

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
20 November 2008 (20.11.2008)

PCT

(10) International Publication Number
WO 2008/139249 A2

(51) International Patent Classification: **Not classified**

(21) International Application Number:
PCT/IB2007/002902

(22) International Filing Date: 2 October 2007 (02.10.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
06020735.4 2 October 2006 (02.10.2006) EP
11/605,402 29 November 2006 (29.11.2006) US

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(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).

Published:

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

(54) Title: **ADVANCED FEEDBACK SIGNALING FOR MULTI-ANTENNA TRANSMISSION SYSTEMS**

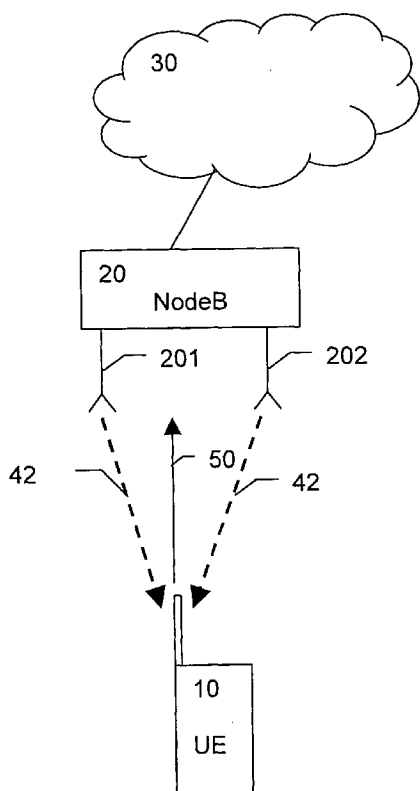


Fig. 1

(57) Abstract: The present invention relates to methods, a system, a transmitter apparatus, a receiver apparatus, and computer program products for providing enhanced feed-back in a multi-antenna transmission system, wherein an operation mode of a multi-antenna transmission end is determined at a reception end of a connection, and a feedback information and a mode indicator are generated based on the determined operation mode and transmitted to the multi-antenna transmission end where the feedback information is interpreted based on the mode indicator. Thereby, different operation modes can be supported by the same amount of total feedback information and without requiring any change in signaling setup.

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Advanced Feedback Signaling for Multi-Antenna Transmission Systems

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FIELD OF THE INVENTION

The present invention relates to methods, a system, a transmitter apparatus, a receiver apparatus, and computer program products for providing feedback signaling in a multi-antenna transmission system, such as multiple-input multiple-output (MIMO) system.

BACKGROUND OF THE INVENTION

15 Rising importance of wireless services has led to corresponding increased demand for higher network capacity and performance. Conventional options include higher bandwidth, optimized modulation or code-multiplex systems, but offer practically only limited potential to increase the spectral efficiency.

20 In so-called MIMO (Multiple Input Multiple Output) systems antenna arrays are used to enhance bandwidth efficiency. MIMO systems provide multiple inputs and multiple outputs for a single channel and are thus able to exploit spatial diversity and spatial multiplexing. Further information about MIMO systems can be gathered from the IEEE specifications 802.11n, 802.16-2004 and 802.16e, as well as
25 802.20 and 802.22 which relate to other standards. Specifically, MIMO systems have been introduced to radio systems like e.g. WiMAX (Worldwide Interoperability for Microwave Access) and are currently standardized in 3GPP for WCDMA (Wideband Code Division Multiple Access) as well as 3GPP E-UTRAN (Enhanced Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access
30 Network), such as LTE (Long Term Evolution) or 3.9G.

In case of MIMO systems, multi-stream transmission increases the possible peak-data rate and as a consequence also the achievable system capacity. Currently in 3GPP, there is single user MIMO (SU-MIMO) as well as MU-MIMO (multi-user
35 MIMO) discussed for the downlink (DL) shared data channel of 3GPP LTE systems.

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SU-MIMO denotes transmission to a single user on a resource block with either single stream or multi-stream transmission. The adaptation between single stream transmission and multi-stream transmission depends on the available rank of the mobile radio channel as well as the operation point in respect to SINR (signal-to-interference-plus-noise ratio).

MU-MIMO denotes transmission to several users on a single resource block in DL by precoded transmission from a base station device (BS, referred to as "Node B" in 3GPP terminology) to several users. It is of advantage, if the transmission to several users in the same resource is done with mutual orthogonal transmission weights and/or precoding. It is noted that the number of users which can transmit at the same time within a single resource block by Space Division Multiple Access (SDMA) is limited by the number of available transmission (Tx) antennas at the Node B.

Different MIMO transmission modes in downlink require different information in order to allow appropriate link adaptation. A mobile station (MS, also referred to as "user equipment" (UE) in 3G terminology) may have a linear or non-linear reception unit and M_r reception antennas, while the node B has M_t transmission antennas. Based on partial or full channel state information (CSI) fed back from the MS, the BS may perform appropriate space-time processing such as multiuser scheduling, power and modulation adaptation, beamforming, and space-time coding. The CSI may include a channel direction information (CDI) and a channel quality information (CQI), which can be used for determining beamforming direction and power allocation.

According to the transmitter structure of per-antenna rate control (PARC) systems, separately encoded data streams are transmitted from each antenna with equal power but possibly with different data rates. The data rates for each antenna are controlled by adaptively allocating transmission resources such as modulation order, code rate, and in case of CDMA systems the number of spreading codes. The post-decoding SINR or any other measure indicating the supported data rate of each transmission antenna is estimated at the receiver and then fed back to the transmitter, which is used to determine the data rate on each antenna. The CQI feedback may be transmitted directly as a quantization in the SINR domain, or it may be mapped to a supportable transport format before transmission. A vector signaling with more feedback overhead over conventional scalar signaling is thus

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required for link adaptation. E.g. in case of PARC for 2 Tx antennas, a CQI for both streams is fed back to the BS regardless of whether the transmission with two streams makes sense at all, e.g., due to channel correlation or SNR (signal-to-noise ratio) operation point make. Similar issues are also valid for CSI or precoding information.

In case of SU-MIMO with two transmission antennas and multi-codeword transmission, two streams (i.e., spatial multiplexing rate 2) with independent modulation and coding are provided, so that the CQI information of both streams is needed in order to allow link adaptation, whereas in case of a single stream fallback mode (e.g. single stream beamforming) just a single CQI information is needed for adaptive modulation and coding (AMC).

Thus, different MIMO transmission modes in downlink require different information in order to allow appropriate processing, such as link adaptation. However, traditional CQI or CSI feedback schemes are independent of the selected MIMO transmission scheme, so that an advanced feedback transmission scheme is necessary.

SUMMARY

It is therefore an object of the present invention to provide a method and system for advanced and flexible feedback signaling in multi-antenna transmission systems.

This object is achieved by a method comprising:

- determining at a reception end of a connection a preferred operation mode of a multi-antenna transmission end of said connection;
- generating feedback information and a mode indicator based on said determined preferred operation mode; and
- forwarding said feedback information together with said mode indicator in a data stream transmitted from said reception end via said connection to said multi-antenna transmission end.

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Furthermore, the above object is achieved by a method comprising:

- 5 • receiving at a multi-antenna transmission end a data stream which comprises a feedback information;
- extracting from said received data stream said feedback information and a mode indicator which indicates an operation mode of said multi-antenna transmission end; and
- 10 • interpreting said feedback information based on said mode indicator in order to control multi-antenna transmission.

Additionally, the above object is achieved by a receiver apparatus comprising:

- 15 • determination means for determining an operation mode of a multi-antenna transmission end;
- generating means for generating feedback information and a mode indicator based on said determined operation mode; and
- 20 • forwarding means for forwarding said feedback information together with said mode indicator in a data stream transmitted from said receiver apparatus to said multi-antenna transmission end.

25 Moreover, the above object is achieved by a transmitter apparatus comprising:

- receiving means for receiving a data stream which comprises a feedback information;
- 30 • extracting means for extracting from said received data stream said feedback information and a mode indicator which indicates an operation mode of a selected multi-antenna transmission scheme; and
- interpretation means for interpreting said feedback information based on
- 35 said mode indicator in order to control multi-antenna transmission in response to said feedback information.

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Further, the above object is achieved by a transmission system comprising at least one transmitter apparatus as defined above, and at least one receiver apparatus as defined above.

- 5 In addition, the above object is achieved by respective computer program products comprising code means for producing the steps of the above methods when run on a computer device.

10 Accordingly, a simple and effective feedback scheme is provided, which is based on a mode indicator for indicating different kinds of feedback information in the same signaling setup in order to facilitate scheduling, link adaptation or any other processing required for multi-antenna transmission. Thereby, different operation modes can be supported by the same amount of total feedback information and without requiring any change in the signaling setup. Of course, this advantage is
15 valid for each kind of feedback scheme where the feedback information is dependent on the operating mode of involved transmission beams.

The additional amount of feedback related to the spatial domain can thus be kept small in addition to conventional single-stream feedback. Feedback bit-fields can
20 be made dependent on the operation mode and therefore used to signal different kinds of information. This enables small amount of feedback compared to fixed reporting structures. The proposed feedback structure can be utilized for any kind of operation mode.

25 As an example, the determination of the operation mode may be performed based on a signaling received from the multi-antenna transmission end. This signaling may for example be a signaling of a protocol layer higher than the protocol layer of the data stream. Of course, various other ways or means of determining the operation mode could be implemented. It might for example be set by the network
30 operator or the user to influence operation of the transmission end.

In a specific example, the operation mode may be selected from one of a single-stream transmission mode, a single-user transmission mode, a multi-user transmission mode, a diversity transmission mode, or an open loop single-user transmission mode.
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In addition to mode identification or signaling, the mode indicator may for example be used to indicate additional information specifying the operation mode.

5 In an exemplary embodiment, the feedback information may indicate at least one of a channel quality information, a channel state information and a precoding information. Of course, other information may be indicated or signaled by the feedback information depending on the concerned kind of multi-antenna transmission system. The mode indicator may also be used to define an allocation and interpretation of individual bits of this feedback information.

10

According to specific implementation examples, a one-bit mode indicator or a two-bit mode indicator may be used in a system where the multi-antenna transmission end comprises two transmission antennas. As an alternative, a three-bit mode indicator may be used in a system where the multi-antenna transmission end comprises four transmission antennas. Of course, even mode indicators with higher bit numbers can be used if the available number of operation modes demands a higher number of values

15

The control of multi-antenna transmission may comprise at least one of scheduling, precoding, beamforming, multiplexing and link adaptation.

20

Further advantageous modifications or developments are defined in the dependent claims.

25

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described on the basis of an embodiment with reference to the accompanying drawings in which:

30 Fig. 1 shows a schematic diagram of a multi-antenna transmission system according to the embodiment;

Fig. 2 shows a schematic block diagram of a mobile transceiver unit according to the embodiment;

35

Fig. 3 shows a schematic block diagram of a base station device according to the embodiment;

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Fig. 4 shows a flow diagram of a feedback generation method according to the embodiment;

- 5 Fig. 5 shows a flow diagram of a feedback processing method according to the embodiment;

Fig. 6 a schematic block diagram of a computer-based implementation of the embodiment; and

10

Figs. 7A to 7F show various interpretation examples of feedback information for different operation modes.

DESCRIPTION OF THE EMBODIMENT

15

The embodiment will now be described based a wireless multi-antenna transmission system, such as - but not limited to – a MIMO system with a general UL feedback scheme for MIMO DL transmission, including different multi-antenna operating modes, e.g., SU-MIMO as well as MU-MIMO, for an exemplary case of two
20 available Tx antennas at a transmitter unit of a base station device, such as a Node B. However, it will be apparent from the following description and is therefore explicitly stressed that the present invention can be applied to any other network architecture with different radio access technologies involving multi-antenna transmitter devices (e.g. base station devices, access points or other access devices)
25 vices) capable of being operated in different operating modes.

30

Fig. 1 shows an exemplary multi-antenna system according to the embodiment, in which a mobile station (MS) 10 (or UE in 3G terminology) is radio-connected to a base station device (BS) 20 (or Node B in 3G terminology) which comprises two
30 Tx antennas 201 and 202 for transmitting respective DL radio transmission 42 towards the MS 10. The MS 10 transmits an UL transmission 50 towards the base station device 20 which provides access to a radio access network 30, such as an E-UTRAN or the like. The UL signal may be received at the BS 20 by the same antennas 201 or 202 or an additional reception antenna may alternatively be provided. The MS 10 might alternatively have more than a single antenna available
35 that could be used for dual-antenna or multi-antenna transmission in UL direction and/or SU-MIMO reception of DL radio transmissions 42.

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In an implementation example of the embodiment, an SU-MIMO operation mode with the two Tx antennas 201 and 202 and a multi-codeword transmission mode are considered. Of course, other operation modes may be provided as well. In
5 case that two transmission streams (i.e., spatial multiplexing rate "2") with independent modulation and coding (multi-codeword MIMO – such as "PARC") are used, a CQI information is required for both streams in order to allow link adaptation, whereas in case of a single stream fall-back mode (e.g. single stream beamforming) just a single CQI information for AMC is needed.

10

According to the embodiment, an advanced feedback scheme is proposed, which is based on a mode indicator for signaling the transmission scheme or method and which allows transmission of different kinds of CQI and CSI or precoding information in the same signaling setup to the BS 20 in order to facilitate scheduling and
15 link adaptation. It is thus proposed to change the interpretation of the feedback information based on the MIMO operation mode and to transmit a mode indicator, which is needed at the BS 20 in order to correctly interpret the provided feedback information received from the MS 10.

20 In the present example, the basic MIMO operation mode – either SU-MIMO or MU-MIMO may be defined semi-statically (e.g., on a longer term scale) by the BS 20, e.g. by using a higher layer signaling. As an alternative or in addition thereto, the basic operation mode may be set by the network operator and/or by the user, or may be derived from any other network signaling. Depending on this basis or
25 initial operation mode, the MS 10 is supposed to feed back different kind of MIMO related feedback information – e.g., either related to SU-MIMO or multi-user MIMO.

In the following, possible kinds of feedback information which may be required for
30 different transmission modes are described. In case of SU-MIMO with two transmit antennas, there is the possibility to have single stream transmission as well as two stream transmission. For single stream transmission, the CQI for the stream as well as some precoding and/or beamforming information is required. In case the CQI feedback information requires five bits (same as in SISO), three bits can be
35 provided for precoding information (which allows a precoding codebook of size $2^3=8$). Therefore, in such an example, the feedback information for a user in a channel/system situation that only supports single stream transmission requires a

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total of eight bits for combined CSI and CQI, wherein three of the eight bits are multi-antenna transmission specific.

5 In case of SU-MIMO with two-stream transmission, some CQI information from two/both streams is required. However, not the full CQI information for each stream needs to be transmitted but some relative CQI for the second stream with respect to the first stream is sufficient. This relative CQI may have a length of three bit. The relative CQI has the effect, that only a certain difference in applicable AMC is allowed between the streams. For multi-codeword MIMO with two
10 streams and two Tx antennas, the precoding has a very limited effect on the achievable throughput. Therefore, this feedback information could be left out. Thus, for multi-stream transmission SU-MIMO, the absolute CQI is needed for the first stream (as in case of SISO) as well as three bits for the relative CQI for the second stream. The three bits for the relative CQI are multi-antenna transmission
15 specific.

In order to tell the BS 20 how the spatial feedback information should be interpreted, a mode indicator – which may in the present example consist of a single bit (but is not limited to this single bit) - shows if spatial multiplexing or beamforming is
20 signalled. In case of more Tx antennas or more operation modes, a multi-bit mode indicator can be used to differentiate more operating modes.

Fig. 2 shows a schematic block diagram of a transmit and receive unit according to the embodiment, such as the MS 10, which is configured to support or implement
25 the suggested advanced feedback signaling with mode indicator. Access to the radio access network is provided by a transceiver unit 14 capable of receiving and transmitting RF signals via at least one antenna. As an alternative the transceiver unit 14 may comprise or may be replaced by separate transmitter and receiver units with separate transmission and receiving paths. As an example, in order to
30 support SU-MIMO reception, the MS 10 has to be capable of receiving RF signals via at least two antennas.

The transceiver unit 14 is connected to a signal processing stage 12 which is responsible for receiver-related processing, such as demodulating, descrambling,
35 decoding etc. of received DL data, and for transmitter-related processing, such as modulating, scrambling, coding etc. of UL data to be transmitted, and which is additionally configured to determine or extract a basic operation mode 68 received

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for example by a higher-layer signaling from a radio-connected BS, e.g. BS 20 of Fig. 1. This basic operation mode 68 is supplied to an UL feedback circuit 16 which generates an UL feedback information 70 and a mode indicator 80 as described below in more detail. The UL feedback information 70 and the mode indicator 80 are added, e.g. as a binary control word, to an UL stream transmitted via the UL transmission beam 50 towards the radio-connected BS.

Fig. 3 shows a schematic block diagram of a base station device, e.g. the BS 20, according to the embodiment, with two antennas for transmitting and receiving data. In the present example, both antennas are connected to respective transceiver units 22 and 24. Of course, both antennas can be connected to a single transceiver unit capable of processing two transmission and reception streams. Alternatively, both antennas may be pure Tx antennas, while at least one separate reception antenna may be provided for receiving an UL data stream with the feedback information 70 and the mode indicator 80. Furthermore, a feedback extraction unit 28 is provided, to which the received UL data is supplied in order to extract or derive the feedback information 70 and mode indicator 80. The transceiver units 22 and 24 are further connected to a signal processing stage 26 which is responsible for receiver-related processing, such as demodulating, descrambling, decoding etc. for received UL data, and for transmitter-related processing, such as modulating, scrambling, coding, beamforming, user selection etc. for DL data to be transmitted. The signal processing stage 26 is controlled by the feedback information 70 and the mode indicator 80 supplied by the feedback extractor unit 28, so as to control multi-antenna transmission based on the feedback information which is interpreted under consideration of the mode indicator 80.

Figs. 4 and 5 show flow diagrams of the basic processing steps at both radio communication ends of a MIMO transmission system with multiple transmission antennas according to an implementation example with the proposed advanced feedback signaling according to the embodiment.

The processing at the receiving end, e.g., at the MS 10, is shown in Fig. 4 and comprises a first step S101 of receiving a higher layer DL signaling in which the basic MIMO operating mode, e.g. SU-MIMO or MU-MIMO, is indicated. Then, the required feedback information 70 is generated in step S102 based on the received or indicated basic MIMO operation mode. In step S103, the generated feedback information and the reported mode indicator 80, which has been set and is used to

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signal the selected operation mode to be reported for multi-antenna DL transmission, are added to the UL transmission stream forwarded to the transmitting end of the MIMO system.

5 Furthermore, the processing at the transmitting end, e.g., at the BS 10, is shown in Fig. 5 and comprises a first step S201 of receiving an UL stream with the incorporated advanced feedback signaling. Then, the incorporated feedback information 70 and the added mode indicator 80 are extracted in step S202. Then, in step S203, the extracted feedback information 70 is interpreted at the transmitting end
10 by referring to the extracted mode indicator 80. Thereby, the transmitting end is capable of controlling multi-antenna transmission based on the interpreted feedback information 70.

Fig. 6 shows a schematic block diagram of a software-based implementation of the proposed advanced feedback transmission system. Here, the transmitter
15 shown in Fig. 3 and the receiver shown in Fig. 2 each comprise a processing unit 210, which may be any processor or computer device with a control unit which performs control based on software routines of a control program stored in a memory 212. Program code instructions are fetched from the memory 212 and are
20 loaded to the control unit of the processing unit 210 in order to perform the processing steps of the above functionalities described in connection with the respective Figs. 4 and 5 or with the respective blocks 12 and 16 of Fig. 2 or blocks 26 and 28 of Fig. 3. These processing steps may be performed on the basis of input data DI and may generate output data DO, wherein at the receiver end the input
25 data DI may correspond to the received DL data and the output data DO may correspond to the feedback information 70 and mode indicator 80. On the other hand, at the transmitter side, the input data may correspond to the received UL data and the output data may correspond to control information required to control multi-antenna transmission.

30

Figs. 7A to 7F show various interpretation examples of or bit allocation schemes for the extracted feedback information for different operation modes, wherein the first bit(s) on the left side of the depicted binary control words are used to indicate the mode indicator 80, and the following second portion 72 (3 bits) and third portion 74 are interpreted based on the binary value(s) of the mode indicator 80.
35

In Fig. 7A, an exemplary feedback signaling structure for SU-MIMO with single

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stream transmission and spatial CQI/CSI feedback is illustrated. The feedback information 70 consists of a "0"-bit as mode indicator 80, a 3-bit precoding/beamforming information (e.g. a non-frequency-selective codebook index) in the second portion 72 as well as a basic (e.g. frequency selective) CQI information for the AMC/LA and possible frequency domain packet scheduling in the third portion 74

Fig. 7B shows the case of dual stream (e.g. multi-codeword transmission) with a "1"-bit mode indicator 80 that indicates PARC transmission, the basic (e.g. frequency selective) CQI information in the third portion 74 available for the first stream and a non-frequency selective 3-bit relative CQI in the second portion 72 for the second stream with respect to the first stream.

In the above examples, when talking about CQI, basically the spatial CQI is meant. In addition thereto, a CQI in the frequency domain can be used, allowing frequency domain packet scheduling. Then, the CQI information in the third portion 74 can be used for the first transmission stream, which is basically the same allocation as in case of SISO according to Fig. 7A. This is indicated by the larger bit-field in Fig. 7A to 7F for the third portion 74 allowing frequency selective CQI reporting e.g. for OFDM (Orthogonal Frequency Division Multiplexing) systems. Thus, the additional feedback information (in addition to the SISO case), requires four bits – namely the 1-bit mode indicator 80 as well as in the second portion 72 either the 3-bit relative CQI of Fig. 7B for the second stream for PARC or the 3-bit precoding/beamforming information of Fig. 7A for single stream beamforming. The same precoding can be assumed for all allocated resource blocks as well as the relative CQI allows AMC with respect to the first stream (as long as the same modulation and coding scheme is used for all allocated resource blocks).

In an exemplary modification of the embodiment, the feedback information may be divided into two parts. The type of one part of the feedback information may not depend on the transmission mode, whereas the other part of the feedback information may depend. The part of the feedback information that does not depend on the transmission mode may be a bit field of a fixed length. It may be related for example to the channel quality of one data stream, possibly indicated in the frequency domain.

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The part that depends on the transmission mode may be a bit field of fixed length, which may refer to different characteristics of the transmission for different modes. For example, in one mode, the bits in this bit field may refer to spatial precoding information, whereas in another mode, the bits may refer to relative CQI information.

In another exemplary modification of the embodiment, the part of the feedback information that does not depend on the transmission mode may be the only information that a scheduler needs to decide on the scheduling of users. The other bits of the feedback information may be needed to determine the actual transmission mode of the user. For example, the bits that do not depend on the mode may indicate the frequency selective sum CQI for a multi-stream transmission, and the CQI for a single stream for a precoded single-stream transmission. The bits depending on the mode selection then determine the division of the sum CQI among the streams for a multi-stream transmission, and the precoding for a single-stream transmission.

In the following, an example for the use of the above four bits for multi-user MIMO DL transmission is described. It is assumed in these examples that MU-MIMO as the basic MIMO operation mode has been signaled via higher layer DL signaling by the NodeB 20 to the MS 10.

First of all, in case of DL MU-MIMO with two Tx antennas, there is just the possibility to transmit to a single user or two users. The precoding in case of MU-MIMO can use a unitary transmission matrix (where the transmission vectors for different users are orthogonal). In case of a user who is in bad channel conditions (e.g. therefore needs the full available Tx power for himself in order to support the minimum modulation and coding scheme) or in case that the interference produced by MU transmission would be so high that the expected throughput would be e.g. less than $\frac{1}{2}$ compared to the case of SU beamforming transmission, the receiver at the MS 10 chooses to set the mode indicator 80 to "0" in order to report for single-stream SU beamforming, so that the calculated and reported CQI in the third part 74 assumes full transmission power as well as no intracell interference due to MU transmission in addition to the precoding vector. The bit allocation of the codeword then corresponds to Fig. 7A (mode indicator set to "0"), where the 3-bit beamforming/precoding information is allocated to the second portion 72 as

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well as the estimated CQI assuming single user transmission in the third section 74.

On the other hand, in case MU transmission is reasonable from the user's point of view (i.e., minimum modulation and coding scheme can be supported and interference power results in e.g. more than half of the throughput compared to SU transmission for this single user), the receiver at the MS 10 chooses to set the mode indicator 80 to "1" in order to report for MU transmission, so that the reported CQI assumes half the available TX power for its transmission as well as intercell interference from a multi-user transmission with an orthogonal transmission weight in addition to the preferred precoding vector (3bits). Here, the bit allocation of the codeword corresponds to Fig. 7B (mode indicator set to "1"), where the 3-bit beamforming/precoding information is allocated to the second portion 72 as well as the estimated CQI assuming multi-user transmission to the third section 74. The difference between the reporting in the MU-MIMO mode of single user transmission described in the previous paragraph and multi-user transmission, is the mode indicator 80 ("0" or "1" respectively) and how the CQI information in 74 is calculated at the MS 10 and has to be interpreted.

The difference between these two reporting modes can be indicated by the 1-bit mode indicator 80 which indicates if the report is valid for MU transmission or SU transmission.

So far, it has been assumed, that the BS 20 defines either SU or MU MIMO operation modes by higher layer signaling. If this would be not the case (and the MS 10 can define itself its best operation mode taking its current channel and signal-to-noise ratio (SNR) operation point into account), some more feedback information (at least one bit) would be needed.

Figs. 7C to 7F show exemplary feedback signaling structures or bit allocation schemes, where (the first) two bits are allocated to or reserved for the mode indicator 80.

According to Fig. 7C, the bit combination "00" of the mode indicator 80 signals single-user and single-stream transmission, where the second portion 72 is to be interpreted as (non-frequency-dependent) precoding/beamforming codebook index

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and the third portion 74 is to be interpreted as general (e.g. frequency-selective) CQI information.

5 According to Fig. 7D, the bit combination "01" of the mode indicator 80 denotes single-user multi-stream transmission, where the second portion 72 is to be interpreted as a (non-frequency-selective) relative CQI information for the second transmission stream, while the third portion 74 is to be interpreted as a (e.g. frequency-selective) CQI information for the first transmission stream.

10 According to Fig. 7E, the bit combination "10" of the mode indicator 80 denotes multi-user transmission, where the second portion 72 is to be interpreted as a (non-frequency-selective) precoding/beamforming codebook index, while the third portion 74 is to be interpreted as a frequency-selective CQI information assuming SDMA to two users.

15 According to Fig. 7F, the remaining bit combination "11" of the mode indicator 80 can be used by the receiver at the MS 10 to indicate its desire to utilize diversity transmission methods or other open-loop single-user transmission schemes. Then, the three bits of the second portion 72 might either not be allocated or utilized for something specifying the diversity or other open-loop transmission
20 scheme further (e.g. the selection of the delay value for cyclic delay diversity for OFDM systems, the number of streams supported for OL SU-MIMO transmission using matrix modulations).

25 It is however strongly pointed out that the above bit allocation or interpretation examples are in now way limiting and can be extended or amended in various ways. The position, interpretation and bit number of the second and third portions 72, 74 as well as the mode indicator 80 may be changed based on the requirements of other implementations. As an example, in case of four Tx antennas, the interpretation of the feedback information 70 may change depending on the number of
30 transmission streams etc. In an exemplary case of multi-codeword single-user MIMO with up to 4 streams, the strongest stream and also the relative CQI (3bit) in the negative direction from the strongest stream could be signaled by the feedback information. The following table gives some possible information contents of the
35 feedback information 70 and the corresponding total numbers of bits in dependence on the number of transmission streams:

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Number of streams	Ordering information	Beam selection	Relative CQI	Total for x streams
1	0	32	0	4*8
2	2	6	8 (3bit)	12*8
3	6	4	8 (3bit)	24*8
4	24	0	8	24*8
In total				64*8 = 9bit

As can be gathered from the above table, when putting the streams in order of their strength, there are 24 possibilities for 4 streams (i.e., $4! = 4*3*2*1 = 24$), 6 ($=3!$) for 3 streams, and 2 for 1 stream. For a single stream no ordering is needed. Furthermore, the relative CQI is assumed to have a length of three bits. The relative CQI can be used in a sense that the CQI of the second strongest stream is approximated as CQI + relative CQI, the one for the third strongest stream CQI + 2*relative CQI and so on. For this example, up to nine bits of information are allocated to the feedback information depending on the number of streams. Other set-ups for four Tx antennas are of course possible as well.

At this point, it is again noted that the functionalities of blocks 12 and 16 of Fig. 2 as well as blocks 26 and 28 of Fig. 3 can be implemented as discrete hardware or signal processing units, or alternatively as software routines or programs controlling a processor or computer device to perform the processing steps of the above functionalities.

Hence, a flexible and rather straightforward feedback signaling option is provided, by means of which it can be defined at the receiving end what kind of information should be fed back and in which format in order to be able to use the same amount of total feedback information independent of the operation mode (e.g., single stream transmission vs. SU-MIMO with two streams vs. multi-user MIMO).

To summarize, methods, a system, a transmitter apparatus, a receiver apparatus, and computer program products for providing enhanced feedback in a multi-antenna transmission system have been described, wherein an operation mode of a multi-antenna transmission end is determined at a reception end of a connection, and a feedback information and a mode indicator are generated based on the determined operation mode and transmitted to the multi-antenna transmission end where the feedback information is interpreted based on the mode indicator.

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Thereby, different operation modes can be supported by the same amount of total feedback information and without requiring any change in signaling setup.

5 Conventional methods for compressing frequency domain CQI reporting may be used. For example, the CQI report of a user may be built up based on multiple feedback reports, with the granularity increasing with the number of reports.

10 It is to be noted that the present invention is not restricted to the embodiment described above, but can be implemented in any network environment involving multi-antenna transmission controlled by feedback signaling. Any signaling format or means can be used for feeding back the mode indicator and the feedback information. The embodiment may thus vary within the scope of the attached claims.

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Claims

1. A method comprising:
 - a. determining at a reception end of a connection an operation mode of a multi-antenna transmission end of said connection;
 - b. generating feedback information (70) and a mode indicator (80) based on said determined operation mode; and
 - c. adding said feedback information (70) together with said mode indicator (80) to a data stream transmitted from said reception end via said connection to said multi-antenna transmission end.
2. The method according to claim 1, wherein said determination is performed based on a signaling received from said multi-antenna transmission end.
3. The method according to claim 2, wherein said signaling is a signaling of a protocol layer higher than the protocol layer of said data stream.
4. The method according to any one of the preceding claims, further comprising selecting as said operation mode one of a single-user single-stream transmission mode, a single-user multi-stream transmission mode, a multi-user transmission mode, a diversity transmission mode, or an open loop single-user transmission mode.
5. The method according to claim 1, wherein said feedback information is divided into two parts, and wherein one part of said feedback information does not depend on said operation mode, whereas the other part of said feedback information depends on said operation.
6. The method according to claim 5, wherein said part of said feedback information that does not depend on said operation mode and said part is a bit field of a fixed length.

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7. The method according to claim 5, wherein said part of said feedback information that depends on said operation mode is a bit field of fixed length, which refers to different characteristics of the transmission for different modes
- 5 8. The method according to claim 7, wherein in one operation mode, the bits in said bit field refers to a spatial precoding information, and in another operation mode, said bit field refers to a relative channel quality information.
- 10 9. The method according to claim 5, wherein said part of said feedback information that does not depend on said operation mode is the only information based on which that a scheduler decides on scheduling of users, and wherein other bits of said feedback information are used to determine the actual operation mode of the user.
- 15 10. The method according to claim 9, wherein said part of said feedback information that does not depend on said operation mode is used to indicate a frequency selective sum of channel quality information for a multi-stream transmission, and the channel quality information for a single stream of a precoded single-stream transmission, and wherein said part of said feedback information
20 that depends on said operation mode is used to determine a division of said sum channel quality information among streams for a multi-stream transmission and precoding for a single-stream transmission.
- 25 11. The method according to claim 4, further comprising using said mode indicator to indicate additional information specifying said operation mode.
- 30 12. The method according to any one of the preceding claims, further comprising indicating by said feedback information at least one of a channel quality information, a channel state information, a precoding information and an open loop or diversity transmission mode information.
- 35 13. The method according to any one of the preceding claims, further comprising using said mode indicator to define allocation and interpretation of individual bits of said feedback information.

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14. The method according to claim 1, further comprising using said method with a one-bit mode indicator or a two-bit mode indicator, wherein said multi-antenna transmission end comprises two transmission antennas.
- 5 15. The method according to claim 1, further comprising using said method with a three-bit mode indicator, wherein said multi-antenna transmission end comprises four transmission antennas.
16. A method comprising:
- 10
- a. receiving at a multi-antenna transmission end a data stream which comprises a feedback information (70);
 - b. extracting from said received data stream said feedback information (70) and a mode indicator (80) which indicates an operation mode of said multi-antenna transmission end; and
 - c. interpreting said feedback information (70) based on said mode indicator (80) in order to control multi-antenna transmission.
- 15
- 20
17. The method according to claim 16, wherein said control of multi-antenna transmission comprises at least one of scheduling, precoding, beamforming, multiplexing and link adaptation.
- 25
18. The method according to claim 16 or 17, further comprising selecting as said operation mode one of a single-stream transmission mode, a single-user transmission mode, a multi-user transmission mode, a diversity transmission mode, or an open loop single-user transmission mode.
- 30
19. The method according to claim 18, further comprising determining from said mode indicator additional information specifying said operation mode.
20. The method according to any one of claims 16 to 19, further comprising deriving from said feedback information at least one of a channel quality information, a channel state information and a precoding information.
- 35

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21. The method according to any one of claims 16 to 20, further comprising using said mode indicator to derive allocation and interpretation of individual bits of said feedback information.
- 5 22. The method according to claim 16, further comprising using said method with a one-bit mode indicator or a two-bit mode indicator, wherein said multi-antenna transmission end comprises two transmission antennas.
- 10 23. The method according to claim 16, further comprising using said method with a three-bit mode indicator, wherein said multi-antenna transmission end comprises four transmission antennas.
24. A transmitter apparatus comprising:
- 15 a. receiving means (22, 24) for receiving a data stream which comprises a feedback information (70);
- b. extracting means (28) for extracting from said received data stream said feedback information (70) and a mode indicator (80) which indicates an operation mode of a selected multi-antenna transmission scheme; and
- 20 c. interpretation means (26) for interpreting said feedback information (70) based on said mode indicator (80) in order to control multi-antenna transmission in response to said feedback information.
- 25 25. The transmitter apparatus according to claim 24, wherein said interpretation means (26) is configured to control at least one of scheduling, precoding, beamforming, multiplexing and link adaptation for said multi-antenna transmission.
- 30 26. The transmitter apparatus according to claim 24 or 25, wherein said interpretation means (26) is configured to derive from said feedback information one of a single-stream transmission mode, a single-user transmission mode, a multi-user transmission mode, a diversity transmission mode, or an open loop single-user transmission mode.
- 35

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27. The transmitter apparatus according to claim 26, wherein said interpretation means (26) is configured to determine from said mode indicator additional information specifying said operation mode.
- 5 28. The transmitter apparatus according to any one of claims 24 to 27, wherein said feedback information comprises at least one of a channel quality information, a channel state information and a precoding information.
- 10 29. The transmitter apparatus according to any one of claims 24 to 28, wherein said interpretation means (26) is configured to derive allocation and interpretation of individual bits of said feedback information based on said mode indicator.
- 15 30. The transmitter apparatus according to claim 24, wherein said transmitter apparatus comprises two transmission antennas and said mode indicator is a one-bit or a two-bit information.
- 20 31. The transmitter apparatus according to claim 24, wherein said transmitter apparatus comprises four transmission antennas and said mode indicator is three-bit information.
32. A receiver apparatus comprising:
- 25 a. determination means (16) for determining an operation mode of a multi-antenna transmission end;
- b. generating means (16) for generating feedback information (70) and a mode indicator (80) based on said determined operation mode; and
- 30 c. adding means (12) for adding said feedback information (70) together with said mode indicator (80) to a data stream transmitted from said receiver apparatus to said multi-antenna transmission end.
- 35 33. The receiver apparatus according to claim 32, wherein said determination means (16) is configured to determine said operation mode based on a signaling received from said multi-antenna transmission end.

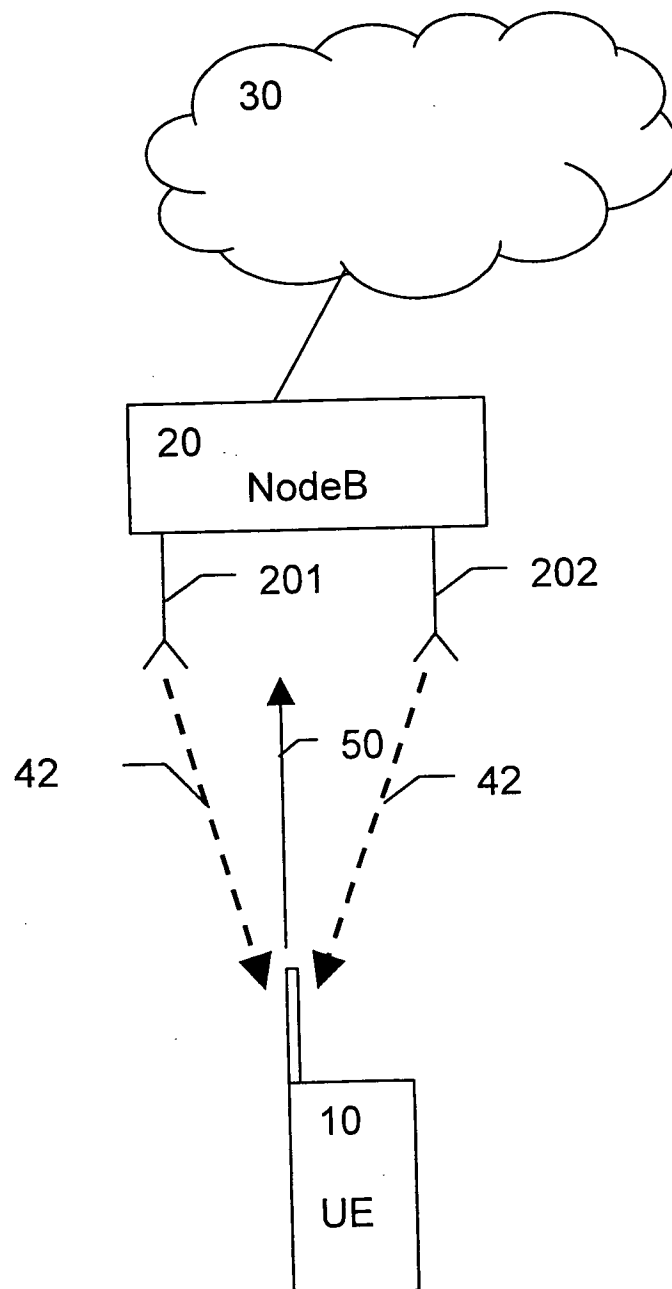
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34. The receiver apparatus according to claim 33, wherein said signaling is a signaling of a protocol layer higher than the protocol layer of said data stream.
- 5 35. The receiver apparatus according to any one of claims 32 to 34, wherein said determination means (16) is configured to determine as said operation mode one of a single-stream transmission mode, a single-user transmission mode, a multi-user transmission mode, a diversity transmission mode, or an open loop single-user transmission mode.
- 10 36. The receiver apparatus according to claim 35, wherein said generating means (16) is configured to generate said mode indicator so as to indicate additional information specifying said operation mode.
- 15 37. The receiver apparatus according to any one of claims 32 to 36, wherein said generating means (16) is configured to indicate by said feedback information at least one of a channel quality information, a channel state information and a precoding information.
- 20 38. The receiver apparatus according to any one of claims 32 to 37, wherein said generating means (16) is configured to generate a one-bit mode indicator or a two-bit mode indicator for a multi-antenna transmission end with two transmission antennas.
- 25 39. The receiver apparatus according to any one of claims 32 to 37, wherein said generating means (16) is configured to generate a three-bit mode indicator for a multi-antenna transmission end with four transmission antennas.
- 30 40. A transmission system comprising at least one transmitter apparatus according to claim 24, and at least one receiver apparatus according to claim 32.
41. A computer program product comprising code means for producing the steps of method claim 1 when run on a computer device.
- 35 42. A computer program product comprising code means for producing the steps of method claim 16 when run on a computer device.

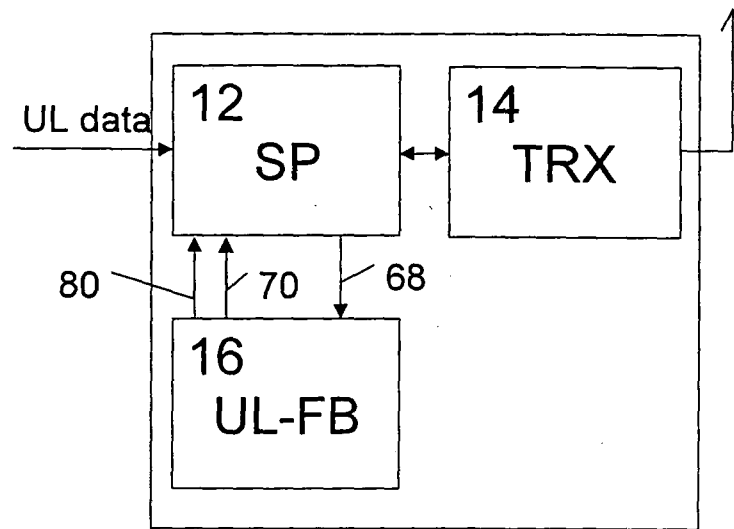
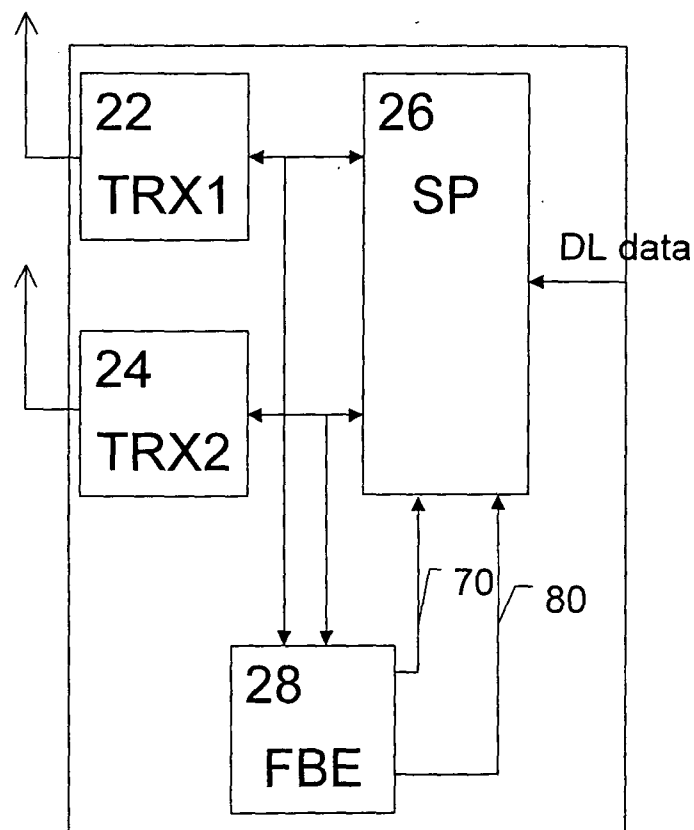
- 24 -

43. A base station device comprising a transmitter apparatus according to claim 24.

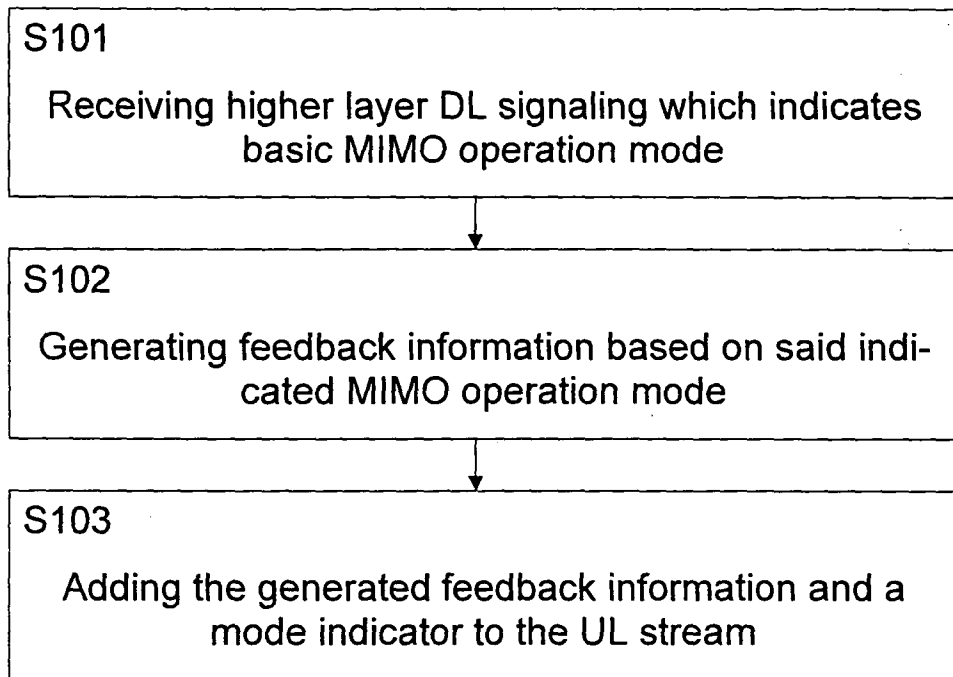
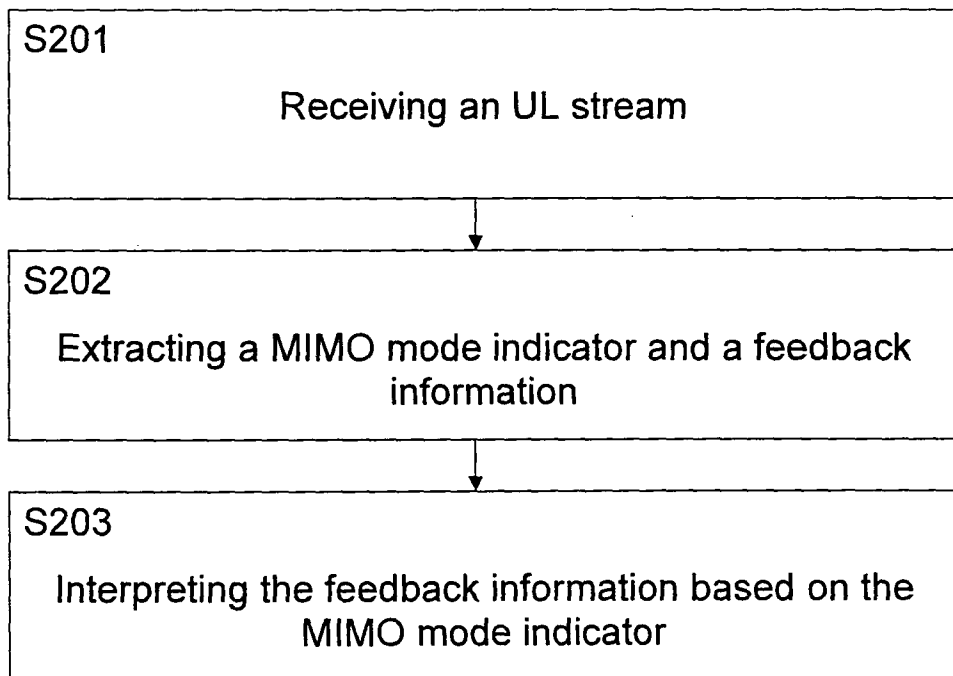
44. A mobile station comprising a receiver apparatus according to claim 32.

**Fig. 1**

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**Fig. 2****Fig. 3**

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**Fig. 4****Fig. 5**

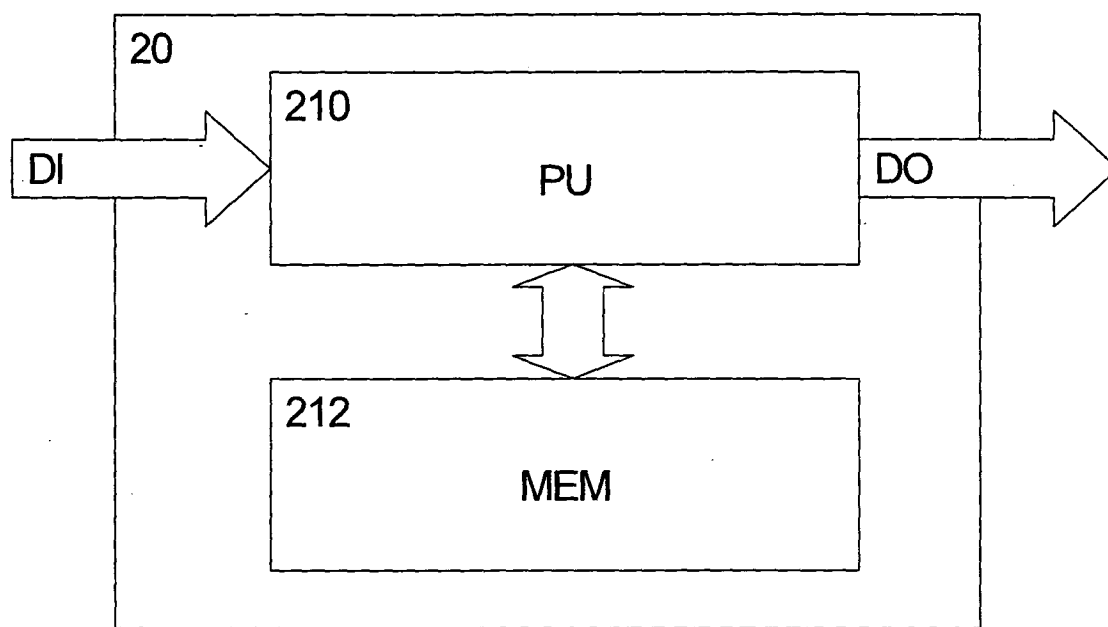


Fig. 6

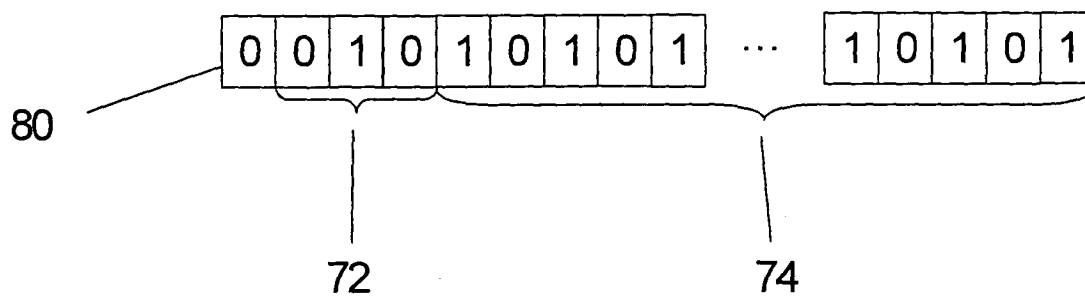


Fig. 7A

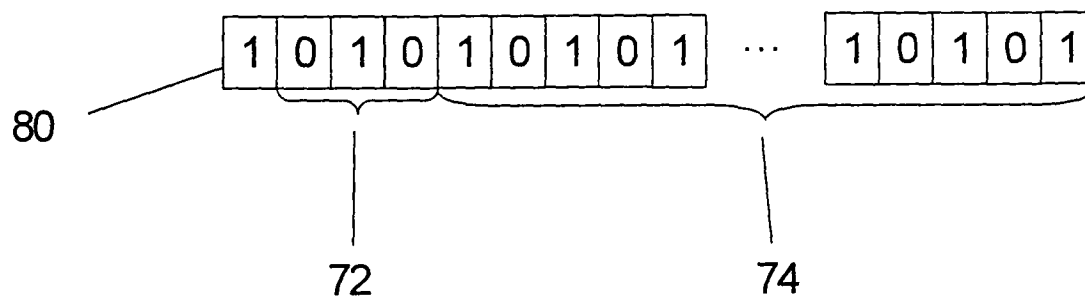
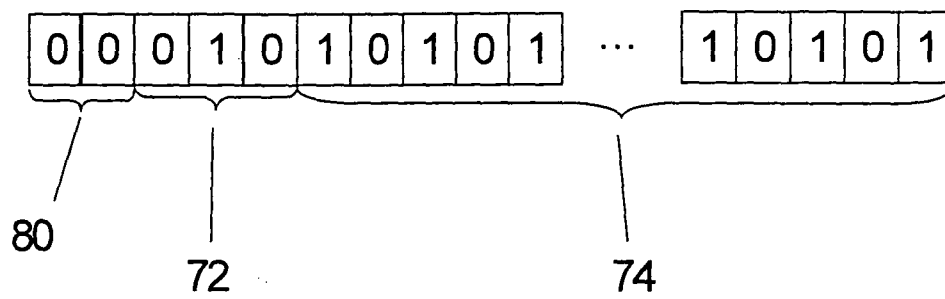
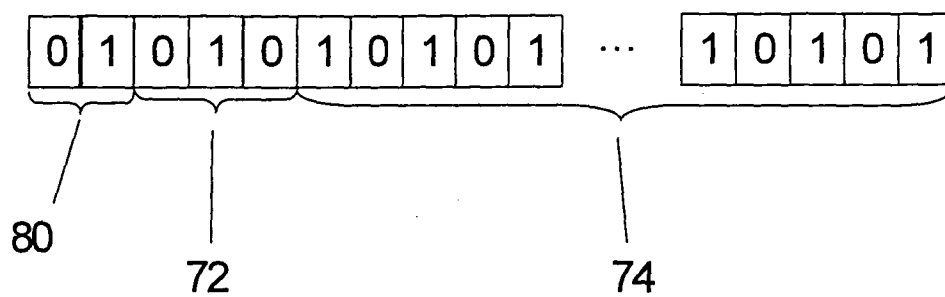
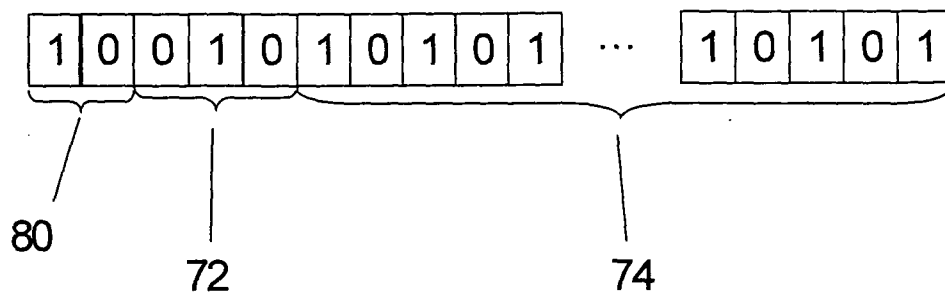
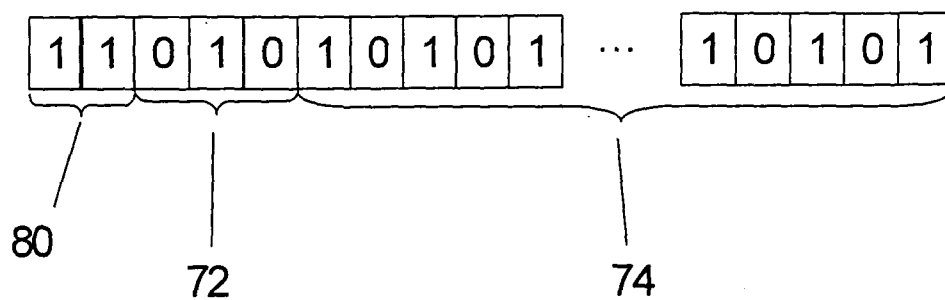


Fig. 7B

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**Fig. 7C****Fig. 7D****Fig. 7E****Fig. 7F**