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

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
13 March 2008 (13.03.2008)

PCT

(10) **International Publication Number**
WO 2008/031037 A2

(51) **International Patent Classification:**
H03D 1/04 (2006.01) ***H04L 27/00*** (2006.01)

(21) **International Application Number:** PCT/US2007/077891

(22) **International Filing Date:** 7 September 2007 (07.09.2007)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**

60/824,870	7 September 2006 (07.09.2006)	US
60/827,973	3 October 2006 (03.10.2006)	US
60/891,074	22 February 2007 (22.02.2007)	US

(71) **Applicant** *(for all designated States except US)*: **TEXAS INSTRUMENTS INCORPORATED** [US/US]; P.o. Box 655474, Mail Station 3999, Dallas, TX 75265-5474 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants** *(for US only)*: **ONGGOSANUSI, Eko, N.** [ID/US]; 1430 McClure Drive, Allen, TX 75013 (US). **VARADARAJAN, Badri** [IN/US]; 8200 Southwestern Blvd., Apt. 1002, Dallas, TX 75206 (US).

(74) **Agents: FRANZ, Warren, L.** et al.; Warren L. Franz, Deputy General Patent Counsel, P.o. Box 655474, Ms 3999, Dallas, TX 75265-5474 (US).

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

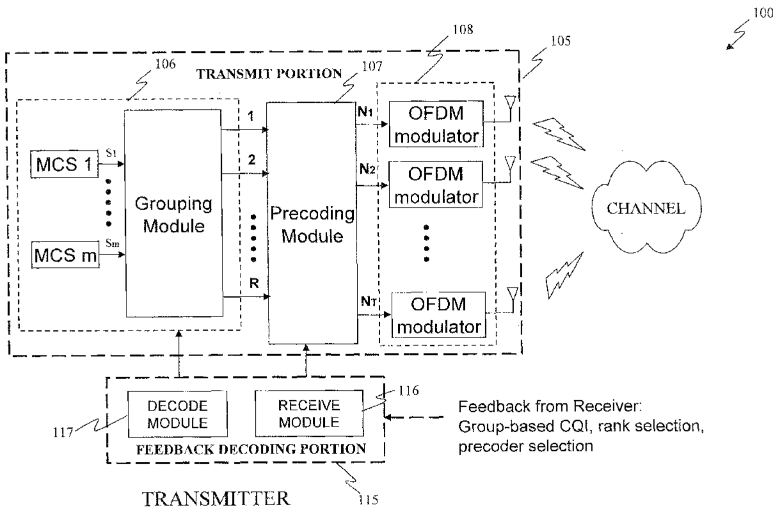
(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) **Title:** ANTENNA GROUPING FOR MIMO SYSTEMS



(57) **Abstract:** Embodiments of the disclosure provide a transmitter, a receiver and methods of operating a transmitter and a receiver. In one embodiment, the transmitter has at least three transmit antennas and includes a feedback decoding portion (115) configured to recover at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings. The transmitter also includes a modulator portion (108) configured to generate at least one symbol stream and a mapping portion (106) configured to multiplex each symbol stream to at least one transmission layer grouping. The transmitter further includes a precoder portion (107) configured to couple the transmission layers to the transmit antennas for a transmission.

WO 2008/031037 A2

Published:

— *without international search report and to be republished upon receipt of that report*

ANTENNA GROUPING FOR MIMO SYSTEMS

This disclosure is directed, in general, to wireless communication systems; and, more specifically, to Multiple-Input Multiple-Output (MIMO) communication employing a transmitter, a receiver and methods of operating a transmitter and a receiver.

BACKGROUND

Multiple-input multiple-output (MIMO) communication systems offer large increases in throughput due to their ability to support multiple parallel data streams that are each transmitted from different (real or virtual) antennas. In the most general form, MIMO transmissions employ a number of parallel spatial streams that are independently FEC encoded. Each stream is then mapped to one or more virtual antennas. Mapping to multiple real antennas can be done by simply distributing the encoder stream output on all the antennas by switching from one antenna to the next. The number of virtual antennas is called the rank of transmission, and the virtual antennas are mapped to the real transmit antennas. This mapping is typically accomplished by linearly combining the virtual antenna signals to obtain the actual transmit signals. Although current MIMO communications offer advantages over single antenna systems, further improvements would prove beneficial in the art.

SUMMARY

Embodiments of the disclosure provide a transmitter, a receiver and methods of operating a transmitter and a receiver. In one embodiment, the transmitter has at least three transmit antennas and includes a feedback decoding portion configured to recover at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings. The transmitter also includes a modulator portion configured to generate at least one symbol stream and a mapping portion configured to multiplex each symbol stream to at least one transmission layer grouping. The transmitter further includes a precoder portion configured to couple the transmission layers to the transmit antennas for a transmission.

In another embodiment, the receiver includes a receive portion employing a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping and a stream decoder portion configured to separate and demultiplex transmission layers corresponding to the transmission layer grouping. The receiver also includes a feedback generator portion configured to provide at least one group-based channel quality indicator that is

fed back to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

In another aspect, the disclosure provides a method of operating a transmitter. The transmitter has at least three transmit antennas, and the method includes recovering at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings. The method also includes generating at least one symbol stream, multiplexing each symbol stream to at least one transmission layer grouping, and coupling the transmission layers to the transmit antennas for a transmission.

In yet another aspect, the disclosure provides a method of operating a receiver. The method includes receiving a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping and decoding to separate and demultiplex transmission layers corresponding to the transmission layer grouping. The method also includes feeding back at least one group-based channel quality indicator to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a system diagram of a transmitter as provided by one embodiment of the disclosure;

FIGS. 2A-2C illustrate diagrams of several transmitter configurations as provided by embodiments of the disclosure;

FIG. 3 illustrates a system diagram of a receiver as provided by one embodiment of the disclosure;

FIG. 4 illustrates an embodiment of a method of operating a transmitter; and

FIG. 5 illustrates an embodiment of a method of operating a receiver.

DETAILED DESCRIPTION

Embodiments of the disclosure presented below employ channel quality indicators that are group-based (i.e., group-based CQIs) that correspond to a transmission rank grouping, which is a grouping of active virtual antennas. The group-based CQIs are fed back from a user equipment (UE), which employs a receiver, to a base station (node B) that employs a transmitter having multiple transmit antennas. The group-based CQI may be one of or a combination of various feedback quantities such as (but not limited to) the signal-to-interference plus noise ratio (SINR), preferred data rate or modulation-coding scheme, capacity-based or other mutual information or received signal power. The transmission rank grouping dictates the number of parallel spatial streams to be transmitted to the UE.

System performance may be optimized by adapting various parameters, which may include the following a modulation and coding scheme (MCS) of each spatial stream. This is determined by the group-based CQI for each spatial stream employed. . The group-based CQI for each stream should indicate the average SNR seen by the FEC decoder for that stream. Clearly the group-based CQI depends strongly on the MMO decoder used to combat spatial interference. An embodiment employs a group successive interference cancellation (G-SIC) MIMO decoder, which offers high throughput with low latency and easy link adaptation.

Larger transmission ranks allow more data to be transmitted per unit of time. However, sometimes the MIMO channel cannot support the highest possible rank R, which is equal to the number of physical or real antennas, wherein the transmission rank grouping is chosen based on receiver feedback. To reduce feedback, it is desirable to reduce the number of spacial streams while maintaining the same rank. This can be done by grouping multiple virtual antennas to one spatial stream. In particular, support for rank 3 and rank 4 transmissions is addressed.

The mapping from virtual-to-real antennas, called precoding, may be adapted to make the effective MIMO channel between virtual antennas more orthogonal. Precoding may be based on receiver feedback, or it can be done in a feedback-independent way, by using a time-varying precoding pattern when non-trivial grouping is done.

FIG. 1 illustrates a system diagram of a transmitter 100 as provided by one embodiment of the disclosure. In the illustrated embodiment, the transmitter 100 operates in an OFDM communication system (typically as a node B) although the principles of the disclosure may be employed in other communication systems. The transmitter 100 includes a transmit portion 105 and a feedback decoding portion 115. The transmit portion 105 includes a grouping module 106, a precoding module 107 and an OFDM module 108 having multiple OFDM modulators that feed corresponding transmit antennas. The feedback decoding portion 115 includes a receiver module 116 and a decoder module 117.

The transmitter 100 has at least three transmit antennas and is capable of transmitting at least one spatial codeword corresponding to a transmission rank grouping. The feedback decoding portion 115 is configured to recover at least one group-based CQI provided by a feedback signal from a UE receiver wherein the group-based CQI corresponds to one of a set of transmission rank groupings. The transmit portion 105 is coupled to the multiple transmit antennas and provides a transmission based on the transmission rank groupings.

Grouping is done by mapping one spatial stream to multiple virtual antennas wherein the number of active virtual antennas is given by a transmission rank R. Embodiments of the disclosure include groupings for transmission ranks of three and four. However the principles of the disclosure apply to higher transmission ranks, as well.

For a rank three transmission, two transmission rank groupings are possible. These include one group of three virtual antennas and two groups of one and two virtual antennas, respectively. The one group case provides an advantage that only one CQI needs to be fed back to the transmitter. A disadvantage is the loss of link adaptation flexibility, and the fact that this grouping cannot exploit the G-SIC decoder, as mentioned above. Two groups may be advantageously employed in that their use offers a compromise between feedback requirement and link adaptation performance. There are multiple options on how the two groups may be specified.

For example, there are three possible selections for the two group case, depending on which virtual antenna is used separately. This may be considered an optimized grouping wherein the UE can only feed back information regarding the separately chosen virtual antenna. That is, the UE can feed back the index of the virtual antenna that is not grouped with another virtual antenna. Alternatively, a fixed grouping may be employed wherein one of the three selections is assumed to be a default. For instance, it might be assumed that virtual antennas two and three are always grouped together.

For a rank four transmission, two transmission rank groupings are possible. These include one group of four virtual antennas and a two group case involving an asymmetrical grouping of one and three virtual antennas, respectively. For the two group case, it is possible to either assume a fixed grouping or feed back an optimum grouping, as before.

A combination of grouping strategies may be considered wherein the UE feeds back the transmission rank groupings and corresponding group-based CQIs for a set of transmission ranks. In a preferred embodiment, the set of transmission rank groupings may be only the optimum rank, which is determined by the UE using some criterion like sum throughput.

Alternatively, the transmission rank groupings may be all ranks associated with the possible groups for the number of transmit antennas. Additionally, any other combination of ranks between these two may be employed.

For a rank three transmission and a preferred grouping of two groups, two group-based CQIs, antenna indices and a grouping index are fed back to the transmitter 100. For a rank four transmission and a preferred grouping of two asymmetrical groups, two group-based CQIs, antenna indices and a grouping index are also feed back to the transmitter 100.

The precoding module 107 provides group permutation of spacial streams associated with the transmission rank grouping provided by the grouping module 106. Precoding consists of a mapping between the R virtual antennas to the N_T physical antennas. Embodiments of the precoders presented are linear. That is, the signal on each of the physical antennas is some linear combination of the signals on the virtual antennas. Thus the mapping can be specified by an $N_T \times R$ linear precoding matrix. The following options exist for the precoding matrix.

The precoding matrix is fixed irrespective of channel conditions. One such example is antenna selection, where each of the R virtual antennas is mapped to a physical antenna. This amounts to a precoding matrix obtained by picking R columns out of the $N_T \times N_T$ identity matrix.

A group-based precoder, where more than two antennas are employed, may be chosen from a fixed codebook of possible precoding matrices. The UE receiver then feeds back the index of the matrix to be used. Alternatively, a layer permutation may be used where the precoding proceeds in a two-stage manner. In stage one, the signal out of the virtual antennas is permuted in a time-varying manner. For instance, in time k, the virtual antenna signals could be cyclically shifted by k positions. In the second stage, the output of the permuted virtual antennas is precoded by a fixed or fed-back precoding matrix. Group-based precoding may also employ group permutation and precoder-hopping.

Group permutation may be applied to the case of a rank four transmission, with two groups of two antennas each. It is an extension of layer permutation, where the permutation preserves the grouping of the antennas. In other words, the permutation is done independently between the first and second antennas of each group. Thus, if the antenna grouping is {1,4} and {2,3}, then the virtual antennas are permuted as follows in every even time instant, $1 \to 2,\ 2 \to 1,\ 3 \to 4,\ 4 \to 3$.

Precoder hopping is a generalization of layer permutation. Here, instead of just letting the layer permutation vary from time to time, the precoder matrix itself is allowed to vary from time to time in a known manner. The precoder can vary over a subset of the codebook of allowed precoding matrices. The subset can optionally be chosen by UE receiver feedback.

Embodiments of transmission rank grouping and group-based precoding may be employed to achieve near-optimum throughput with low feedback using virtual antenna grouping precoder enhancement and enhanced decoders. In summary, advantages include grouping all three antennas together or using two groups having one and two antennas, respectively, for a transmission of rank three. For the case of two groups, the grouping of the antennas may be explicitly chosen among the three possibilities, or a default grouping may be used. Precoding may employ group permutation wherein the groups are permuted in a periodic manner before precoding by a time-invariant matrix. Time-variant precoding may be employed, which includes precoding matrix varies from time to time over a subset of a codebook of allowed matrices. The subset can be either fixed, or chosen by UE receiver feedback.

FIGS. 2A-2C illustrate diagrams of several transmitter configurations 200-220 as provided by embodiments of the disclosure. Per group rate control (PGRC), as depicted in FIGS. 2A-2C is an efficient four-layer, two-codeword transmission scheme that achieves the performance of four-codeword transmission (per antenna rate control (PARC)) while reducing the total uplink (UL) and downlink (DL) overhead. Any precoding scheme may be applied with PGRC as depicted in FIGS. 2A-2C. In particular, any codebook may be used in conjunction with PGRC. The illustrated embodiments of FIGS. 2A-2C address simple codebook-based pre-coding design based on antenna/layer grouping, and the codebook design in relation to HARQ and rank override flexibility.

One possible codebook for PGRC may be constructed based on antenna grouping. For a given channel realization, the grouping may be chosen based on a certain optimality criterion (e.g., maximum SINR, maximum throughput, etc.). Alternatively, the grouping can be based on long-term channel statistics and therefore is adapted at a slower rate.

For rank three transmission of FIG. 2A, the grouping can be represented as a size-12 codebook. Instead of giving the codebook matrix representation, we express the rank three grouping in terms of the antenna index combination in equation (1).

$$\Gamma^{1+2} \in \left\{ \begin{matrix} (1,2,3),(1,2,4),(1,3,4),(2,1,3),(2,1,4),(2,3,4), \\ (3,1,2),(3,1,4),(3,2,4),(4,1,2),(4,1,3),(4,2,3) \end{matrix} \right\} \tag{1}$$

For example, the $(1,2,4)$ and $(2,1,3)$ groupings can be expressed as the following 4x3 matrices, respectively in equation (2).

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \tag{2}$$

For the rank four transmission of FIG. 2B ($2+2$ mapping pattern), the antenna grouping codebook can be described in equation (3) as a size-3 codebook:

$$\Gamma^{2+2} \in \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \right\} \tag{3}$$

Alternatively, when frequency selective pre-coding is applied (different pre-coders can be applied to different groups of sub-carriers, which is termed the pre-coding sub-band), introducing ordering across codewords is beneficial. One way to capture this is by expanding the codebook in equation (3) to a size-6 codebook as shown in equation (4) below.

$$\Gamma_O^{2+2} \in \left\{ \begin{matrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \\ \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{matrix} \right\} \tag{4}$$

Instead of incorporating the codeword ordering into the codebook, it is also possible to infer the ordering from the CQI feedback (i.e., the relative magnitude of CQI-1 and CQI-2 where CQI-n denotes the CQI for codeword n). The Node-B selects the codeword for ordering for each pre-coding sub-band and signals the chosen ordering via the shared control channel. Although this approach is more efficient in terms of the UL and DL overhead (the codebook size is two times smaller while the DL overhead remains the same), it limits the UE flexibility in performing G-SIC detection ordering. This limitation does not apply when the grouping codebook is expanded as shown in equation (2).

For the rank four transmission of FIG. 2C ($1+3$ mapping pattern), ordering across codewords may not apply due to the asymmetry. For better performance, the first codeword (associated with one layer) needs to be decoded first. In addition, the CQI feedback is defined per codeword. Hence, the grouping codebook for $1+3$ mapping (size-4) may be seen in equation (3).

$$\Gamma_O^{1+3} \in \left\{ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \right\} \quad (5)$$

Similar to $1+3$ mapping for rank four transmissions, due to the asymmetry of $1+2$ mapping for rank three, ordering across codewords may not be applicable. Furthermore, it is also possible to select a subset of the above codebooks to reduce the codebook size.

As an example, an extended codebook construction based on grouping may be seen in equation (6).

$$CB = \bigcup_{n=1}^{N} f_n(\Gamma)$$
$$f_n(\Gamma) = \{A_n G_i, G_i \in \Gamma\} \quad (6)$$

A_n is a 4x4 matrix that provides a basis for the grouping codebook Γ (Γ could be the grouping for $1+2$ mapping, $1+3$ mapping, $2+2$ mapping without codeword ordering, or $2+2$ mapping with codeword ordering given in equations (1)-(4)). Essentially, it multiplies each of the grouping matrices in Γ. Hence, the grouping operation is performed in a set of transformed domains. Another term that is used to represent transform domain is virtual antenna domain. In general, A_n may be unitary or non-unitary, although a unitary transformation may be more natural.

An example for $N = 3$ is to choose (A_1, A_2, A_3) to be a 4x4 identity matrix, a 4x4 Walsh-Hadamard matrix, and a 4x4 DFT matrix, respectively. Some other examples include 4x4 Given rotation matrices and 4x4 Householder (reflection) matrices.

While the codebook construction in equation (6) encompasses a wide range of transformed (virtual antenna) domains and hence different types of deployment/channel scenarios, the total codebook size (including all the transmission ranks) may become prohibitively large. To prevent this from happening, it is beneficial to choose the same codebook size $|\Gamma|$ while adapting the virtual domain matrix A_n semi-statically (long-term adaptation). That is:

$$CB_n = \{A_N G_i, G_i \in \Gamma\} \quad (7)$$

The UE can signal a low rate feedback to request for the change in A_n. The signaling may be performed in layer L1 or even higher layers (L2 or L3). Then the Node-B responds to the request from the UE accordingly. The change in A_n is later signaled by the Node-B to the UE via a low rate downlink signaling (layer L1 or even higher layers).

The slow adaptation is initiated by the Node-B without the request from the UE. In this case, the decision to change A_n is based only on some measurements from the Node-B. Similarly, the change in A_n is later signaled by the Node-B to the UE via a low rate downlink signaling (layer L1 or even higher layers). Note that while this codebook is designed for PGRC, it also applies to any other 4x4 transmission scheme such as PARC or single-codeword VBLAST. It also applies to either single-user or multi-user MIMO.

The grouping-based codebook Γ for all the transmission ranks based on the transmission schemes depicted in FIG. 2A-2C (assuming $2+2$ mapping pattern) are shown below. To streamline the description, the codebook is represented showing the antenna index combination. The codebook construction is given in Tables 1 and 2 for the cases with and without codeword ordering, respectively.

Table 1. Grouping codebook Γ without codeword ordering

Rank	Codebook
3	$(1,2,3),(1,2,4),(1,3,4),(2,1,3),(2,1,4),(2,3,4),(3,1,2),(3,1,4),(3,2,4),(4,1,2),(4,1,3),(4,2,3)$
4	$(1,2,3,4),(1,3,2,4),(1,4,2,3)$

Table 2. Grouping codebook Γ with codeword ordering

Rank	Codebook
3	$(1,2,3),(1,2,4),(1,3,4),(2,1,3),(2,1,4),(2,3,4),(3,1,2),(3,1,4),(3,2,4),(4,1,2),(4,1,3),(4,2,3)$
4	$(1,2,3,4),(1,3,2,4),(1,4,2,3),(3,4,1,2),(2,4,1,3),(2,3,1,4)$

For the construction given in Tables 1 and 2, A_n is applied as described above either to construct an expanded codebook or to perform grouping in single or multiple (semi-statically adapted) virtual antenna domains. Furthermore, it is also possible to select a subset of the above codebooks to reduce the codebook size. This holds for each of the transmission ranks. Also, a grouping codebook construction may be obtained by choosing the codebooks in Table 1 for a set of ranks, and in Table 2 for the other ranks. From Tables 1 and 2, a lower rank pre-coding matrix is always a subset of a higher rank pre-coding matrix. That is, a nested property is preserved in this codebook construction.

Advantages of this codebook construction may be summarized as follows. The construction is simple and flexible with an expandable design. The grouping operation may be performed in any transform (virtual antenna) domain. The nested design (across transmission ranks) allows efficient precoder override when the transmission rank selected by the Node B is lower than the UE recommended rank (e.g., when the available data for the UE is less than the sustainable data rate for the UE). In this case, the Node B simply chooses a matrix subset of rank-ρ of the recommended pre-coding matrix corresponding to the higher rank R (recommended by the UE).

The flexibility given in the grouping codebook makes it possible to reduce the CQI inaccuracy upon rank override. For example, consider the following scenario. The UE recommends rank four and $(1,2,3,4)$ grouping to the Node-B and G-SIC receiver is used (CW1 is detected first). In this case, CQI-1 (for CW1 associated with layer 1 and 2) and CQI-2 (for CW2 associated with layer 3 and 4) are fed back to the Node-B. CQI-2 assumes that the interference from CW1 has been removed by the G-SIC operation.

For some reason, the Node-B decides to override the rank four recommendation with rank three. In this case, $(1,3,4)$ and $(2,3,4)$ grouping is a better choice since CQI-2 (assuming rank four transmission) represents an accurate G-SIR/quality metric for CW2 upon rank three override. Having the flexibility given in Table 1 or 2 is clearly beneficial from this perspective.

When employing a hybrid ARQ (HARQ) operation, the following may occur. With incremental redundancy, it is possible to perform rank override. In this case, the scenario given above is also relevant. For very low UE speed (or even a nomadic/semi-stationary scenario), it is beneficial to vary the precoding matrix depending on the channel variation. Different grouping can be optimal upon retransmissions.

For moderate UE speed where time diversity is limited but precoding feedback becomes unreliable, varying the precoding matrix (which in this case corresponds to grouping) is also beneficial. Note that these advantages are valid for any codebook-based scheme having a nested property.

FIG. 3 illustrates a system diagram of a receiver 300 as provided by one embodiment of the disclosure. In the illustrated embodiment, the receiver 300 operates in an OFDM communications system as part of a UE. The receiver 300 includes a receive portion 305 and a feedback generation portion 310. The receive portion 305 includes an OFDM module 306 having Q OFDM demodulators (Q is at least one) coupled to corresponding receive antenna(s), a MIMO detector 307, a QAM demodulator plus de-interleaver plus FEC decoding module 308 and a channel estimation module 309. The feedback generation portion 310 includes a group-based selection module 311 and a feedback encoder 312.

In the receiver 300, the receive portion 305 employs transmission signals from a transmitter having at least three transmit antennas that is capable of transmitting at least one spatial codeword and adapting a transmission rank grouping. Additionally, the feedback generation portion 310 is configured to provide at least one group-based channel quality indicator (G-CQI) that is fed back to the transmitter, wherein each G-CQI corresponds to one of a set of transmission rank groupings.

The receive portion 305 is primarily employed to receive data from the transmitter based on a pre-coder selection that was determined by the receiver and feedback to the transmitter. The OFDM module 306 demodulates the received data signals and provides them to the MIMO detector 307, which employs channel estimation and pre-coder information to further provide the received data to the module 308 for further processing (namely QAM demodulation, de-interleaving, and FEC decoding). The channel estimation module 309 employs previously transmitted channel estimation signals to provide the channel estimates need by the receiver 300.

The feedback generation portion 310 determines the information to be fed back to the transmitter. For each possible transmission rank grouping, the group-based selection module 311 determines the G-CQI and group-based precoder feedback. This module uses the channel and noise-variance/interference estimates computed by the receiver. Rank selection then makes a choice of the set of ranks for which the information needs to be fed back. The feedback encoder 112 then encodes the precoder selection and the G-CQI information and feeds it back to the transmitter.

The module 308 provides an advanced decoder for groups of size greater that one virtual antenna. G-CQI feedback techniques compatible with these antenna grouping are also presented.

One method of approaching MIMO channel capacity is to use a successive interference cancellation (SIC) structure, where decoding is done in stages. In the first state of decoding, signals transmitted from one virtual antenna are decoded, after nulling out interference from other virtual antennas using a MIMO decoder. A typical MIMO decoder used is the LMMSE decoder. The output is then re-encoded and used to cancel out spatial interference to subsequent virtual antennas. Then the second virtual antenna is decoded and used for further cancellation, and so on.

Group successive interference cancellation (G-SIC) is employed in the receiver 300 for the transmission rank grouping of virtual antennas employed in embodiments of the disclosure. Here, the virtual antennas are extracted one group at a time. Thus, in the first stage, the first group is decoded by nulling or canceling the effect of other groups. The output from the decoder 308 is then re-encoded and used to cancel interference to subsequent groups.

An advantage of grouping multiple virtual antennas together is that the number of CQIs fed back may be reduced. In one embodiment, the CQI for a group (i.e., the G-CQI) is obtained by combining the CQIs for different virtual antennas within the group. For instance, exponential averaging with a well-chosen weighting parameter may be used. The optimum weighting parameter typically depends on the MCS scheme to be used. However, since the UE does not know the MCS beforehand, it can provide an estimated value of a likely MCS based on the supportable throughput and use the corresponding MCS.

Computation of G-CQI, when group permutation/time-varying precoding is used may employ a similar approach. The true post-decoding G-CQI varies from time to time depending on the precoder used. The same approach used to combine group CQIs may be used here, except that the combination is done over all virtual antenna CQIs at all possible precoders.

Techniques to achieve near-optimum throughput with low feedback using virtual antenna grouping precoder enhancement and enhanced decoders have been presented. These include employing G-SIC decoding wherein the receiver 300 can decode the groups successively. Additionally, G-CQI for grouped antennas is employed.

FIG. 4 illustrates an embodiment of a method 400 of operating a transmitter. The method 400 starts in a step 405 with a transmitter having at least three transmit antennas. Then, in a step 410, at least one group-based channel quality indicator is recovered that is provided by a feedback signal from a receiver. In one embodiment, at least one transmission layer index based on one group-based channel quality indicator is also recovered. Similarly, at least one index of transmission layer grouping based on one group-based channel quality indicator may also be recovered. Each group-based channel quality indicator corresponds to one of a set of transmission layer groupings, and at least one symbol stream is generated in a step 415.

Each symbol stream is multiplexed to at least one transmission layer grouping in a step 420. In one embodiment, the multiplexing provides a three-layer transmission having a transmission layer grouping of one or two groups for three transmit antennas. In another embodiment, the multiplexing provides a four-layer transmission having a transmission layer grouping of one group or two asymmetrical groups for four transmit antennas. Alternately, the multiplexing may the four-layer transmission having a transmission layer grouping of two symmetrical groups for four transmit antennas. For these cases, the multiplexing provides a transmission employing an explicit grouping or a default grouping for a transmission layer grouping of at least two groups.

The transmission layers are coupled to the transmit antennas for the transmission in a step 425. In one embodiment, the coupling provides the transmission employing a time-variant precoder matrix in response to the feedback signal from the receiver. In an alternate embodiment, the coupling provides the transmission employing a group permutation precoding codebook. Additionally, the coupling may provide the transmission employing a grouping-based codebook.

The transmission may also be provided by employing a precoding codebook that is constructed by multiplying at least one base matrix with each permutation matrix from a group permutation precoding codebook. Similarly, the transmission may be provided by employing a precoding codebook that is constructed by multiplying at least one base matrix with each grouping matrix from a grouping-based codebook. The method 400 ends in a step 430.

FIG. 5 illustrates an embodiment of a method 500 of operating a receiver. The method 500 starts in a step 505. Then, in a step 510, a transmission is received from a transmitter having at least three transmit antennas and capable of a transmission layer grouping. Decoding to separate and demultiplex transmission layers corresponding to the transmission layer grouping is performed in a step 515. At least one group-based channel quality indicator is fed back to the transmitter in a step 520, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

In the step 520, the feeding back provides the group-based channel quality indicator based on employing a group successive interference cancellation decoding in the step 515. Additionally, the step 520 provides the group-based channel quality indicator as a combination of individual channel quality indicators respectively corresponding to each transmission layer of the transmission layer grouping. In one embodiment, this combination corresponds to an exponential averaging of the individual channel quality indicators that employs a weighting parameter. The method 500 ends in a step 525.

While the methods disclosed herein have been described and shown with reference to particular steps performed in a particular order, it will be understood that these steps may be combined, subdivided, or reordered to form an equivalent method without departing from the teachings of the disclosure. Accordingly, unless specifically indicated herein, the order or grouping of the steps is not a limitation of the disclosure.

Those skilled in the art to which the disclosure relates will appreciate that other and further additions, deletions, substitutions and modifications may be made to the described example embodiments without departing from the scope of the claimed invention.

CLAIMS:

What is claimed is:

1. A method of operating a transmitter having at least three transmit antennas, comprising:

recovering at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings;

generating at least one symbol stream;

multiplexing each symbol stream to at least one transmission layer grouping; and

coupling the transmission layers to the transmit antennas for a transmission.

2. The method of Claim 1 further comprising recovering at least one transmission layer index, or one index of transmission layer grouping, based on the at least one group-based channel quality indicator.

3. The method of Claim 1 or 2, wherein the multiplexing provides the transmission employing at least one of: a) a three-layer transmission having a transmission layer grouping of one or two groups for three transmit antennas; b) a four-layer transmission having a transmission layer grouping of one group or two asymmetrical groups for four transmit antennas; a four-layer transmission having a transmission layer grouping of two symmetrical groups for four transmit antennas; d) an explicit grouping or a default grouping for a transmission layer grouping of at least two groups.

4. The method of Claim 1 or 2, wherein the coupling provides the transmission employing at least one of: a) a time-variant precoder matrix in response to the feedback signal from the receiver; b) a group permutation precoding codebook; c) a grouping-based codebook; d) a precoding codebook that is constructed by multiplying at least one base matrix with each permutation matrix from a group permutation precoding codebook; e) a precoding codebook that is constructed by multiplying at least one base matrix with each grouping matrix from a grouping-based codebook.

5. A method of operating a receiver, comprising:

receiving a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping;

decoding to separate and demultiplex transmission layers corresponding to the transmission layer grouping; and

feeding back at least one group-based channel quality indicator to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

6. The method of Claim 5, wherein the feeding back provides the group-based channel quality indicator based on employing at least one of: a) a group successive interference cancellation decoding; b) a combination of individual channel quality indicators respectively corresponding to each transmission layer of the transmission layer grouping.

7. The method of Claim 5, wherein the feeding back provides the group-based channel quality indicator based on a combination of individual channel quality indicators respectively corresponding to each transmission layer of the transmission layer grouping; and wherein the combination corresponds to an exponential averaging of the individual channel quality indicators that employs a weighting parameter.

8. A method of operating a communication system, comprising:

sending a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping to a receiver;

decoding the transmission at the receiver to separate and demultiplex transmission layers corresponding to the transmission layer grouping; and

feeding back at least one group-based channel quality indicator from the receiver to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

recovering the at least one group-based channel quality indicator provided by the feedback signal from the receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings;

generating at least one symbol stream;

multiplexing each symbol stream to at least one transmission layer grouping; and

coupling the transmission layers to the transmit antennas for a transmission.

9. A transmitter having at least three transmit antennas, comprising:

a feedback decoding portion configured to recover at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings;

a modulator portion configured to generate at least one symbol stream;

a mapping portion configured to multiplex each symbol stream to at least one transmission layer grouping; and

a precoder portion configured to couple the transmission layers to the transmit antennas for a transmission.

10. A receiver, comprising:

a receive portion employing a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping;

a stream decoder portion configured to separate and demultiplex transmission layers corresponding to the transmission layer grouping; and

a feedback generator portion configured to provide at least one group-based channel quality indicator that is fed back to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

11. A communication system comprising a transmitter having at least three transmit antennas and a receiver, wherein:

the transmitter comprises:

a feedback decoding portion configured to recover at least one group-based channel quality indicator provided by a feedback signal from a receiver, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings;

a modulator portion configured to generate at least one symbol stream;

a mapping portion configured to multiplex each symbol stream to at least one transmission layer grouping; and

a precoder portion configured to couple the transmission layers to the transmit antennas for a transmission; and

the receiver comprises:

a receive portion employing a transmission from a transmitter having at least three transmit antennas and capable of a transmission layer grouping;

a stream decoder portion configured to separate and demultiplex transmission layers corresponding to the transmission layer grouping; and

a feedback generator portion configured to provide at least one group-based channel quality indicator that is fed back to the transmitter, wherein each group-based channel quality indicator corresponds to one of a set of transmission layer groupings.

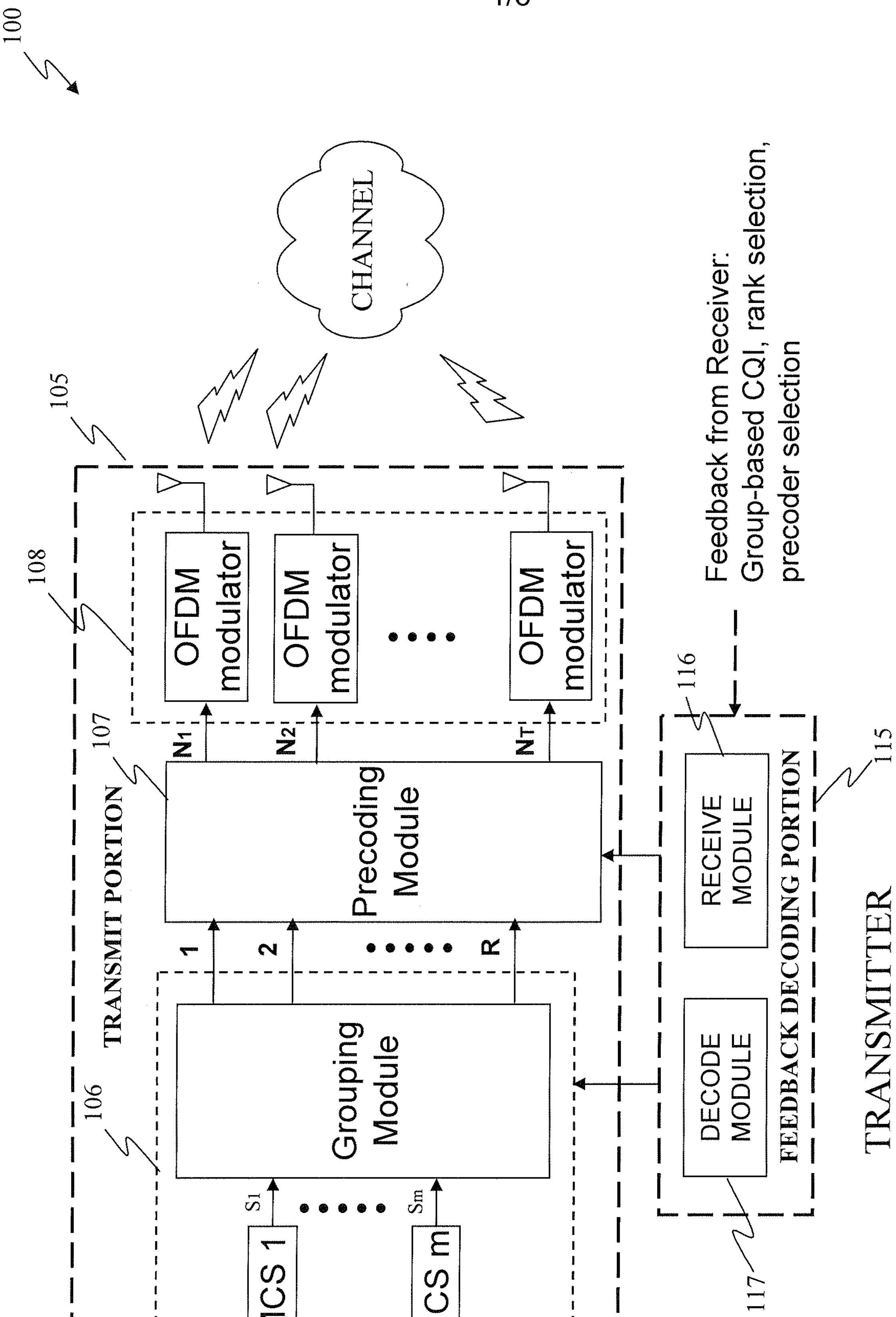

100
105
108
107
106
116
115
117
CHANNEL
TRANSMIT PORTION
OFDM modulator
OFDM modulator
OFDM modulator
N_1
N_2
N_T
Precoding Module
Grouping Module
1
2
R
MCS 1
MCS m
S_1
S_m
Feedback from Receiver:
Group-based CQI, rank selection, precoder selection
RECEIVE MODULE
DECODE MODULE
FEEDBACK DECODING PORTION
TRANSMITTER

Fig. 1

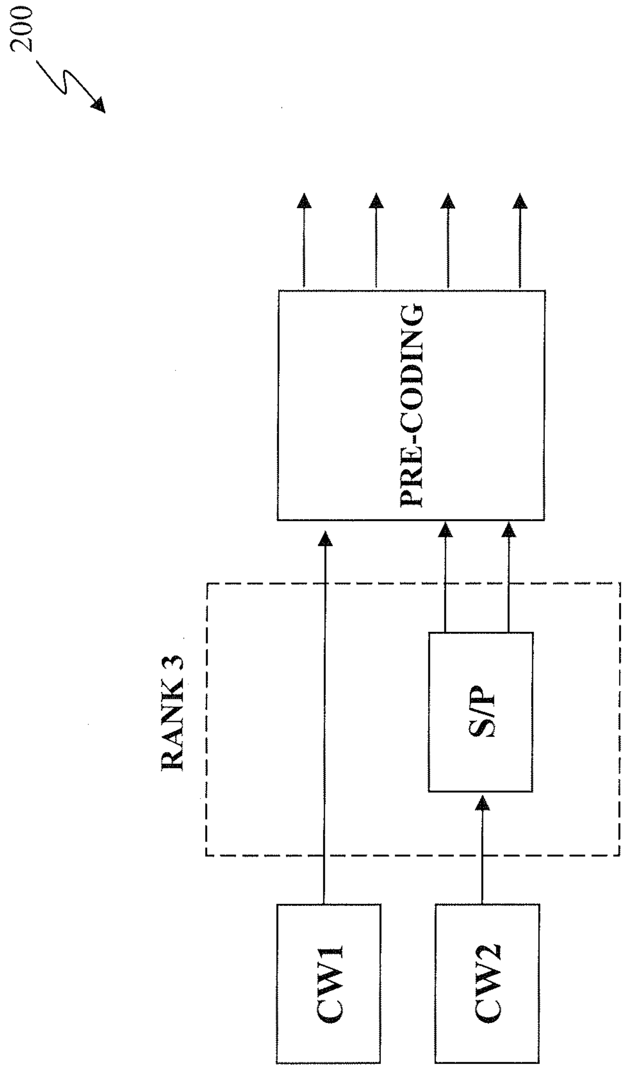


Fig. 2A

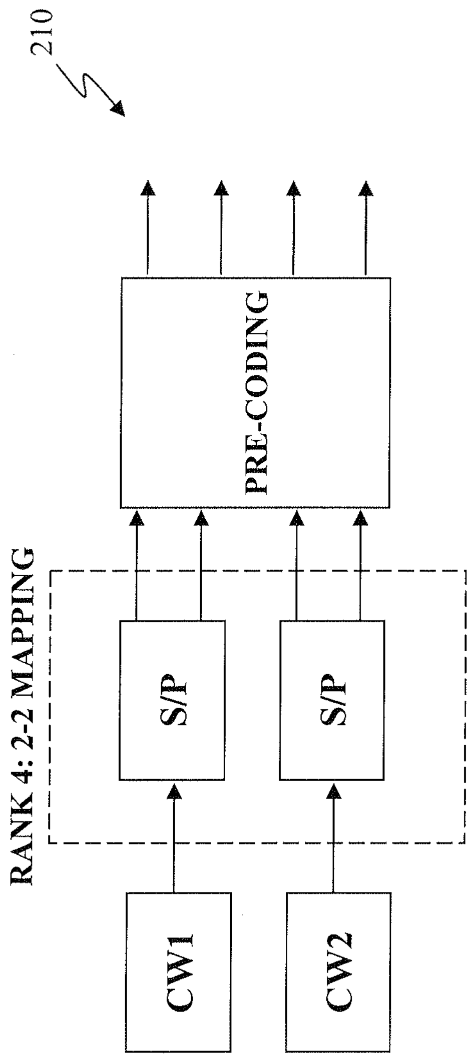

210
RANK 4: 2-2 MAPPING
CW1
CW2
S/P
S/P
PRE-CODING

Fig. 2B

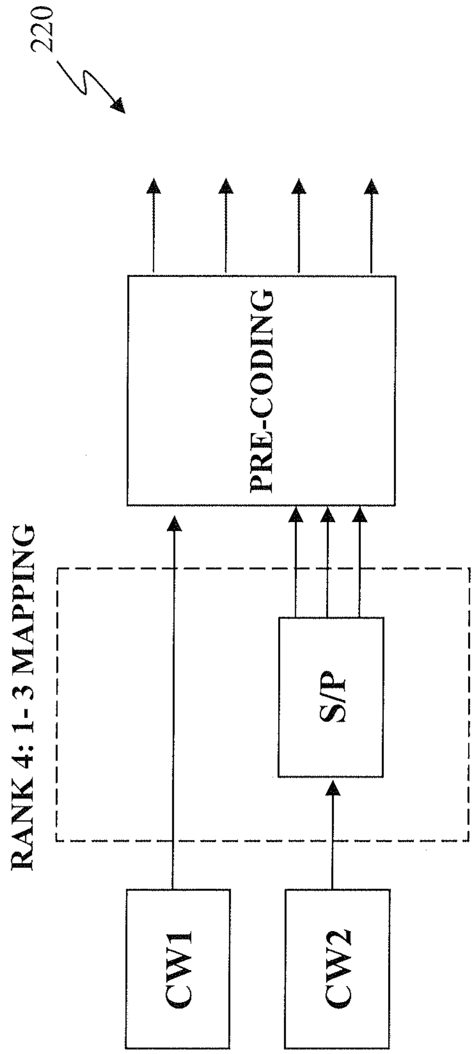

220
RANK 4: 1- 3 MAPPING
CW1
CW2
S/P
PRE-CODING

Fig. 2C

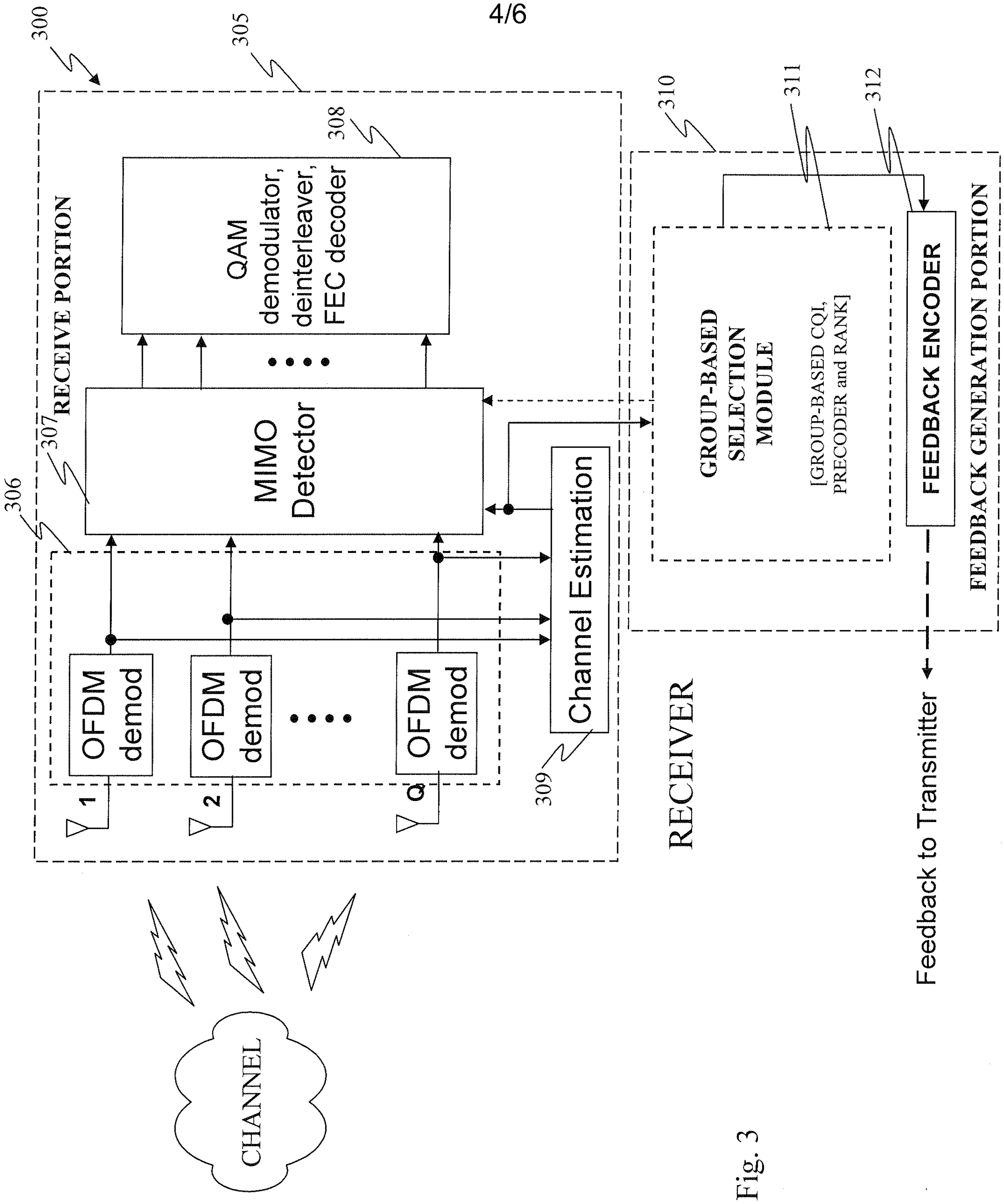

300
305
RECEIVE PORTION
308
QAM demodulator, deinterleaver, FEC decoder
307
MIMO Detector
306
OFDM demod
OFDM demod
OFDM demod
1
2
Q
Channel Estimation
309
RECEIVER
310
311
312
GROUP-BASED SELECTION MODULE
[GROUP-BASED CQI, PRECODER and RANK]
FEEDBACK ENCODER
FEEDBACK GENERATION PORTION
Feedback to Transmitter
CHANNEL

Fig. 3

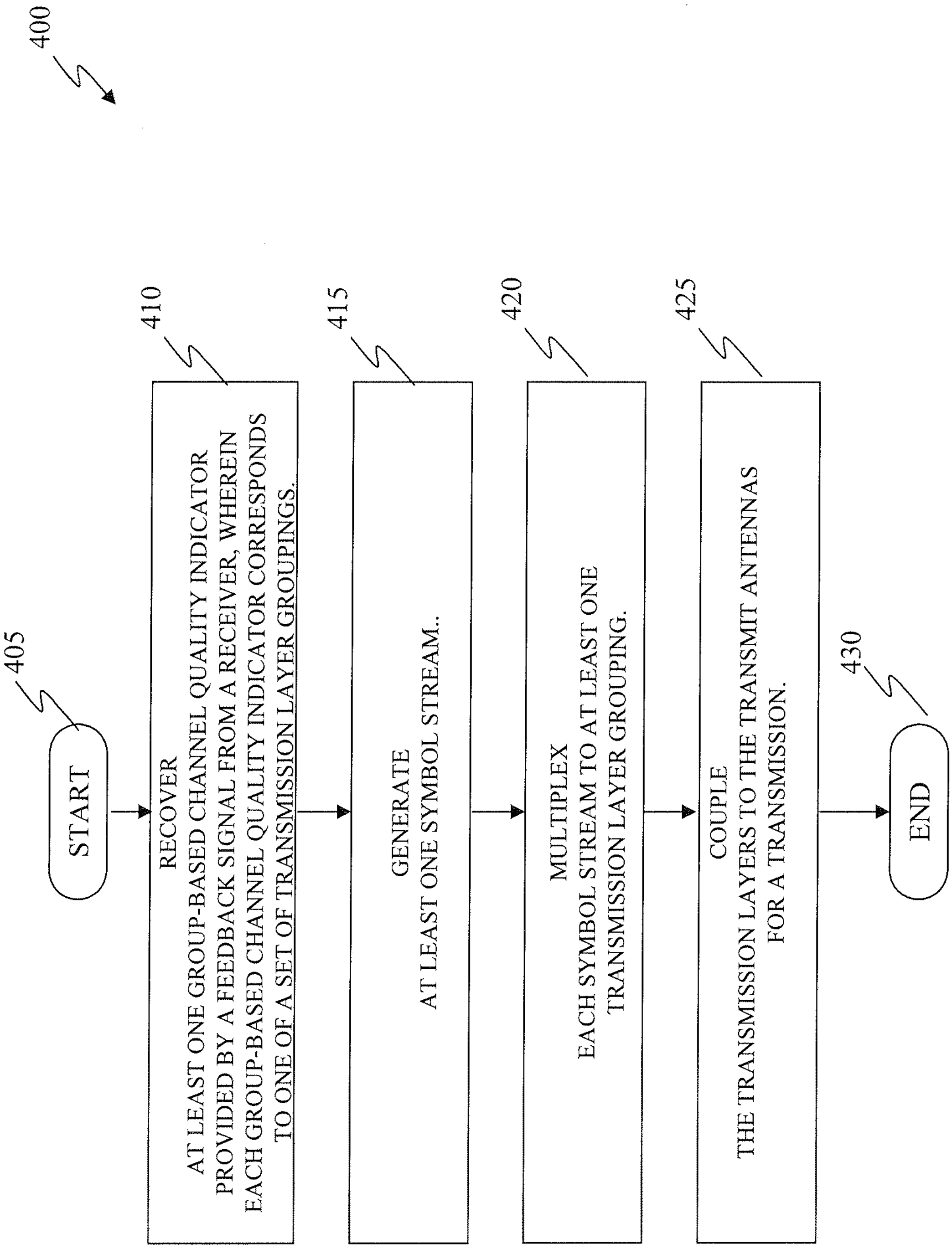

400
405
START
410
RECOVER
AT LEAST ONE GROUP-BASED CHANNEL QUALITY INDICATOR PROVIDED BY A FEEDBACK SIGNAL FROM A RECEIVER, WHEREIN EACH GROUP-BASED CHANNEL QUALITY INDICATOR CORRESPONDS TO ONE OF A SET OF TRANSMISSION LAYER GROUPINGS.
415
GENERATE
AT LEAST ONE SYMBOL STREAM..
420
MULTIPLEX
EACH SYMBOL STREAM TO AT LEAST ONE TRANSMISSION LAYER GROUPING.
425
COUPLE
THE TRANSMISSION LAYERS TO THE TRANSMIT ANTENNAS FOR A TRANSMISSION.
430
END

Fig. 4

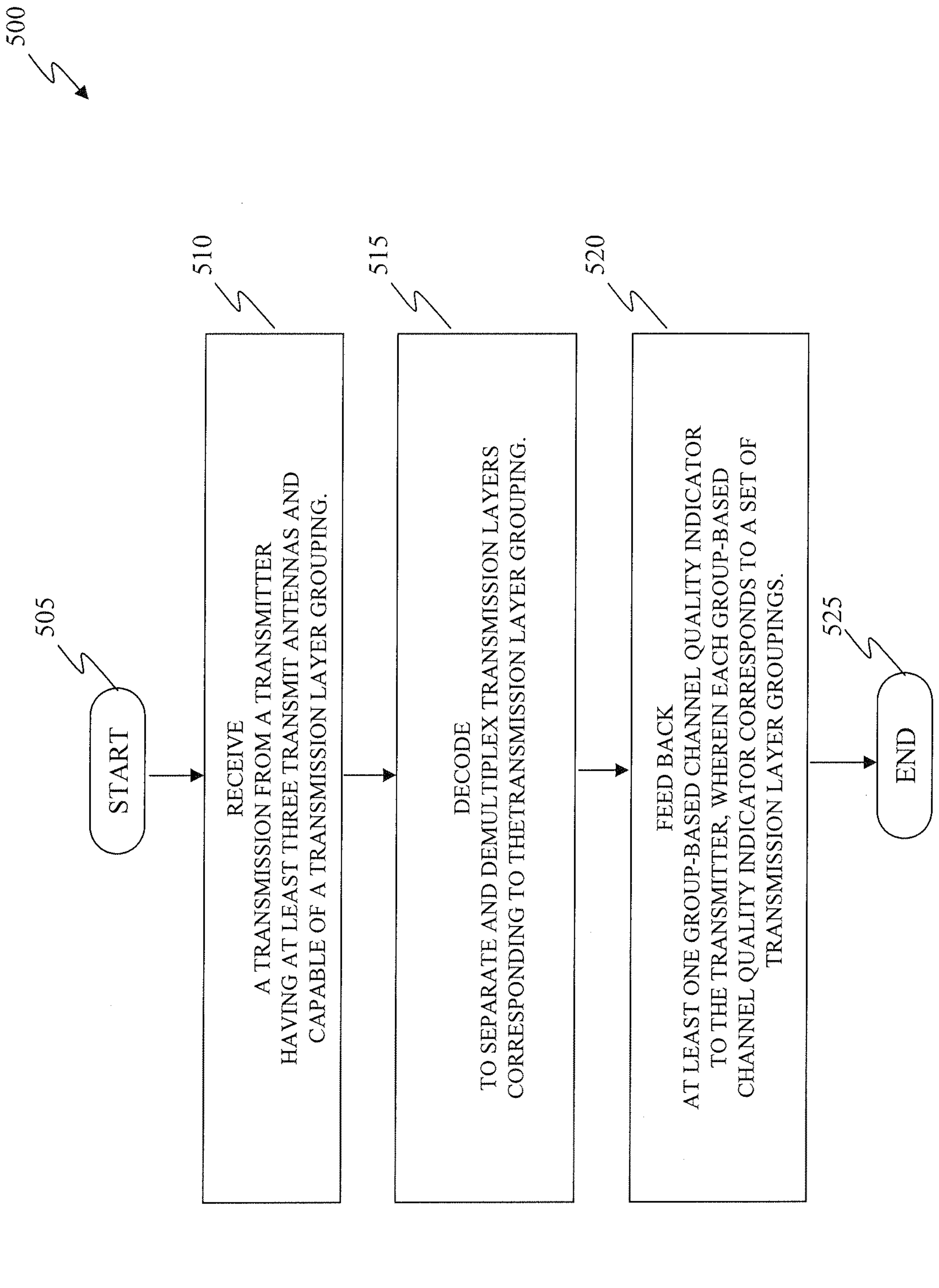

500
505
START
510
RECEIVE
A TRANSMISSION FROM A TRANSMITTER
HAVING AT LEAST THREE TRANSMIT ANTENNAS AND
CAPABLE OF A TRANSMISSION LAYER GROUPING.
515
DECODE
TO SEPARATE AND DEMULTIPLEX TRANSMISSION LAYERS
CORRESPONDING TO THETRANSMISSION LAYER GROUPING.
520
FEED BACK
AT LEAST ONE GROUP-BASED CHANNEL QUALITY INDICATOR
TO THE TRANSMITTER, WHEREIN EACH GROUP-BASED
CHANNEL QUALITY INDICATOR CORRESPONDS TO A SET OF
TRANSMISSION LAYER GROUPINGS.
525
END

Fig. 5