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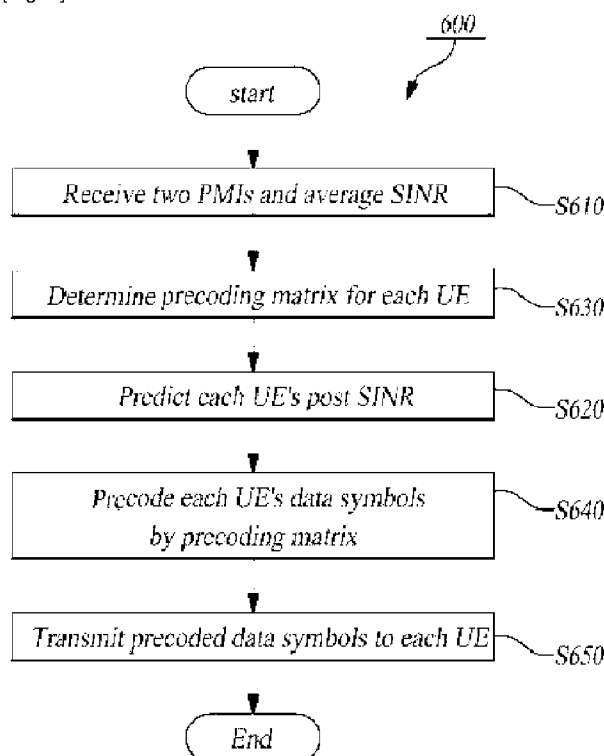
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(54) Title: METHOD FOR FEEDBACK AND RECEIVE CHANNEL INFORMATION METHOD, RECEIVER AND TRANSMITTER THEREOF IN WIRELESS COMMUNICATION SYSTEM

[Fig. 6]



(57) Abstract: The present invention relates to precoding and feedback channel information in wireless communication system.

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Description

Title of Invention: METHOD FOR FEEDBACK AND RECEIVE CHANNEL INFORMATION METHOD, RECEIVER AND TRANSMITTER THEREOF 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 of each of two or more receivers in a MU MIMO mode comprising: feedbacking the channel information and an CQI information to a transmitter; and Receiving a signal from the transmitter which predicts a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling.
- [4] In accordance with the other aspect, there is provided a method comprising: a method, comprising: receiving the channel information and an CQI information from each of two or more receivers; calculating the precoding matrix for MU-MIMO and predicting a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling; and transmitting a signal to each of two or more receivers.
- [5] In accordance with another aspect, there is provided a receiver comprising: an estimator configured to feedback the channel information and an CQI information to a transmitter and receive a signal from the transmitter which predicts a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling; and a post-decoder configured to decode the received signal to recover the set of data symbols.
- [6] In accordance with another aspect, there is provided a receiver comprising: an estimator configured to feedback the Precoding matrix index (PMI) and two CQI in-

formation to a transmitter and receive a signal from the transmitter which predicts a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling; and a post-decoder configured to decode the received signal to recover the set of data symbols.

- [7] In accordance with another aspect, there is provided a transmitter, comprising: a layer mapper configured to map one or two codewords to the layers; a precoder configured to receive the channel information from each of two or more receivers and transmit a signal to each of two or more receivers; and a scheduler configured to receive an CQI information from each of two or more receivers and predict a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling.

Brief Description of Drawings

- [8] FIG.1 is the block diagram of the wireless communication system using a MU-MIMO system according to one embodiment.
- [9] FIG.2 is the flowchart of operation for the receiver in the MU-MIMO system according to the other embodiment.
- [10] FIG.3 is the flowchart of operation for the transmitter in the MU-MIMO system according to another embodiment.
- [11] FIG.4 is the block diagram of the wireless communication system using the MU-MIMO system according to further embodiment.
- [12] FIG.5 is the flowchart of operation for the receiver in the MU-MIMO system according to further another embodiment.
- [13] FIG.6 is the flowchart of operation for the transmitter in the MU-MIMO system according to further another embodiment.
- [14] 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

- [15] Hereinafter, embodiments of the present invention will be described in detail with reference to the attached drawings.
- [16] FIG.1 is the block diagram of the wireless communication system using a MU-MIMO system according to one embodiment.
- [17] Referring to FIG.1, the wireless 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 one embodiment comprises a transmitter 110 and one or more receivers 120a to 120k. The wireless communication system 100 may be a MU-MIMO system which may allow the transmitter 110 to transmit signal to two or more receivers 120a to 120k in the same band simultaneously.

- [18] The transmitter 110 may act as a base station, while each of the receivers 120a to 120k 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, each of the receivers/subscriber stations 120a to 120k where "k" is an integer representing the number of the receivers in a given geographic area can also transmit signals which are received by the transmitter/base station 110. The signals communicated between the transmitter 110 and each of the receivers 120a to 120k can include voice, data, electronic mail, video, and other data, voice, and video signals.
- [19] In operation, the transmitter 110 transmits a signal data stream through one or more antennas over a channel to each of the receivers 120a to 120k, 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.
- [20] The transmitter 110 comprises a layer mapper 130, a precoder 140 and a scheduler 145.
- [21] 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).
- [22] 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 $N_L \times N_A$.
- [23] 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.

- [24] The precoder 140 may comprise two level precoders to enhance or substantially optimize the performance.
- [25] To assist the base station in selecting a suitable precoding matrix for transmission by the transmitter 110, each of the receivers/mobile terminals 120a to 120k 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.
- [26] Each of the receivers 120a to 120k may comprise a channel estimator 150 and a post-decoder 160.
- [27] Each of the receivers 120a to 120k estimates the channel state information (CSI) by the channel estimator 150. The channel estimator 150 estimates the downlink channel state information including its channel matrix H_i by using a pilot signal or a reference signal such as a SRS (sounding Reference Signal) or a CSI-RS (channel state information-Reference Signal). The channel estimator 150 selects the matrix index from the codebook which is the nearest one to the CSI. This refers to "codebook based CSI".
- [28] As to the matrix index search from the corresponding codebook, a chordal distance may be employed but it isn't limited thereto. For example, the chordal distance still may be one choice. The chordal distance between two matrices U and V is defined as follows.
- [29] [Formula 1]
- [30]
$$d(U, V) = \frac{1}{\sqrt{2}} \|UU^H - VV^H\|_F$$
- [31] where
- $$\|U\|_F = \|V\|_F = 1$$
- .
- [32] The channel estimator 150 may estimate the average SINR (Signal to Interference plus Noise Ratio) level which includes the noise and intercell interference as to the CQI (Channel Quality index). The noise and intercell interference among different layer in a Multiple Input Multiple Output (MIMO) may be not taken into account for this CQI.
- [33] The channel estimator 150 may feedback both the codebook based CSI as a CSI and the average SINR as the CQI to the transmitter 110.

[34] Based on the feedback information from the receivers 120a to 120k, the transmitter 110 runs Multi User-Multiple Input Multiple Output(MU-MIMO) scheduling by the scheduler 145. For example, the transmitter 110 selects two or more receivers to pair them together and calculate the precoding matrices of them based on their feedback information such as the codebook based CSI. When there is the MIMO operation in the MU-MIMO mode, the transmitter 110 can predict the post SINR for each of receivers based on their feedback information such as the average SINR and then decide the MCS(Modulation and Coding Scheme) level for each receiver. The average SINR referred to is the geometric average of the linear scale SINRs, or equivalently, the arithmetic average of the log-scale SINRs. The average SINR indicate the average power of intercell interference plus noise.

[35] It should be noted that there is not the average SINR of the receiver k over all its L_k data streams $SINR_k =$

$$\sum_{j=1}^{L_k} SINR_{kj} / L_k$$

as the performance measure, but the average SINR which is the average signal power over intercell interference plus noise. In the average SINR, the interference among different layers is not included.

[36] Assume that H_i is the channel matrix $N_r \times N_t$ at the receiver i which is known at the transmitter 110 from the receiver feedback and C_i is the precoding matrix $N_t \times R_i$ for the receiver i which is calculated by the transmitter 110.

[37] The received signal can be expressed with the virtual channel matrix

$$\tilde{H}_i = H C_i$$

as follows:

[38] [Formula 2]

[39]

$$Y = \tilde{H}_i X_i + n$$

[40] Where

$$\tilde{H}_j$$

$j=1,...,k$ and n is the noise plus intercell interference at the receiver i.

[41] The transmitter 110 may predict the CSI including the channel matrix H_i from the codebook based on the codebook based CSI and determine the precoding matrix from the channel matrix H_i .

[42] The precoding matrix can be calculated by follows: Here, we assume that two receivers are paired together for MU-MIMO operation. The precoder of the receiver 1(UE 1) is expressed as

$$[43] \quad C_1 = \arg \max_w \frac{W^H H_1^H H_1 W}{W^H (H_2^H H_2 + P_2 I_{N_t}) W} = \text{evec}\{(H_2^H H_2 + P_2 I_{N_t})^{-1} \times H_1^H H_1\}$$

$$C_2 = \arg \max_w \frac{W^H H_2^H H_2 W}{W^H (H_1^H H_1 + P_1 I_{N_t}) W} = \text{evec}\{(H_1^H H_1 + P_1 I_{N_t})^{-1} \times H_2^H H_2\}$$

[44] Where P_1 and P_2 is the average power of noise plus intercell interference feedback by the receiver and $(.)^H$ menans herman matrix of matrix $(.)$.

[45] As a result, the transmitter 110 can exactly know the virtual channel matrix

$$\tilde{H}_i = H C_i$$

. The receiver i can get its date symbols as follows:

[46] [Formula 3]

$$[47] \quad \hat{X}_i = W_i Y = W_i \tilde{H}_i X_i + W_i n$$

[48] W_i may be usually gotten by MMSE(minimum mean square error) as follows:

[49] [Formula 4]

$$[50] \quad W_i = ((\tilde{H}_i^H \tilde{H}_i + \sigma^2 I)^{-1} \tilde{H}_i^H)_i$$

[51] where

$$\sigma^2$$

is the variance of the noise plus intercell interference which is feed back as the CQI from each receiver and I is the identity matrix.

[52] The post SINR which is the SINR of each data stream of each layer at the receiver i can be predicted by the transmitter 110 as follows:

[53] [Formula 5]

[54]

$$SINR = \frac{Diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)}{(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\| - diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)) + \|\mathbf{W}_i \mathbf{n}\|}$$

[55]

Where " $\|x\|$ " is the power of the matrix X and $diag(\|x\|)$ means the power of the diagonal elements of a matrix X.

[56]

The former of denominator at the above equation means the power of the interference among different layers of MIMO operation and the latter of denominator means the power of intercell interference plus the noise.

[57]

Assume there are only 2 receivers. If each receiver has only one layers, the SNIR prediction can be shows as follows:

[58]

$$CQI_{1,predict} = \frac{\|C_1^H H_1^H H_1 C_1\|_F^2}{\|C_1^H H_1^H H_1 C_2\|_F^2 + P_1 \|C_1^H H_1^H H_1 C_1\|_F}$$

[59]

As described above, it is very clear that the transmitter 110 can predict each receiver's post SINR without CQI mismatch. So it can decide the CQI for each receiver with higher accuracy.

[60]

Then the transmitter 110 transmits the data symbols of the receiver 120a to 120k which are precoded by the precoding matrix.

[61]

Each of the receivers 120a to 120k may estimate the precoded information such as a precoding matrix by the reference signal such as DM-RS(Demodulation-RS). Then each of the receivers 120a to 120k may recover the original data symbols by the post decoder 160 with the precoding matrix. In other word, the post-decoder 160 processes the received signal and decodes the precoded symbols.

[62]

FIG.2 is the flowchart of operation for the receiver in the MU-MIMO system according to the other embodiment.

[63]

Referring to FIGs. 1 and 2, in the MU-MIMO system, each of the receivers 120a to 120k may estimate the channel state information(CSI) at S210. The downlink channel state information including its channel matrix H_i may be estimated by using a pilot signal or a reference signal such as a SRS(sounding Reference Signal) or a CSI-RS. The matrix index "codebook based CSI" which is the nearest one to the estimated CSI may be selected from the codebook, for example, by using the chordal distance in formula 1.

[64]

The codebook based CSI may be used when the transmitter determines the precoding matrix from the channel matrix H_i which is predicted by means of the codebook based CSI from the corresponding codebook. As a result, the transmitter may know the

virtual channel matrix

$$\tilde{\mathbf{H}}_i = \mathbf{H}\mathbf{C}_i$$

- [65] The average SINR level which includes the noise and intercell interference may be estimated as to the CQI(Channel Quality index). The transmitter may get the W_i with both the estimated noise plus intercell interference as the CQI and the virtual channel matrix

$$\tilde{\mathbf{H}}_i = \mathbf{H}\mathbf{C}_i$$

in formula 4.

- [66] Each of the receivers 120a to 120k may feedback both the codebook based CSI as a CSI and the average SINR as the CQI to the transmitter 110 at S220.
- [67] When the transmitter 110 runs MU-MIMO scheduling to selects two or more receivers to pair them together, each of the receivers 120a to 120k may receive the signals which are precoded by the precoding matrix from the transmitter 110 at S230.
- [68] Each of the receivers 120a to 120k may estimate the precoded information such as a precoding matrix by using the reference signal such as DM-RS(Demodulation-RS) at S240.
- [69] Then each of the receivers 120a to 120k may recover the original data symbols by the processing device such as the post decoder 160 with the precoding matrix at S250.
- [70] FIG.3 is the flowchart of operation for the transmitter in the MU-MIMO system according to another embodiment.
- [71] Referring to FIGs.1 and 3, the transmitter 110 may receive both the codebook based CSI as a CSI and the average SINR as the CQI from each receiver at S310.
- [72] When there is the MIMO operation in the MU-MIMO mode, the transmitter 110 may predict the post SINR for each of receivers based on their feedback information such as the average SINR and then decide the MCS(Modulation and Coding Scheme) level for each receiver at S320.
- [73] Based on the feedback information from the receivers 120a to 120k, the transmitter 110 runs MU-MIMO scheduling. For example, the transmitter 110 selects two or more receivers to pair them together and calculate the precoding matrices of them based on their feedback information such as the codebook based CSI at S320.
- [74] The transmitter 110 may predict the CSI including the channel matrix H_i from the codebook based on the codebook based CSI and determine the precoding matrix from the channel matrix H_i at S320. As a result, the transmitter 110 may know the virtual

channel matrix

$$\tilde{\mathbf{H}}_i = \mathbf{H}\mathbf{C}_i$$

- [75] The post SINR at each receiver i can be predicted by the transmitter 110 in Formula 5 at S330.
- [76] Then the transmitter 110 may precode the data symbols of each of the receiver 120a to 120k by the precoding matrix at S340.
- [77] Then the transmitter 110 transmits the precoded data symbols of each of the receiver 120a to 120k at S350.
- [78] FIG.4 is the block diagram of the wireless communication system using the MU-MIMO system according to further embodiment.
- [79] Referring to FIG.4, the wireless communication system 400 may be a MU-MIMO system which may allow the transmitter 410 to transmit signal to two or more receivers 420a to 420k in the same band simultaneously.
- [80] The transmitter 410 comprises a layer mapper 430, a precoder 440 and a scheduler 445.
- [81] The layer mapper 430 of the transmitter 410 maps one or two codewords, corresponding to one or two transport, to the layers N_L .
- [82] After layer mapping by the layer mapper 430, 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 440. This combining/mapping can be described by means of a precoding matrix $\mathbf{P}$ of size $N_L \times N_A$.
- [83] The precoder 440 may comprise two level precoders to enhance or substantially optimize the performance.
- [84] Each of the receivers 420a to 420k may comprise a channel estimator 450 and a post-decoder 460.
- [85] Each of the receivers 420a to 420k estimates the channel state information (CSI) by the channel estimator 450. The channel estimator 450 estimates the downlink channel state information including its channel matrix $\mathbf{H}_i$ by using a pilot signal or a reference signal such as a SRS (Sounding Reference Signal) or a CSI-RS (Channel state information-Reference Signal). The channel estimator 450 may select two PMIs (Precoding Matrix Indices) from the codebook.
- [86] The channel estimator 450 estimates not only the post SINR of SU-MIMO but also the average SINR level for MU-MIMO mode which includes the noise and intercell interference as to the additional CQI (Channel Quality index). The noise and intercell interference among different layer in MIMO may be not taken into account for the ad-

ditional CQI.

[87] The channel estimator 450 may feedback both the two PMIs as the precoding information and the post SINR of SU-MIMO as the CQI and the average SINR as the additional CQIs to the transmitter 410. These two CQIs such as the post SINR of SU-MIMO and the average SINR may be feedback separately or together, that is feed back in the same subframe or in different subframe.

[88] Based on the feedback information from the receivers 420a to 420k, the transmitter 410 runs MU-MIMO scheduling by the scheduler 445. For example, the transmitter 410 selects two or more receiversto pair them together and calculate the precoding matrices of them based on their feedback information. Then the transmitter 410 transmits the data symbols of the receiver 420a to 420k which are precoded by the precoding matrix.

[89] When there is the MIMO operation in the MU-MIMO mode, the transmitter 410 may predict the post SINR for each of receivers based on their feedback information such as the post SINR of SU-MIMO and the average SINR and then decide the MCS(Modulation and Coding Scheme) level for each receiver.

[90] If it is assumed that the precoding matrix may feedback by two PMIs of different receivers V_1 and V_2 for each hypothetical pair of the receivers, MU beamforming with ZFBF(Zero forcing BeamForming) is derived as follows;

[91] [Formula 6]

[92]

$$F = \begin{bmatrix} F_1 & F_2 \end{bmatrix} = V^H (V V^H + \rho I)^{-1}$$

[93] where

$$V^H = [\hat{V}_1^H ; \hat{V}_2^H]$$

, ρ is a regularization factor (e.g. a heuristic function of the geometry/SNR or a constant) which can be optimized based on the feedback noise level. The MU precoding vector for the j-th receiver is the normalized k-th column of F.

[94] The reported the post SINR as a SU-MIMO CQI is processed by the transmitter 410 to derive the predicted CQI for link adaptation, factoring in the specific beamforming scheme at the transmitter 410 and conjectured residual interference.

[95] One example of MU CQI prediction at the receiver 1 is given by

[96] [Formula 7]

[97]

$$CQI_{1,predict} = \frac{CQI_1/(2n) \times \beta_{11}^2 ./ \| F_1 \|_F^2}{1 + CQI_1/(2n) \times \beta_{12}^2 / \| F_2 \|_F^2}$$

[98] where

$$\beta_{i,j} = \left((V'V)(V'V + \rho I)^{-1} \right)_{i,j}$$

, CQI₁ is the SU CQI report such as the post SINR from the receiver 1. Moreover, the ρ may be optimized by noise level feedback such as the average SINR.

[99] Based on the research, the optimal value of ρ depends on the noise level as follows at the table 1. As the average SNR increases, the optimal value of ρ decreases. If the average is very high, the optimal value of ρ is near 0.

[100] Table 1

[Table 1]

[Table]

Index	SINR	ρ
0	<5dB	0.5
1	5~15dB	0.1
2	15~25db	0.01
3	>25dB	0

[101] Each of the receivers 420a to 420k may estimate the precoded information such as a precoding matrix by the reference signal such as DM-RS(Demoulation-RS). Then each of the receivers 420a to 420k may recover the original data symbols by the post decoder 460 with the precoding matrix. In other word, the post-decoder 460 processes the receivedsignal and decodes the precoded symbols.

[102] FIG.5 is the flowchart of operation for the receiver in the MU-MIMO system according to further another embodiment.

[103] Referring to FIGs. 4 and 5, in the MU-MIMO system, Each of the receivers 420a to 420k may estimate the channel state information(CSI) at S510. The downlink channel state information including its channel matrix H_i may be estimated by using a pilot signal or a reference signal such as a SRS(sounding Reference Signal) or a CSI-RS.

[104] Each of the receivers 420a to 420k may select two PMIs(Precoding Matrix Indices) from the codebook. Each of the receivers 420a to 420k estimates not only the post SINR of SU-MIMO but also the average SINR level for MU-MIMO mode which

includes the noise and intercell interference as to the CQI(Channel Quality index). The noise and intercell interference among different layer in MIMO may be not taken into account for this CQI.

[105] Each of the receivers 420a to 420k may feedback both the two PMIs as the precoding information and the post SINR of SU-MIMO and the average SINR as the CQIs to the transmitter 410 at S520. These two CQIs such as the post SINR of SU-MIMO and the average SINR may be feedback separately or together, that is feed back in the same subframe or in different subframe.

[106] The two PMIs may be used when the transmitter 410 determines the precoding matrix from the corresponding codebook. As a result, the transmitter may know the virtual channel matrix

$$\tilde{\mathbf{H}}_i = \mathbf{H}\mathbf{C}_i$$

[107] The post SINR at the receiver i can be predicted by the transmitter 410 in Formula 7 using the post SINR of SU-MIMO and the average SINR.

[108] When the transmitter runs MU-MIMO scheduling to selects two or more receivers to pair them together, each of the receivers 420a to 420k may receive the signals which are precoded by the precoding matrix from the transmitter at S530.

[109] Each of the receivers 420a to 420k may estimate the precoded information such as a precoding matrix by using the reference signal such as DM-RS(Demodulation-RS) at S540.

[110] Then each of the receivers 420a to 420k may recover the original data symbols by the processing device such as the post decoder 460 with the precoding matrix at S550.

[111] FIG.6 is the flowchart of operation for the base station in the MU-MIMO system according to further another embodiment.

[112] Referring to FIGs.4 and 6, the transmitter 410 may receive both the two PMIs as a precoding information and, the post SINR of SU-MIMO and the average SINR as the CQIs from the receiver at S610.

[113] When there is the MIMO operation in the MU-MIMO mode, the transmitter 410 may predict the post SINR for each of receivers based on their feedback information such as the post SINR of SU-MIMO and the average SINR and then decide the MCS(Modulation and Coding Scheme) level for each receiver at S620. In other words, the post SINR at the receiver i can be predicted by the transmitter 410 in Formula 7 at S620.

[114] Based on the feedback information from the receivers 420a to 420k, the transmitter 410 runs MU-MIMO scheduling. For example, the transmitter 410 selects two or more

receivers to pair them together and calculate the precoding matrices of them based on their feedback information such as the codebook based CSI at S630.

[115] Then the transmitter 410 may precode the data symbols of each of the receiver 420a to 420k by the precoding matrix at S640.

[116] Then the transmitter 410 transmits the precoded data symbols of each of the receiver 420a to 420k at S650.

[117] In the original LTE MU-MIMO, all the feedbacks from the receiverside are for SU-MIMO. So for MU-MIMO, both the PMI and CQI are not optimized for MU-MIMO operation. In LTE, release 9, the transmitter can freely optimized the precoding matrix and send the precoding information by DM-RS. However, CQI is still a problem. There is CQI mismatch between SU-MIMO and MU-MIMO.

[118] In this embodiment, we propose a simple new feedback scheme for MU-MIMO. In proposed scheme, we feedback CSI or PMI information and average noise plus intercell interference instead of post SINR as a CQI. Based on the feedback, the transmitter can optimized the MU-MIMO transmission and calculate the post SINR for SU-MIMO mode and MU-MIMO mode. The CQI mismatch in MU-MIMO mode disappears for MU-MIMO.

[119] 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.

[120] 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.

[121] 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 of each of two or more receivers in a MU MIOM mode, comprising:
feedbacking the channel information and an CQI information to a transmitter; and
Receiving a signal from the transmitter which predicts a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling.
- [Claim 2] The method in claim 1, wherein the channel information comprises at least one of a channel matrix and two PMIs.
- [Claim 3] The method in claim 1, wherein the CQI information comprises an average SINR which indicate the power of intercell interference plus noise .
- [Claim 4] The method in claim 3, wherein the CQI information further comprises a post SINR for SU-MIMO and a additional CQI which indicate the power of intercell interference plus noise.
- [Claim 5] A method, comprising:
receiving the channel information and an CQI information from each of two or more receivers;
calaulating the precoding matrix for MU-MIMO and predicting a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling; and
transmitting a signal to each of two or more receivers.
- [Claim 6] The method in claim 5, wherein the channel information comprises one of a channel matrix or two PMIs which is used for predicting the precoding matrix and/or the virtual channel matrix each of the receivers at the transmitter.
- [Claim 7] The method in claim 5, wherein the CQI information comprises an average SINR and the post SINR for each of two or more receivers for MU-MIMO mode is predicted as follows.

$$SINR = \frac{Diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)}{(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\| - diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)) + \|\mathbf{W}_i \mathbf{n}\|}$$

Where

$$W_i = ((\tilde{H}^H \tilde{H} + \sigma^2 I)^{-1} \tilde{H}^H)_i$$

where

$$\sigma^2$$

is the variance of the noise plus intercell interference which is feedback as the CQI from the receivers and I is the identity matrix, "||x||" is the power of the matrix X and diag(||x||) means the power of the diagonal elements of a matrix X.

[Claim 8]

The method in claim 5, wherein the CQI information comprises an average SINR and a post SINR for SU-MIMO and the post SINR for each of two or more receivers for MU-MIMO mode is predicted as follows.

$$CQI_{1,predict} = \frac{CQI_1 / (2n) \times \beta_{11}^2 / \|F_1\|_F^2}{1 + CQI_1 / (2n) \times \beta_{12}^2 / \|F_2\|_F^2}$$

Where

$$F = \begin{bmatrix} F_1 & F_2 \end{bmatrix} = V^H (V V^H + \rho I)^{-1}$$

where V_1 and V_2 are two PMIs of different receivers

$$V^H = [\hat{V}_1^H ; \hat{V}_2^H]$$

, ρ is a regularization factor,

$$\beta_{i,j} = ((V' V)(V' V + \rho I)^{-1})_{i,j}$$

and CQI_1 is the post CQI report from one of the receivers.

[Claim 9]

A receiver comprising:

an estimator configured to feedback the channel information and an CQI information to a transmitter and receive a signal from the transmitter which predicts a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling and
a post-decoder configured to decode the received signal to recover the set of data symbols.

- [Claim 10] The receiver in claim 9, wherein the channel information comprises at least one of a channel matrix and two PMIs.
- [Claim 11] The receiver in claim 9, wherein the CQI information comprises an average SINR.
- [Claim 12] The receiver in claim 11, wherein the CQI information further comprises a post SINR for SU-MIMO.
- [Claim 13] A transmitter, comprising:
a layer mapper configured to map one or two codewords to the layers;
a precoder configured to receive the channel information from each of two or more receivers and transmit a signal to each of two or more receivers; and
a scheduler configured to receive an CQI information from each of two or more receivers and predict a post SINR for each of two or more receivers based on the feedback CQI information when there is a MU-MIMO scheduling.
- [Claim 14] The transmitter in claim 13, wherein the channel information comprises one of a channel matrix or two PMIs which is used for predicting the precoding matrix and/or the virtual channel matrix for each of the receivers at the transmitter.
- [Claim 15] The transmitter in claim 13, wherein the CQI information comprises an average SINR and the post SINR for each of two or more receivers for MU-MIMO mode is predicted as follows.

$$SINR = \frac{Diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)}{(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\| - diag(\|\mathbf{W}_i \tilde{\mathbf{H}}_i\|)) + \|\mathbf{W}_i \mathbf{n}\|}$$

Where

$$W_i = ((\tilde{H}^H \tilde{H} + \sigma^2 I)^{-1} \tilde{H}^H)_i$$

where

$$\sigma^2$$

is the variance of the noise plus intercell interference which is feed back as the CQI from the receivers and I is the identity matrix, " $\|X\|$ " is the power of the matrix X and $\text{diag}(\|X\|)$ means the power of the diagonal elements of a matrix X.

[Claim 16]

The transmitter in claim 13, wherein the CQI information further comprises an average SINR and a post SINR for SU-MIMO and the post SINR for each of two or more receivers for MU-MIMO mode is predicted as follows.

$$CQI_{1,\text{predict}} = \frac{CQI_1 / (2n) \times \beta_{11}^2 / \|F_1\|_F^2}{1 + CQI_1 / (2n) \times \beta_{12}^2 / \|F_2\|_F^2}$$

Where

$$F = \begin{bmatrix} F_1 & F_2 \end{bmatrix} = V^H (V V^H + \rho I)^{-1}$$

where V_1 and V_2 are two PMIs of different receivers

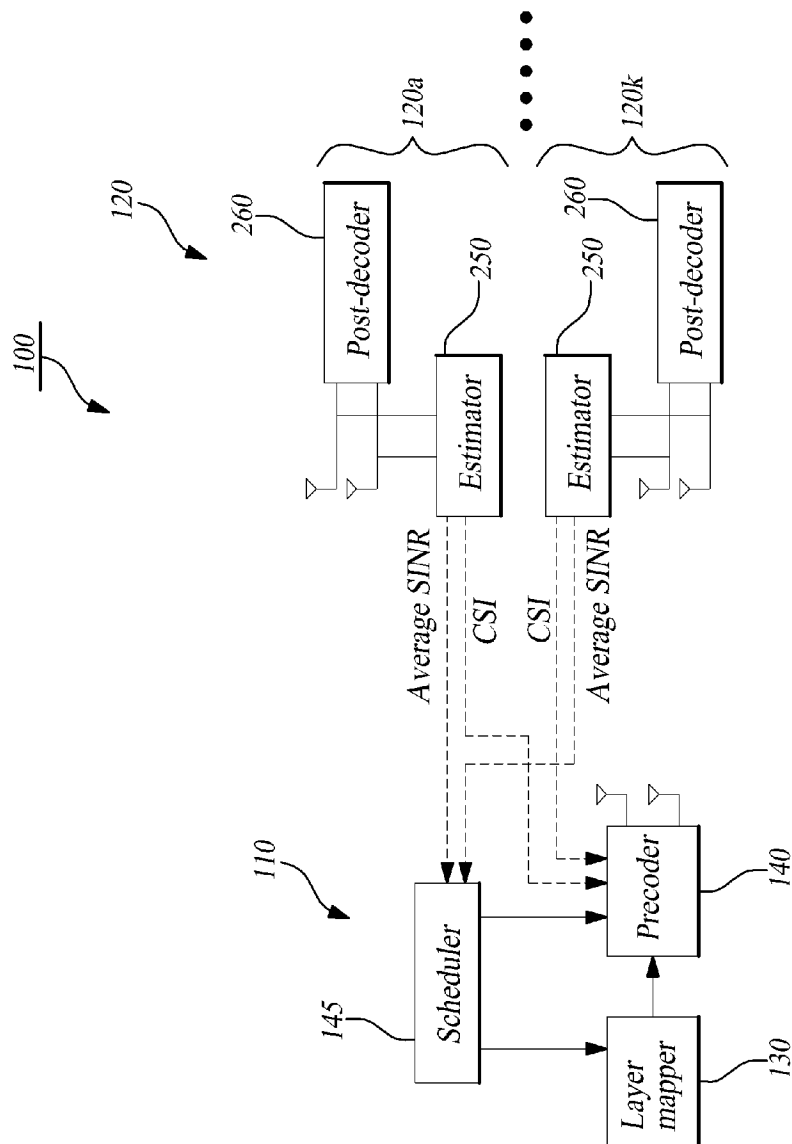
$$V^H = [\hat{V}_1^H ; \hat{V}_2^H]$$

, ρ is a regularization factor,

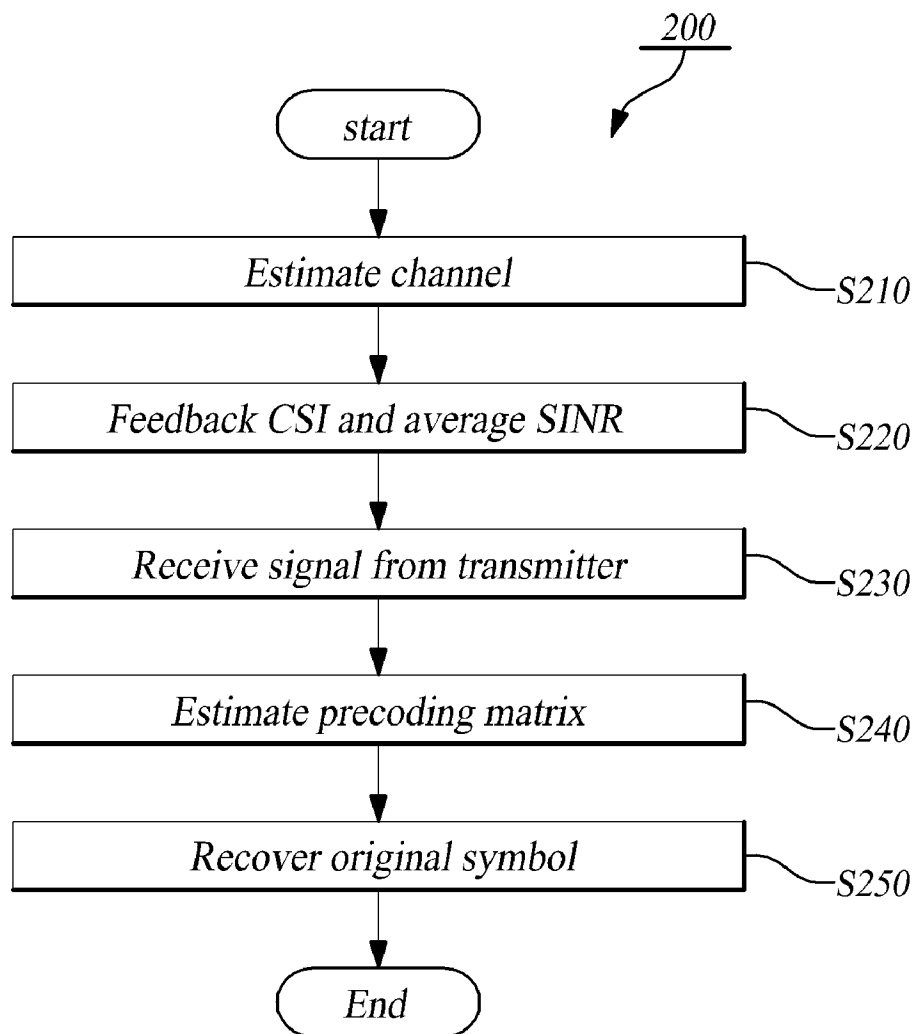
$$\beta_{i,j} = ((V' V)(V' V + \rho I)^{-1})_{i,j}$$

and CQI_1 is the post CQI report from one of the receivers.

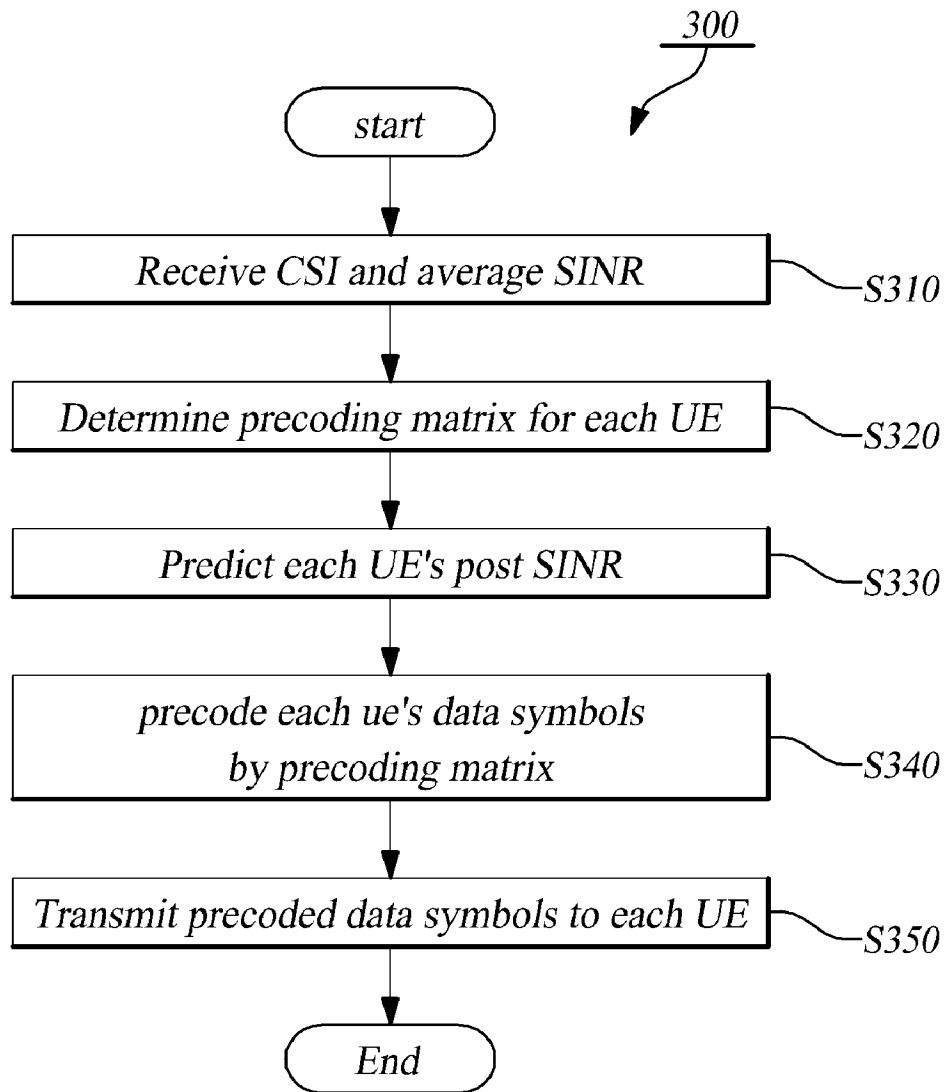
[Fig. 1]



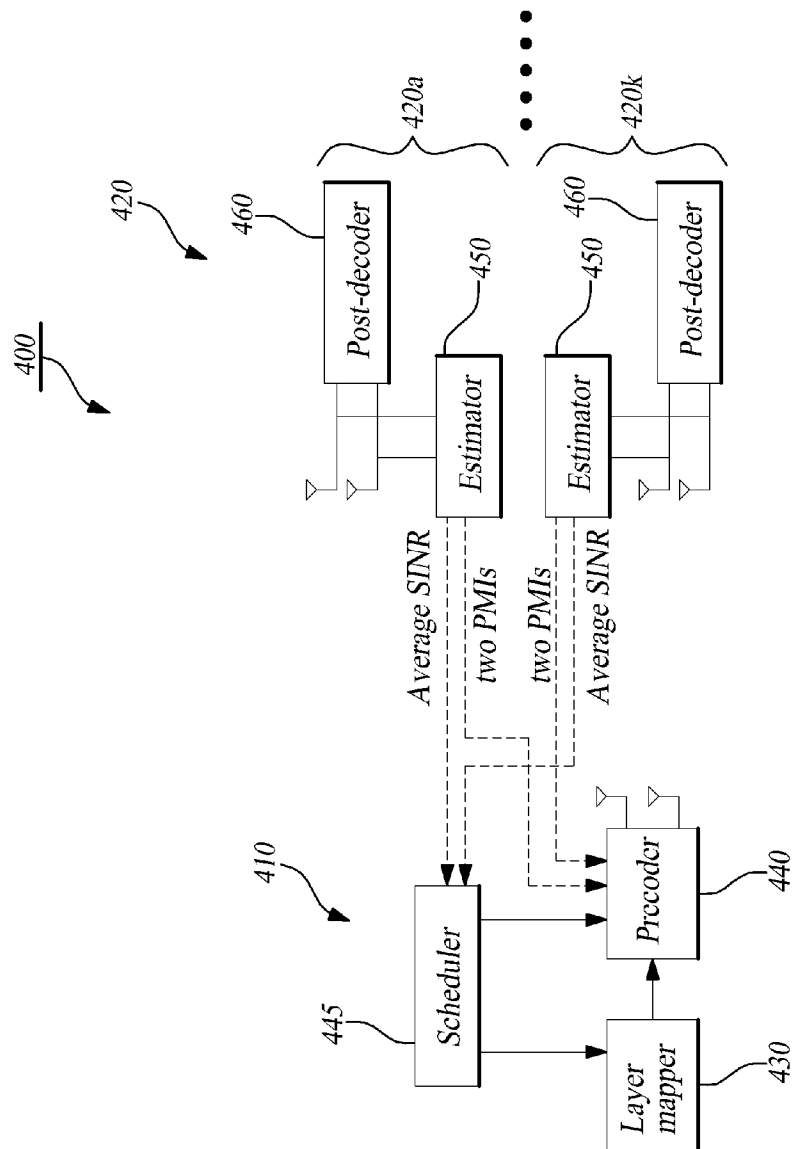
[Fig. 2]



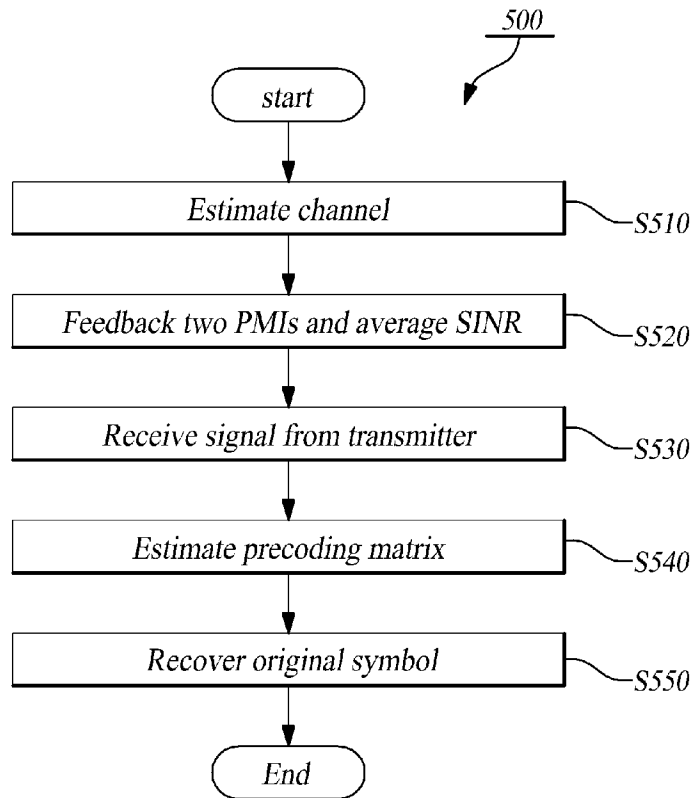
[Fig. 3]



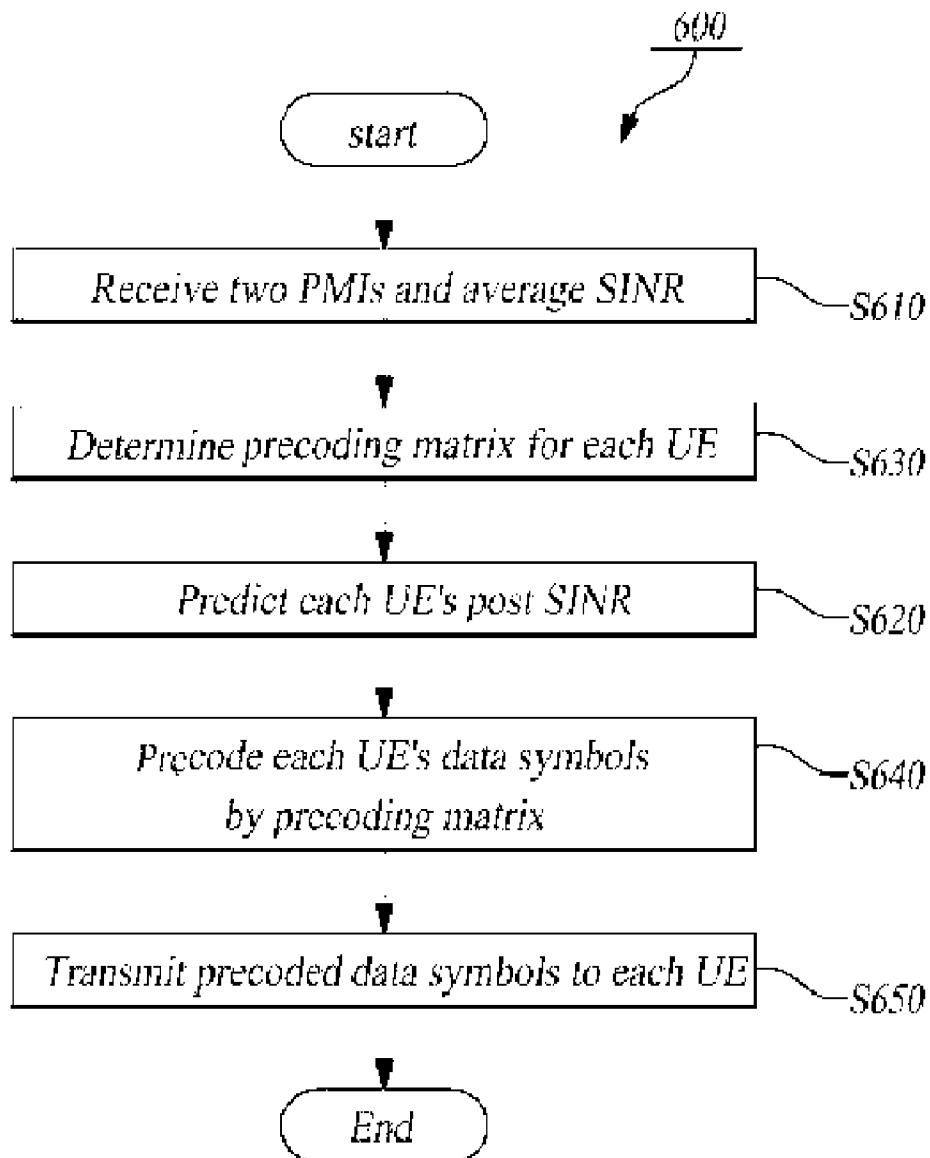
[Fig. 4]



[Fig. 5]



[Fig. 6]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2010/002816**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; H04L 27/00; NotA vai/lable; H04B 7/005

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) & Keywords: predict, post SNIR, feedback, MU-MIMO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2003-071711 A2 (QUALCOMM INCORPORATED) 28 August 2003 See abstract; claims 1-21	1-16
A	US 2004-0047425 A1 (KATSUTOSHI ITOH) 11 March 2004 See abstract; claims 1-4	1-16
A	WO 2005-104651 A2 (NOKIA CORPORATION et al.) 10 November 2005 See abstract; claims 1-13; Fig.3	1-16

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

* Special categories of cited documents:

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"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

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Date of the actual completion of the international search

27 DECEMBER 2010 (27.12.2010)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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