder 660.

If the input date symbol is
\[
\begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

the output signal of the transmitter 610 is
\[
TC_{j}^{(1)} \begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

where
\[
C_{j}^{(1)}
\]

the short term precoding matrix and T is the transform matrix.

FIG.7 is the block diagram of the wireless communication system using closed-loop spatial multiplexing according to another embodiment.

Referring to FIG.7, in the communication system, the wireless communication system 700 using closed-loop spatial multiplexing according to another embodiment comprises a transmitter 710 and a receiver 720.

The transmitter 710 may comprise the precoder 740 which comprises the first precoder 742 and second precoder 730. All elements of the transmitter 710 are sub-
stantially equal to them of the transmitter 610 in FIG.4. Except that the first precoder 742 may precode a set of symbols from the layer mapper by means of the first precoding matrix derived from the long term feedback information from the corresponding codebook 775 such as the long term PMI. The second precoder 744 may also precode a set of symbols from the first precoder 742 by means of the second precoding matrix derived from the short term feedback information such as the short term PMI from the corresponding codebook 755.

Of course, the first precoding matrix derived from the long term PMI is the transform matrix which the transformer 770 transform the selected matrix using several methods to get.

If the input date symbol is

\[
\begin{bmatrix}
  S_1 \\
  S_2
\end{bmatrix}
\]

the output signal of the transmitter 710 is

\[
C^{(1)}_j T \begin{bmatrix} S_1 \\ S_2 \end{bmatrix}
\]

where

\[
C^{(1)}_j
\]

the short term precoding matrix and T is the transform matrix.

FIG.8 is the flowchart of the CL-MIMO system according to further another embodiment.

Referring to FIGs. 4, 5 and 8, in the multilevel precoding CL-MIMO system, there
may estimate the channel at S810.

Based on the estimated channel information such as a short term channel information, there may select the precoding matrix for the first level from the corresponding codebook such as the unitary codebook at S820.

There may feedback the PMI(Precoding Matrix Indication) for the short term precoding matrix to the precoder. The PMI is the index of the selected precoding matrix in the corresponding codebook at S830.

Unless there may select the precoding matrix based on the estimated channel information, there may also estimate the long term/wideband statistic property such as the channel correlation matrix R in time or frequency domain at formula 1 at S840.

There may transform this correlation matrix R to get the transform matrix T. As mentioned above, there are several methods such as a EVD (eigenvalue decomposition) based transform, a square root transform and a direct precoding for the transformation with different complexity and performance.

There may feedback the PMI(Precoding Matrix Indication) for the long term precoding matrix from the codebook to the precoder of the transmitter at S860.

There may select the long term precoding matrix from corresponding codebook which has nearer or the nearest distance with the transform matrix T.

As to the PMI search from the corresponding codebook, a chordal distance at formula 9 or the proposed weighted distance at formula 10 may be employed but it isn't limited thereto.

As a result, the receiver/mobile terminal 420 separately feedback the PMIs of both level to the transmitter at S830 and S860.

The transmitter receives PMI feedback for the first precoding by the short term and PMI feedback for the second precoding by the long term.

There may use the short term PMI to find the short term precoding matrix at S870. There may also use the long term PMI to find the long term precoding matrix at S880. As mentioned above, the short term PMI is the index of the selected short term precoding matrix from the corresponding codebook based on the estimated channel information or matrix. The long term PMI is the index of the selected long term precoding matrix from corresponding codebook which has nearer or the nearest distance with the transform matrix T.

The transmitter may perform the multilevel precoding using the short term precoding matrix and the long term precoding matrix at S890.

At first, the precoder of the transmitter may precode a set of symbols by means of the first precoding matrix as one of the short term precoding matrix and the long term precoding matrix. In turn the precoder of the transmitter may also precode a set of symbols by means of the second precoding matrix as the other of the short term
precoding matrix and the long term precoding matrix.

If the input date symbol is

\[
\begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

the output signal of the transmitter is

\[
C_j^{(1)} C_i^{(2)} \begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

or

\[
C_i^{(2)} C_j^{(1)} \begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

where

\[
C_j^{(1)}
\]

is the short term precoding matrix and

\[
C_i^{(2)}
\]

is the long term precoding matrix.

There may transmit the precoded data symbols by different antennas at the
transmitter.

FIG.9 is the flowchart of the CL-MIMO system according to further another embodiment. Referring to FIGs. 6, 7 and 9, in the multilevel precoding CL-MIMO system, there may estimate the channel at S910. Based on the estimated channel informationsuch as a short term channel information, then there may select the precoding matrix for the first from the corresponding codebooks such as the unitary codebook at S920. There may feedback the PMI(Precoding Matrix Indication) for the precoding matrix to the precoder. The PMI is the index of the selected precoding matrix in the corresponding codebook at S930. Unless there may select the precoding matrix based on the estimated channel information, there may also estimate the long term/wideband statistic property such as the channel correlation matrix R in time or frequency domain at formula 1 at S840. There may feedback the PMI(Precoding Matrix Indication) for the long term precoding matrix from the codebook to the precoder of the transmitter at S860. There may select the long term precoding matrix from corresponding codebook which has nearer or the nearest distance with the channel correlation matrix R. As to the PMI search from the corresponding codebook, a chordal distance at formula 9 or the proposed weighted distance at formula 10 may be employed but it isn't limited thereto.

As a result, the receiver/mobile terminal separately feedback the PMIs of both level to the transmitter at S930 and S960. The transmitter receives PMI feedback for the first precoding by the short term and PMI feedback for the second precoding by the long term. There may use the short term PMI to find the short term precoding matrix at S870. There may also use the long term PMI to find the long term precoding matrix at S880. As mentioned above, the short term PMI is the index of the selected short term precoding matrix from the corresponding codebook based on the estimated channel information or matrix. The long term PMI is the index of the selected long term precoding matrix from corresponding codebook which has nearer or the nearest distance with the correlation matrix R.

There may transform the selected long term precoding matrix using several methods such the EVD based transform, the square root transform and the direct precoding to get the transform matrix T at 985. The several transform methods may be one of the EVD based transform, the square root transform and the direct precoding at Formula 12 to 14.

The transmitter may perform the multilevel precoding using the short term precoding
matrix and the long term transform precoding matrix at S890.

At first, the precoder of the transmitter may precode a set of symbols by means of the first precoding matrix as one of the short term precoding matrix and the long term transform precoding matrix. In turn the precoder of the transmitter may also precode a set of symbols by means of the second precoding matrix as the other of the short term precoding matrix and the long term transform precoding matrix.

If the input date symbol is

\[
\begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

, the output signal of the transmitter 610 is

\[
C_j^{(1)} T \begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

or

\[
T C_j^{(1)} \begin{bmatrix}
S_1 \\
S_2
\end{bmatrix}
\]

where

\[
C_j^{(1)}
\]
the short term precoding matrix and T is the long term transform matrix.

[176] There may transmit the precoded data symbols by different antennas at the transmitter.

[177] In these embodiments, we consider the long term channel correlation matrix/wideband channel property for multilevel precoding. In the proposed scheme, the codebook based transform is investigated for the long term/wideband channel property feedback. The second one is for unitary precoding. With the proposed scheme, we can get harmonized solution of codebook based PMI plus transform multilevel precoding.

[178] The methods and systems as shown and described herein may be implemented in software stored on a computer-readable medium and executed as a computer program on a general purpose or special purpose computer to perform certain tasks. For a hardware implementation, the elements used to perform various signal processing steps at the transmitter(e.g., coding and modulating the data, precoding the modulated signals, preconditioning the precoded signals, and so on) and/or at the receiver(e.g., recovering the transmitted signals, demodulating and decoding the recovered signals, and so on) may be implemented within one or more application specific integrated circuits(ASICs), digital signal processors(DSPs), digital signal processing devices (DSPDs), programmable logic devices(PLDs), field programmable gate arrays(FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof. In addition or in the alternative, a software implementation may be used, whereby some or all of the signal processing steps at each of the transmitter and receiver may be implemented with modules(e.g., procedures, functions, and so on) that perform the functions described herein. It will be appreciated that the separation of functionality into modules is for illustrative purposes, and alternative embodiments may merge the functionality of multiple software modules into a single module or may impose an alternate decomposition of functionality of modules. In any software implementation, the software code may be executed by a processor or controller, with the code and any underlying or processed data being stored in any machine-readable or computer-readable storage medium, such as an on-board or external memory unit.

[179] Although the described exemplary embodiments disclosed herein are directed to various MIMO precoding systems and methods for using same, the present invention is not necessarily limited to the example embodiments illustrate herein. For example, various embodiments of a MIMO precoding system and design methodology disclosed herein may be implemented in connection with various proprietary or wireless communication standards, such as IEEE 802.16e, 3GPP-LTE, DVB and other multi-user MIMO systems. Thus, the particular embodiments disclosed above are illustrative only and should not be taken as limitations upon the present invention, as the invention may
be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Accordingly, the foregoing description is not intended to limit the invention to the particular form set forth, but on the contrary, is intended to cover such alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims so that those skilled in the art should understand that they can make various changes, substitutions and alterations without departing from the spirit and scope of the invention in its broadest form.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature or element of any or all the claims. As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.
Claims

[Claim 1] A method for feedbacking channel information, comprising:
selecting a short term precoding matrix from short term codebook
based on the estimated downlink channel;
estimating a statistic property;
transforming the statistic property to get a long term transform matrix;
and
feedbacking a short term feedback information for the short term
precoding matrix and a long term feedback information for the long
term transform matrix from long term codebook.

[Claim 2] The method in claim 1, wherein the statistic property is a channel correlation matrix.

[Claim 3] The method in claim 1, wherein the short term feedback information
for the short term precoding matrix is a PMI of the short term
precoding matrix in the corresponding codebook and the long term
feedback information for the long term precoding matrix is a PMI of
the long term precoding matrix from corresponding codebook which
has nearer or the nearest distance with the long term transform matrix.

[Claim 4] The method in claim 3, wherein the transforming statistic property is
transformed from the downlink channel correlation matrix using one of
an EVD transform, a Square root transform and direct precoding.

[Claim 5] The method in claim 4, wherein the corresponding codebook for the
long term precoding matrix is one of Hermitian codebook and DFT
codebook.

[Claim 6] A method, comprising:
receiving a short term feedback information for the short term
precoding matrix based on the estimated downlink channel and a long
term feedback information for the long term precoding matrix based on
a statistic property of the estimated downlink respectively;
find the short term precoding matrix and the long term precoding
matrix by searching the short term feedback information and the long
term feedback information from the corresponding codebook re-
spectively;
transforming the long term precoding matrix to get the long term
transform precoding matrix; and
perform the multilevel precoding using the short term precoding matrix
and the long term transform precoding matrix.
[Claim 7] The method in claim 6, wherein the statistic property is a channel correlation matrix.

[Claim 8] The method in claim 6, wherein the statistic property is transformed from the long term precoding matrix using one of a EVD transform, a Square root transform and direct precoding.

[Claim 9] A method, comprising:

- mapping a codeword to a layer;
- precoding a mapped set of symbols using at least two precoding matrices in turn where one of them is the precoding matrix transformed from a downlink channel correlation matrix and
- transmitting a signal that comprises the precoded set of symbols.

[Claim 10] The method in claim 9, wherein the precoding matrix is transformed from a downlink channel correlation matrix at a receiver.

[Claim 11] The method in claim 9, wherein the precoding matrix is transformed from a downlink channel correlation matrix at a transmitter.

[Claim 12] The method in claim 9, wherein the precoding matrix is transformed from a downlink channel correlation matrix using one of a EVD transform, a Square root transform and direct precoding.

[Claim 13] The method in claim 9, wherein at least two precoding matrices are derived from at least two downlink channel information from a receiver.

[Claim 14] The method in claim 13, wherein two downlink channel information are two feedback PMIs (Precoding Matrix Index).

[Claim 15] A mobile terminal comprising:

- an estimator configured to select a short term precoding matrix from short term codebook based on the estimated downlink channel, estimate a statistic property, and feedback a short term feedback information from long term codebook for the short term precoding matrix;
- a transformer configured to transform the statistic property to get a long term transform matrix and feedback a long term feedback information for the long term transform matrix; and
- a post-decoder configured to decode the received signal to recover the set of data symbols.

[Claim 16] The mobile terminal in claim 15, wherein the statistic property is a channel correlation matrix.

[Claim 17] The mobile terminal in claim 15, wherein the short term feedback information for the short term precoding matrix is a PMI of the short term precoding matrix in the corresponding codebook and the long term
feedback information for the long term precoding matrix is a PMI of the long term precoding matrix from corresponding codebook which has nearer or the nearest distance with the long term transform matrix.

[Claim 18] The mobile terminal in claim 17, wherein the transforming statistic property is transformed from the downlink channel correlation matrix using one of a EVD transform, a Square root transform and direct precoding.

[Claim 19] The mobile terminal in claim 18, wherein the corresponding codebook for the long term precoding matrix is one of Hermitian codebook and DFT codebook.

[Claim 20] A base station, comprising:

a layer mapper configured to map one or two codewords to the layers;
a precoder configured to receive a short term feedback information for the short term precoding matrix based on the estimated downlink channel and a long term feedback information for the long term precoding matrix based on a statistic property of the estimated downlink respectively, find the short term precoding matrix and the long term precoding matrix using the short term feedback information and the long term feedback information respectively, and perform the multilevel precoding using the short term precoding matrix and the long term transform precoding matrix and

a transformer configured to transform the long term precoding matrix to get the long term transform precoding matrix.

[Claim 21] The base station in claim 20, wherein the statistic property is a channel correlation matrix.

[Claim 22] The base station in claim 20, wherein the statistic property is transformed from the long term precoding matrix using one of a EVD transform, a Square root transform and direct precoding.
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

**H04B 7/04 (2006.01)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 7/04; G06F 15/16; H04J 3/22; H04B 7/02**

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

- ** Korean utility models and applications for utility models**
- ** Japanese utility models and applications for utility models**

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

- eKOMPASS (KIPO internal), IEEExpl, Google & Keywords: codebook, codeword, MIMO, control information, and similar terms.

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td><code>Overview of IEEE P802.16m Technology and Candidate RIT for IMT-Advanced,</code> in: IEEE 802.16 IMT-Advanced Evaluation Group Coordination Meeting, 13 January 2010. See abstract and page 60.</td>
<td>1-22</td>
</tr>
</tbody>
</table>

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

- **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 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: 29 DECEMBER 2010 (29.12.2010)

Date of mailing of the international search report: 03 JANUARY 2011 (03.01.2011)

Name and mailing address of the ISA/KR

- Korean Intellectual Property Office
  - Government Complex-Deajeon, 139 Seoonsa-ro, Seo-gu, Deajeon 302-701, Republic of Korea
  - Facsimile No. 82-42-472-7140

Authorized officer

- Kim Sun Jong
  - Telephone No. 82-42-481-8260

Form PCT/ISA/210 (second sheet) (My 2009)
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Form PCT/ISA/210 (patent family annex) (July 2009)