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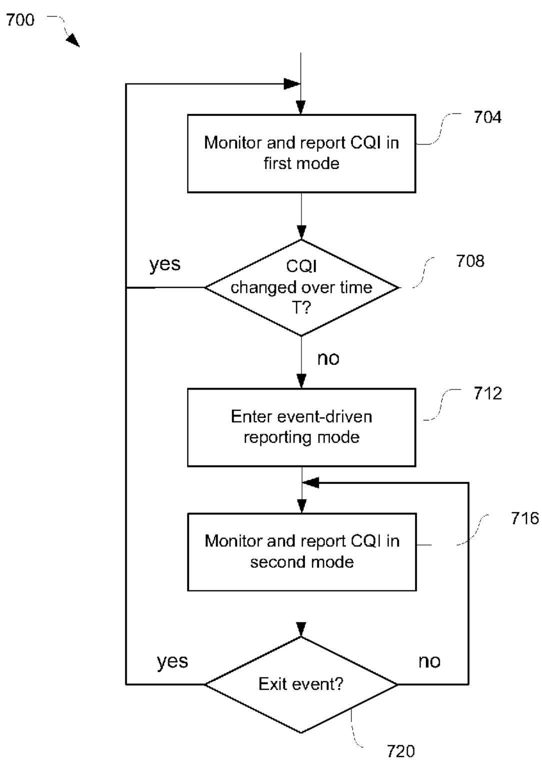
(54) Title: UPLINK AND DOWNLINK CONTROL SIGNALING IN WIRELESS NETWORKS



(57) Abstract: Embodiments of the present invention provide for downlink and uplink control feedback signaling. Other embodiments may be described and claimed.

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UPLINK AND DOWNLINK CONTROL SIGNALING IN WIRELESS NETWORKS

Field

[001] Embodiments of the present invention relate to the field of wireless networks, and more particularly, to providing uplink and downlink control signaling in said wireless networks.

Background

[002] Multi-carrier communications systems use symbol-modulated sub-carriers to communicate. Changing channel conditions, including frequency selective fading, may provide challenges to providing uplink and downlink transmissions to users in the system with desired communication efficiencies.

Brief Description of the Drawings

[003] Embodiments of the present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

[004] **FIG. 1** illustrates a wireless communication system in accordance with various embodiments of the present invention;

[005] **FIG. 2** illustrates a flowchart of a resource allocation algorithm in accordance with various embodiments of the present invention;

[006] **FIG. 3** illustrates a flowchart of another resource allocation algorithm in accordance with various embodiments of the present invention;

[007] **FIG. 4** illustrates a wireless communication node in accordance with various embodiments of the present invention;

[008] **FIG. 5** illustrates another wireless communication node in accordance with various embodiments of the present invention;

[009] **FIG. 6** illustrates a flowchart of a channel condition report in accordance with various embodiments of the present invention; and

[0010] **FIG. 7** illustrates a flowchart of a reporting mode sequence in accordance with various embodiments of the present invention.

Detailed Description of Embodiments of the Invention

[0011] In the following detailed description, reference is made to the accompanying drawings which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments in accordance with the present invention is defined by the appended claims and their equivalents.

[0012] Various operations may be described as multiple discrete operations in turn, in a manner that may be helpful in understanding embodiments of the present invention; however, the order of description should not be construed to imply that these operations are order dependent.

[0013] For the purposes of the present invention, the phrase "A and/or B" means "(A), (B), or (A and B)." For the purposes of the present invention, the phrase "A, B, and/or C" means "(A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C)."

[0014] The description may use the phrases "in an embodiment," or "in embodiments," which may each refer to one or more of the same or different embodiments. Furthermore, the terms "comprising," "including," "having," and the like, as used with respect to embodiments of the present invention, are synonymous.

[0015] **FIG. 1** illustrates a wireless communication system **100** in accordance with an embodiment of this invention. In this embodiment, the communication system **100** is shown with nodes **104**, **108**, and **112** communicatively coupled to one another via a shared wireless medium **116**. The nodes **104**, **108**, and **112** may access the shared wireless medium **116**, hereinafter "medium **116**," through antenna structures **120**, **124**, and **128**, respectively.

[0016] Each of the antenna structures **120**, **124**, and **128** may have one or more antennas, e.g., three antennas as shown, for wireless communication via the common wireless medium **116**. In various embodiments, any number of antennas may be employed. The antennas employed in the antenna structures **120**, **124**, and **128** may be directional or omnidirectional antennas, including, e.g., dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or any other type of antenna suitable for transmission of radio frequency (RF) signals.

[0017] A link utilizing one transmit antenna (at a transmitting node) and one receive antenna (at a receiving node) may be referred to as a single-input, single-output link. A link utilizing more than one transmit and receive antennas may be referred to as a multiple-input, multiple-output (MIMO) link. A multi-antenna node may transmit information via the medium **116** over one or more spatial channels. A multi-antenna node may form up to as many spatial channels as it has antennas. For example, node **104** may form one, two, or three spatial channels for transmitting information over the medium **116**.

[0018] The nodes **104**, **108**, and **112** may be any physical or logical entity for communicating information in the communication system **100** and may be implemented as hardware, software, or any combination thereof, as desired for a given set of design parameters or performance constraints. Although **FIG. 1** may show a limited number of nodes by way of example, it can be appreciated that more or less nodes may be employed for a given implementation.

[0019] In various embodiments, the communication system **100** may be a radio access network compatible with the Universal Mobile Telephone System (UMTS) along with any revisions, amendments, or updates thereto (including, but not limited to, those resulting from the Seventh Release of the Technical Report produced by Third Generation Partnership Project ("3GPP"), 3GPP TR 25.814 V7.1.0 (2006-09)).

[0020] In various embodiments, the nodes **108** and **112** may be user equipment (UE) implemented in, e.g., a mobile computer, a personal digital assistant, a mobile phone, etc., and node **104**, which may also be referred to as a node-B, may be implemented in a base transceiver station (BTS).

[0021] The node **104** may be arranged to communicate information over the medium **116** to and/or from the nodes **108** and **112**. This information may include media information and/or control information. Media information generally may refer to any data representing content meant for a user, such as image information, video information, graphical information, audio information, voice information, textual information, numerical information, alphanumeric symbols, character symbols, and so forth. Control information generally may refer to any data representing commands, instructions or control words meant for an automated system. For example, control information may be used to route media information through a system, instruct a node to process the media information in a certain manner, or to communicate state information of a network to a node.

[0022] Transmissions in the direction of the nodes **108** and **112** to the node **104** may be referred to as an uplink transmission, while transmissions in the opposite direction may be referred to as a downlink transmission. These air interfaces may be compatible with UMTS Terrestrial Radio Access (UTRA) and/or Evolved - UTRA (E-UTRA) technologies. In some embodiments, downlink modulation schemes may be of a first type, e.g., orthogonal frequency division multiple access (OFDMA), while uplink modulation schemes may be of a second type, e.g., single carrier frequency division multiple access (FDMA).

[0023] In some embodiments downlink information may be transmitted over the medium **116** as multiple OFDM symbols spread over multiple sub-carriers, with adjacent sub-carriers being orthogonal to one another. The transmitted information may be organized into physical resource elements ("PREs") of a given channel. A PRE may be composed one or more sub-carriers, which may be arranged as a resource block including *L c*onsecutive sub-carriers and *M* time/frequency symbols. *L* and *M* may be any positive integers. The information to be transmitted may be initially arranged as one or more virtual resource elements (VREs), with the size of the VREs corresponding to the size of the PREs. The VREs may then be assigned to PREs for transmission according to allocation schemes described with reference to various embodiments of the present invention.

[0024] In some embodiments a localized transmission mode (LTM) may provide that information transmitted from a node–B, e.g., node **104**, to a particular UE, e.g., node **108**, may be confined to a set of resource blocks, and, for each sub-frame, a resource block is assigned for transmission to a single UE. In some embodiments, the resource blocks selected for transmission may be selected by the node **104** based on knowledge of instantaneous channel conditions (a.k.a. channel-dependent scheduling).

[0025] Channel-dependent scheduling may help to combat frequency-selective fading on the channel; however, it may not be available and/or desirable in all situations. For example, if the node **108** is highly mobile (e.g., is traveling in a vehicle) it may be difficult to track instantaneous channel conditions. For another example, if the information is being broadcast to more than one UE, e.g., node **108** and node **112**, channel-dependent scheduling to exploit a particular UE's channel may not be possible.

[0026] When channel-dependent scheduling is not available or is not desirable, it may be desirable to increase frequency diversity. Frequency diversity may be attained in LTM by distributing the VREs on resource blocks that are spaced a sufficient distance from one another within the sub-frame. This distribution may work well when the amount of information to be transmitted (e.g., the payload) is sufficient to fill multiple resource blocks.

[0027] If, on the other hand, the amount of information to be transmitted is not sufficient to fill multiple resource blocks, distributing the information over multiple resource blocks may result in portions of the transmitting bandwidth being wasted. Accordingly, for transmitting information with relatively small payloads, a distributed transmission mode ("DTM") may be employed. A DTM may provide for the distribution of payloads for multiple UEs over multiple resource blocks. Thus, in a DTM, a single resource block may include information being transmitted to more than one UE.

[0028] In embodiments of the present invention, both DTM and LTM transmissions may be multiplexed together in a frequency division multiplexing ("FDM") manner in a downlink from node **104** to node **108** and/or node **112**. The allocation of PREs to localized users (e.g., UEs to which an LTM transmission is directed) may be done first to exploit multi-user diversity. Next, the remaining PREs (either a fixed fraction of the overall resource elements, or a dynamically varying fraction) may be allocated among the distributed users (e.g., UEs to which a DTM transmission is directed).

[0029] A VRE to be mapped to a PRE of a resource block assigned for localized transmission may be referred to as a localized VRE ("LVRE"); while a VRE to be mapped to a PRE of a resource block assigned for distributed transmission may be referred to as a distributed VRE ("DVRE").

[0030] Mapping DVREs to PREs may be relatively straightforward when each of the users' resource requirements is the same. As used herein, a user's resource requirement may be the amount of resource elements desired for transmitting relevant information to UE in the downlink transmission. A user's resource requirements may be expressed, and initially arranged, as a number of DVREs. The number of DVREs to satisfy a user's resource requirement may sometimes be referred to as a distributed virtual resource block (DVRB). When the users' resource requirements are different (resulting in a different number of DVREs (or a different sized DVRB) for each user) the distribution becomes more involved.

[0031] Accordingly, embodiments of the present invention, to be described in further detail below, enable a transmitting node, e.g., a node-B, to map information for distributed users to PREs given the possibility of unequal resource requirements.

[0032] In this embodiment, let the different resource requirements for K different users be denoted as l_k, $k = 1, \ldots, K$. Thus, the total number of required resource elements (N_{RE}) may be given by:

[0033] $$N_{RE} = \sum_{k=1}^{K} l_k \ .$$

EQ. 1

[0034] In this embodiment, it may be assumed that the number of required resource elements, N_{RE}, is equal to the number of PREs available for DTM in the sub-frame, N_{PRE}. While embodiments described herein may discuss the time unit of the wireless channel as a sub-frame, other embodiments may utilize other time units, e.g., one or more OFDM symbols. The following description provides instruction for mapping a set of DVREs to the N_{PRE} PREs.

[0035] In various embodiments, the N_{PRE} PREs may be distributed over the entire band, over certain blocks of sub-carriers, or by a hybrid of the previous two. In all of these cases, an ordered set of resource element indices for PREs allocated for DVREs may be extracted, and, without loss of generality, form a unique mapping to the set of PREs $\{S_i = i, i = 1, 2, \ldots, N_{RE}\}$.

[0036] This set of PREs, S_i, may be mapped to DVREs of the different users, $V_k(j)$, to satisfy respective requirements, $\{l_k\}$. The resource allocation that results in the largest average spacing between adjacent PREs for all users may be chosen to provide for desired frequency diversity for the entire set of users allocated these DVREs subject to the resource constraints.

[0037] When the resource requirements for all users are identical, e.g., $l_k = l$ for all $k = 1, \ldots, K$, the mapping that results may be $V_k(j) = S_{k+(j-1)K}$, $k = 1,\ldots, K$ and $j = 1,\ldots, l$.

[0038] In the general case when the resource requirements of the different users are unequal, the desired mapping may provide for the PREs that are evenly distributed across all users. A measure for the evenness of the resource element spacing for the k^{th} user may be defined in terms of the deviation from the mean spacing, e.g.,:

[0039] $$e_k = \sum_{i=2}^{l_k} \left| d_k(i) - \bar{d}_k \right|^{\gamma},$$ EQ. 2

[0040] where $\bar{d}_k = N_{sc} / l_k$ is the mean spacing between resource elements for the k^{th} user, $d_k(i) = V_k(i) - V_k(i-1)$ is the spacing of the i^{th} resource element for the k^{th} user, and $\gamma = 1 \; or \; 2$ (although γ may be any positive number). The resource allocation algorithm may then seek to assign the resource elements among the different users in such a way that the metric

[0041] $$m = \sum_{k=1}^{K} e_k,$$ EQ. 3

[0042] is minimized over all distributions.

[0043] **FIG. 2** illustrates a flowchart of a resource allocation algorithm **200** that seeks to distribute resources in a manner to provide a desired measure of evenness and/or spacing between adjacent assigned resource elements in accordance with an embodiment of the present invention.

[0044] In block **204**, the distributed users may be sorted in order according to their resource requirements such that $l_1 \geq l_2 \geq \ldots \geq l_K$. This sorting operation may not be performed in some embodiments.

[0045] In block **208**, a calculation index, n, may be set to 1.

[0046] In block **212**, a set of resource element indices may be computed. In an embodiment these indices may be computed by the following equation:

[0047] $$q_i = in\left(\frac{i}{l_n} \sum\nolimits_{k=n}^{K} l_k \right), i = 1, \ldots, l_n,$$ EQ. 4

[0048] wherein *in*(.) is an integer function, e.g., *ceil*(.) (which rounds the value up to the nearest integer); *round(.)* (which rounds the value to the nearest integer); or *floor(.)* (which rounds the value down to the nearest integer).

[0049] In block **216**, a set of resource elements may then be assigned to the n^{th} user with requirement l_n by $\{V_n(i) = S_{q_i}\}$.

[0050] In block **220**, the set of resource elements assigned to the n^{th} user in block **216** may be removed from available resource elements, $\{S_i\}$, to form the updated set of resource elements remaining to be assigned. After the update, the remaining elements may be renumbered sequentially (i.e. 1,2,…) to allow EQ. 4 to work for the next round of iteration.

[0051] In block **224**, the calculation index, n, may be compared to the total number of distributed users, K, to determine whether resource assignments have been performed for all of the distributed users. If not, the process may proceed to block **228**, where the calculation index is incremented, and then back to block **212**.

[0052] If resource assignments have been performed for all of the distributed users, the process may proceed to block **232**. In block **232**, S_i (mapped into $V_k(i)$ in block **216**) may be related back to the original resource element indices, which may be potentially distributed in chunks across the total bandwidth.

[0053] In the above algorithm, it is assumed that $N_{PRE} = N_{RE}$; however, in many embodiments N_{PRE} may be greater than N_{RE}. Accordingly, in some embodiments, the mapping algorithm described above may be modified to account for the extra resource elements. For example, a dummy user may be introduced into the mapping along with the real distributed users. The dummy user may be assigned a resource requirement, l_{dummy}, equal to the difference between the number of available resource elements, N_{PRE}, and the number of required resource elements, N_{RE}. That is, $l_{dummy} = N_{PRE} - N_{RE}$.

[0054] The dummy user and its associated resource requirement may be included in the algorithm described in FIG. 2, making the total user set equal to K plus one. Once the mapping is complete, the resource allocated to the dummy user, which may be unused, may add to the spacing between the assigned resource elements of the real users.

[0055] In an embodiment, the dummy user may be placed into at the beginning of the sorted order of users, e.g., in block **204**, regardless of its requirement. This may provide the initial, $n = 1$, distribution to be provided to the dummy user, with the remaining active allocations being interspersed throughout the other PREs. The dummy user may be appended to the ended of the sorted order of users.

[0056] Having extra resource elements may be accounted for in other ways in other embodiments. For example, in another embodiment a spacing factor, S, may be used to adequately spread the resource elements of the distributed users over the available PREs.

[0057] In this embodiment, the set of available PREs may be defined as $S_i = i$, $i = 1, 2, \ldots, N_{PRE}$, where $N_{PRE} \geq N_{RE}$. The spacing factor, S, may be defined as follows:

[0058] $$S = \left\lceil N_{PRB} / N_{RE} \right\rceil .$$ EQ. 5.

[0059] **FIG. 3** illustrates a flowchart of a resource allocation algorithm **300** that seeks to provide a resource allocation accounting for extra available PREs utilizing this spacing factor in accordance with an embodiment of the present invention.

[0060] In block **304**, similar to block **204**, the distributed users may be sorted according to their resource requirements such that $l_1 \geq l_2 \geq \ldots \geq l_K$.

[0061] In block **308**, similar to block **208**, a calculation index, n, may be set to 1.

[0062] In block **312**, a spacing function, j, may be defined by the following equation:

[0063] $$j = \left\{ \begin{array}{c} i \cdot S \ , i = 1, \ldots, \left\lceil N_{PRE} / S \right\rceil \\ \mathrm{mod}(i \cdot S - 1, N_{PRE}) + 1, i > \left\lceil N_{PRE} / S \right\rceil \end{array} \right\}, i = 1, \ldots, l_n,$$ EQ. 6.

[0064] In block **316**, a set of indices, q_i, may be computed. In an embodiment these indices, q_i, may be computed by the following equation:

[0065] $$q_i = in\left(\frac{j}{l_n} \sum_{k=n}^{K} l_k \right), i = 1, \ldots, l_n,$$ EQ. 7

[0066] and further modify the set of indices as follows:

[0067] $$q_i = \mathrm{mod}(q_i - 1, N_{PRE}) + 1 .$$ EQ. 8

[0068] In block **320**, the set of resource elements may be assigned to the n^{th} user with requirement l_n by $\{V_n(i) = S_{q_i}\}$.

[0069] In block **324**, the set of resource elements assigned to the n^{th} user in block **320** may be removed from available resource elements, $\{S_i\}$, to form the updated set of resource elements remaining to be assigned. N_{PRE} may be updated to reflect the reduced number of available resource elements. The updated *NPRE* may be used in EQ. 6 to compute j for a different i.

[0070] In block **328**, similar to block **224**, the calculation index, n, may be compared to the total number of distributed users, K, to determine whether resource assignments have been performed for all of the distributed users. If not, the process may proceed to block **332**, where the calculation index n is incremented, and then back to block **312**.

[0071] If resource assignments have been performed for all of the distributed users, the process may proceed to block **336**. In block **336**, S_i (mapped into $V_k(i)$ in block **320**) may be related back to the original resource element indices, which may be potentially distributed in chunks across the total bandwidth.

[0072] In some embodiments, particularly in the case of grouped approach to mapping of distributed users, downlink performance may be further improved through frequency diversity and interference randomization by varying the mapping in the time domain, e.g., every symbol.

[0073] For example, as discussed above, once the resource mapping for the localized users has been determined, the next phase may be to compute the resource mapping for the distributed users, e.g., as described in **FIG. 2** and associated discussion. This mapping may determine the initial allocation pattern for that scheduling unit, e.g., for a 0.5 millisecond sub-frame or one OFDM symbol. In an embodiment, a mapping scheme employed in a subsequent scheduling unit, e.g., the next sub-frame, may be a variation of the initial mapping scheme. For example, a subsequent mapping scheme may be varied from the previous mapping scheme by a cyclical shift, e.g., the initial mapping is cyclically shifted modulo the number of physical resource elements N_{PRE} by one or more units; by reversal, e.g., the initial mapping may be reversed in the frequency domain; or by a combination of a cyclical shift and reversal.

[0074] These techniques may help to improve the performance of the grouped approach in the case of the distributed users and leverage some of the benefits of the scattered approach.

[0075] **FIG. 4** illustrates a node **400** in accordance with an embodiment of the present invention. The node **400** may be similar to, and substantially interchangeable with, the node **104** shown and described above. In this embodiment, the node **400** may include transmit circuitry **404** coupled to an antenna structure **408**, which may be similar to the antenna structure **120**. The transmit circuitry **404** may include one or more transmit chains to transmit information over one or more spatial channels.

[0076] The node **400** may also include receive circuitry **412** coupled to the antenna structure **120**. Similar to the transmit circuitry **404**, the receive circuitry may include one or more receive chains to receive information over one or more spatial channels.

[0077] The node **400** may further include a scheduler **416** coupled to the transmit circuitry **404** and to the receive circuitry **412**. The scheduler **416** may perform the various resource allocation mapping and assignments discussed above in accordance with various embodiments of the invention.

[0078] The transmit circuitry **404** may receive information **420** to be transmitted to a plurality of users; receive assignments of available resources from the scheduler **416**, and map the information onto the available resources. The transmit circuitry **404** may then cause the information to be transmitted over the antenna structure **408**.

[0079] As discussed above, assignments of transmissions to localized users may be done in accordance with channel-dependent scheduling. Accordingly, in some embodiments, the scheduler **416** may be coupled to the receive circuitry **412** to receive uplink feedback from users (e.g., control information in an uplink transmission) on current channel conditions to facilitate channel dependent scheduling.

[0080] In embodiments where the node **400** is a multi-antenna node, the uplink feedback may include pre-coding information. Pre-coding information may be indices that are transmitted by a UE, e.g., node **108**, to a node-B, e.g., node **420**. The node **420**, and in particular, the scheduler **416**, may receive the indices and access a codebook **424** to select beam-forming vectors to be used in the downlink to the node **108** that accounts for the instantaneous channel conditions. With proper coding of the uplink feedback channel, the probability of the uplink feedback being corrupted may be small. In the event of corruption, the desired beam-forming vectors may be recovered either by blind detection methods, where the node **108** performs a codebook search, or by the convergence of tracking codebooks, especially for low-mobility channels. In addition, for highly mobile UEs, the use of dedicated mid-amble sequences may also be used to validate beam-forming vectors.

[0081] In accordance with an embodiment of the present invention, the node **108** may transmit uplink feedback in a transmission that occurs on a first band of frequencies. The scheduler **416** may receive this uplink feedback and perform a validation of the control information contained therein. The scheduler **416** may then cause an indication of the validation to be transmitted in a downlink transmission back to the node **108**. The validation may be transmitted in a downlink that is in a band of frequencies other than the band used for the uplink feedback. This out-band control signal may avoid the use of mid-amble sequences in the case of high mobility UEs.

[0082] The uplink feedback may have a block code or cyclical redundancy check (CRC) with error detection capabilities in order to facilitate the validation.

[0083] In some embodiments, the out-band control signal may also include hybrid automatic repeat request (ARQ) feedback.

[0084] In some embodiments, the scheduler **416** may also determine feedback rates for channel state information. The node **400** may use the uplink channel to estimate Doppler spread (or inter-carrier interference (ICI) level) and adjust the subcarrier spacing in the downlink to mitigate ICI. The node **400** may additionally/alternatively conduct link and rank adaptation according to the (variation rate or) Doppler spread. In this case, unlike the previous, the transmitter tries to compensate the loss due to Doppler for the receiver. For example, the transmitter at node **400** may reduce modulation order and code rate if the Doppler spread increases because the Doppler spread affects the channel estimation at the receiver.

[0085] By doing these techniques, the scheduler **416** may exploit the reciprocity of the time variation between the uplink and downlink channels. Namely, although the channel response in frequency division duplexing (FDD) may not be reciprocal, the Doppler spread (or time variation rates) may still be the same between downlink and uplink, where the time variation is due to mobility of the UE or medium variation in the propagation path.

[0086] In some embodiments, these techniques may be extended to some time-division duplexing (TDD) cases where channel reciprocity does not exist. For example, the effective downlink channel includes the transmit chain of node **400** and a receive chain of a UE, while the uplink channel includes a transmit chain of the UE and the receive chain of the node **400**. Because the chains have active components the effective channel may not be reciprocal. For another example, a UE may have more receive chains (or antennas) than transmit chains and the effective channel may not be reciprocal because some of the UE's receive antennas may not be sounded in the uplink. In such TDD cases, the channel reciprocity may not exist, but the variation reciprocity still holds.

[0087] While properly timed feedback may facilitate achieving the benefits provided by these techniques, improperly timed feedback may negate them. For example, if the feedback is not sent in a timely manner, the node **400** may only use the previously received feedbacks to conduct beamforming and/or link/rank adaptation. The previous feedback may be outdated if the channel changes too fast and the feedback delay may then cancel out the gain of beamforming. For example, the previous fed back beamforming vector points to 30 degrees while the ideal current beamforming angle may be 60 degrees.

If the beamforming error 30 = 60 - 30 degree cancels out the beamforming gain, then the feedback rate should be increased. For the case of MCS feedback, the outdated feedback can reduce the gain of link adaptation or even cause the link be disconnected.

[0088] Accordingly, to facilitate these techniques, embodiments of the present invention may provide for the scheduler **416** to determine how often the UE should feedback channel state information. This may be done by the following process.

[0089] The scheduler **416** may receive a signal from a UE, via the receive circuitry **412**, in an uplink. The scheduler may then estimate the time variation (or Doppler spread) in the received signal. The scheduler **416** may determine the feedback rate of the channel state information such as beamforming matrix, channel quality indicator (CQI) report, and/or modulation and coding scheme (MCS). The scheduler **416** may then transmit the rate and other requirements, via the transmit circuitry **404**, to the UE. The UE may then feedback information at the specified rate.

[0090] **FIG. 5** illustrates a node **500** in accordance with an embodiment of the present invention. The node **500** may be similar to, and substantially interchangeable with, the nodes **108** and/or **112** shown and described above. The node **500** may include transmit circuitry **504** coupled to an antenna structure **508**, which may be similar to the antenna structure **124** and/or **128**. The transmit circuitry **504** may include one or more transmit chains to transmit information over one or more spatial channels.

[0091] The node **500** may also include receive circuitry **512** coupled to the antenna structure **508**. Similar to the transmit circuitry **504**, the receive circuitry may include one or more receive chains to receive information over one or more spatial channels.

[0092] The node **500** may further include a feedback controller **516**. The feedback controller **516** may include a channel condition detector **520**, coupled to the receive circuitry **512**, and configured to determine a condition of one or more spatial channels over which information is received. The feedback controller **516** may develop a CQI level to indicate the determined condition and transmit the CQI level in the uplink feedback to the node **104**.

[0093] In various embodiments, the CQI feedback may be used by the node **104** for channel-dependent scheduling (as discussed above); selection of modulation and coding scheme; interference management; and/or transmission power control for physical channels.

[0094] **FIG. 6** illustrates a flowchart of a channel condition report **600** in accordance with an embodiment of the present invention. In this embodiment, the channel condition detector **520** may cooperate with the receive circuitry **512** to determine a condition of a channel, block **604**. The feedback controller **516** may then develop a CQI value to indicate the determined condition, block **608**.

[0095] The feedback controller **516** may determine if a report is triggered, block **612** and, if so, report the CQI in an uplink feedback, block **616**. In embodiments utilizing MIMO transmissions, the amount of CQI feedback may vary with the number of channel streams, antenna configurations, and changing channel conditions. A CQI value may have a variable length to account for the varying amount of feedback. Therefore, in addition to transmitting the CQI value itself, the node **500** may also transmit the length of the CQI value.

[0096] If a report is not triggered in block **612**, the reporting process may loop back to block **604**. Determining channel condition in block **604** and developing CQI value in block **608** may collectively be referred to as monitoring the CQI value.

[0097] In various embodiments, a report may be triggered in various ways. For example, a node-B, e.g., node **104**, may periodically schedule an uplink feedback for node **500**. This schedule may be communicated to the node **500** an uplink map broadcast by the node **104**. Receiving an indication of this scheduling may be considered to trigger a CQI report. While periodic reporting may provide for comprehensive channel condition reporting, the overhead required for this reporting may be unnecessarily burdensome on the system **100**. Therefore, in accordance with embodiments of the present invention, an event-driven reporting mode is introduced.

[0098] **FIG. 7** illustrates a flowchart of a reporting mode sequence **700** in accordance with various embodiments of the present invention. In this embodiment, the feedback controller **516** may monitor and report CQI values in a non-event driven mode in block **704**. In the non-event driven mode the reports may be triggered, e.g., on a periodic basis. The feedback controller **516** may determine whether the CQI value has changed over a predetermined time, *T*, in block **708**. The predetermined time *T* may be a configurable value, e.g., a timer could be N*CQI reporting period interval during non-event driven mode; where N is an integer. If the CQI value has changed over time *T*, then the feedback controller **516** may continue to monitor and report CQI in the non-event driven mode in block **704**. If the CQI value has not changed over time *T*, then feedback controller **516** may enter an event-driven CQI reporting mode in block **712**. While in the event-driven reporting mode the feedback controller **516** may monitor CQI values and report the values when certain variances in the channel conditions are detected, rather than on a periodic basis. The feedback controller **516** may determine whether an event-driven reporting mode exit event has occurred in block **720**. If not, the feedback controller **516** may continue to monitor and report CQI value in the event-driven reporting mode. If an exit event does occur, the feedback controller **516** may loop back to block **704** and revert to monitoring and reporting CQI values in the non-event driven mode.

[0099] In some embodiments, an event-driven reporting mode exit event may occur when the channel conditions change within a predetermine interval and the corresponding CQI value is different from the last reported value. In some embodiments, if the channel changes too often, periodic feedback may be more efficient and the detection of the high variation rate triggers the event to exit the event-driven mode.

[00100] In some embodiments, the event-driven reporting mode exit event may occur by the feedback controller **516** sending an in-band control signal to the node **104** or by sending a contention-based CQI report (e.g., transmitting a CQI report during a contention period of an uplink frame). For the contention-based report, consider an embodiment where there are K UEs in the area, and currently L UEs are not in event-driven reporting mode. In this case, the node **104** may schedule the L UEs for periodic CQI reporting. In addition, the node **104** may also schedule M ($M<K-L$) resources in order for the $K-L$ UEs to potentially contend for CQI reporting when they come out of event driven CQI reporting mode. The contention may be code-domain based. These contention based reports may include the UE identifier in addition to the CQI report itself. Note that the value of M compared to $K-L$ may be based on the channel correlation between the $K-L$ users.

[00101] Once the node **104** receives an in-band signaling message or the contention based CQI report from the UE, the node **104** may schedule resources for the UE to send CQI reports in a non-event driven reporting mode.

[00102] In some embodiments, the node **104** may predict that a UE will exit an event driven reporting mode and start scheduling resources for the UE to send CQI reports. There may be a number of ways that the node **104** may predict the channel condition changes at the UE (e.g., by detecting changing channel conditions). In-band signaling or the contention based CQI reporting may be avoided by the node **104**

autonomously performing prediction and assigning the necessary resources for the UE to start sending the CQI report in non event-driven fashion.

[00103] In some embodiments, the techniques, or variations thereof, described above to exploit the variation reciprocity may be used here for the node **104** to schedule feedback modes, e.g., event-driven or periodic, for the UEs.

[00104] In some embodiments, an event-driven reporting mode exit event may be timer based. For example, upon entering the event-driven reporting mode, the feedback controller **516** may start a timer. The timer may be reset whenever the CQI transmission resumes. If the timer expires, the node **104** may schedule resources for the node **500** and the feedback controller **516** may resume its CQI transmission. Alternatively, it is also possible to send the timer-based CQI report using in-band signaling. Once the CQI is sent, the feedback controller **516** may go back to event-driven reporting mode as per the mode entry rule. The value of the timer may be configurable by the node **104**. If the timer is configured to 0, the event driven CQI reporting mode may be disabled.

[00105] Although certain embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodiments shown and described without departing from the scope of the present invention. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments in accordance with the present invention be limited only by the claims and the equivalents thereof.

Claims

What is claimed is:

1. A method comprising:

receiving, in an uplink transmission, control feedback from a wireless node in a first band of radio frequencies; and

transmitting a downlink transmission in a second band of radio frequencies, different from the first band of radio frequencies, said downlink transmission including a validation of said received control feedback.

2. The method of claim 1, wherein said transmitting of the downlink transmission includes

transmitting a hybrid automatic repeat request (ARQ) downlink transmission.

3. The method of claim 1, wherein the control feedback includes an error-detection code and the method further comprises:

validating the received control feedback based at least in part on the error-detection code.

4. The method of claim 1, wherein the control feedback comprises one or more indices and the method further comprises:

selecting a beam-forming vector based at least in part on the one or more indices; and

transmitting another downlink transmission based at least in part on the selected beam-forming vector.

5. A method comprising:

determining a condition of a wireless channel;

developing a channel quality indicator (CQI) value, having a length, to indicate the determined condition; and

transmitting, in an uplink transmission over a shared wireless medium, the CQI value and the length.

6. The method of claim 5, further comprising:

developing another CQI value of another length that is different from the length; and

transmitting, in another uplink transmission, the another CQI value and the another length.

7. The method of claim 5, wherein said determining and developing comprise monitoring the CQI value and the method further comprises:

entering an event-driven reporting mode based at least in part on said monitoring of the CQI.

8. The method of claim 7, wherein said entering an event-driven reporting mode further comprises entering the event-driven reporting mode if the CQI value remains unchanged for longer than a predetermined amount of time.

9. The method of claim 7, further comprising:

exiting the event-driven reporting mode based at least in part on an amount of time lapsed from a previous CQI transmission and/or a detected change in the CQI.

10. The method of claim 9, wherein said exiting the event-driven reporting mode comprises transmitting, in an uplink transmission, a message to exit the event-driven reporting mode.

11. The method of claim 9, wherein said exiting the event-driven reporting mode comprises transmitting the CQI value and the length in a contention period of an uplink frame.

12. The method of claim 9, wherein said exiting the event-driven reporting mode comprises receiving an indication of resources scheduled for said transmitting of the uplink transmission over the shared wireless medium.

13. A machine-accessible medium having associated instructions, which, when accessed result in a machine:

determining a condition of a wireless channel;

developing a channel quality indicator (CQI) value, having a length, to indicate the determined condition; and

transmitting, in an uplink transmission over a shared wireless medium, the CQI value and the length.

14. The machine-accessible medium of claim 13, wherein the associated instructions, when accessed, further results in the machine:

developing another CQI value of another length that is different from the length; and

transmitting, in another uplink transmission, the another CQI value and the another length.

15. The machine-accessible medium of claim 13, wherein said determining and developing comprise monitoring the CQI value and the associated instructions, when accessed further results in the machine:

triggering an event-driven reporting mode based at least in part on said monitoring of the CQI.

16. The machine-accessible medium of claim 15, wherein the associated instructions, when accessed, further results in the machine:

triggering the event-driven reporting mode if the CQI value remains unchanged for longer than a predetermined amount of time.

17. The machine-accessible medium of claim 15, wherein the associated instructions, when accessed, further results in the machine:

exiting the event-driven reporting mode based at least in part on an amount of time lapsed from a previous CQI transmission and/or a detected change in the CQI value.

18. A system comprising:

a plurality of substantially omnidirectional antennas to receive transmissions over a shared wireless medium; and a feedback controller operatively coupled to the plurality of substantially omnidirectional antennas and including a channel condition detector configured to determine a condition of a wireless channel, the feedback controller configured to develop a channel quality indicator (CQI) value, having a length, to indicate the determined condition and to transmit, in an uplink transmission via the plurality of substantially omnidirectional antennas, the CQI value and the length.

19. The system of claim 18, wherein the feedback controller is configured to monitor the CQI value by controlling said channel condition detector to determine the condition of the wireless channel and to develop the CQI value, wherein the feedback controller is further configured to enter an event-driven reporting mode based at least in part on the monitored CQI value.

20. The system of claim 18, wherein the feedback controller is further configured to exit the event-driven reporting mode based at least in part on an amount of time lapsed from a previous CQI transmission and/or a detected change in the CQI.

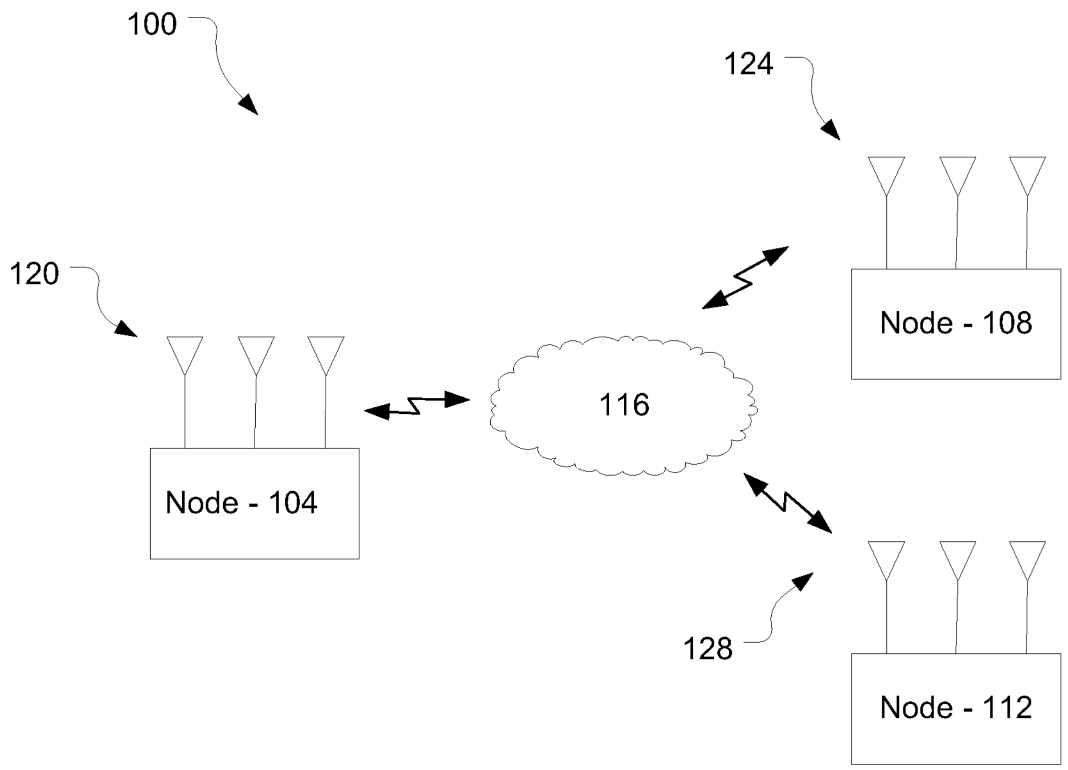

FIG. 1

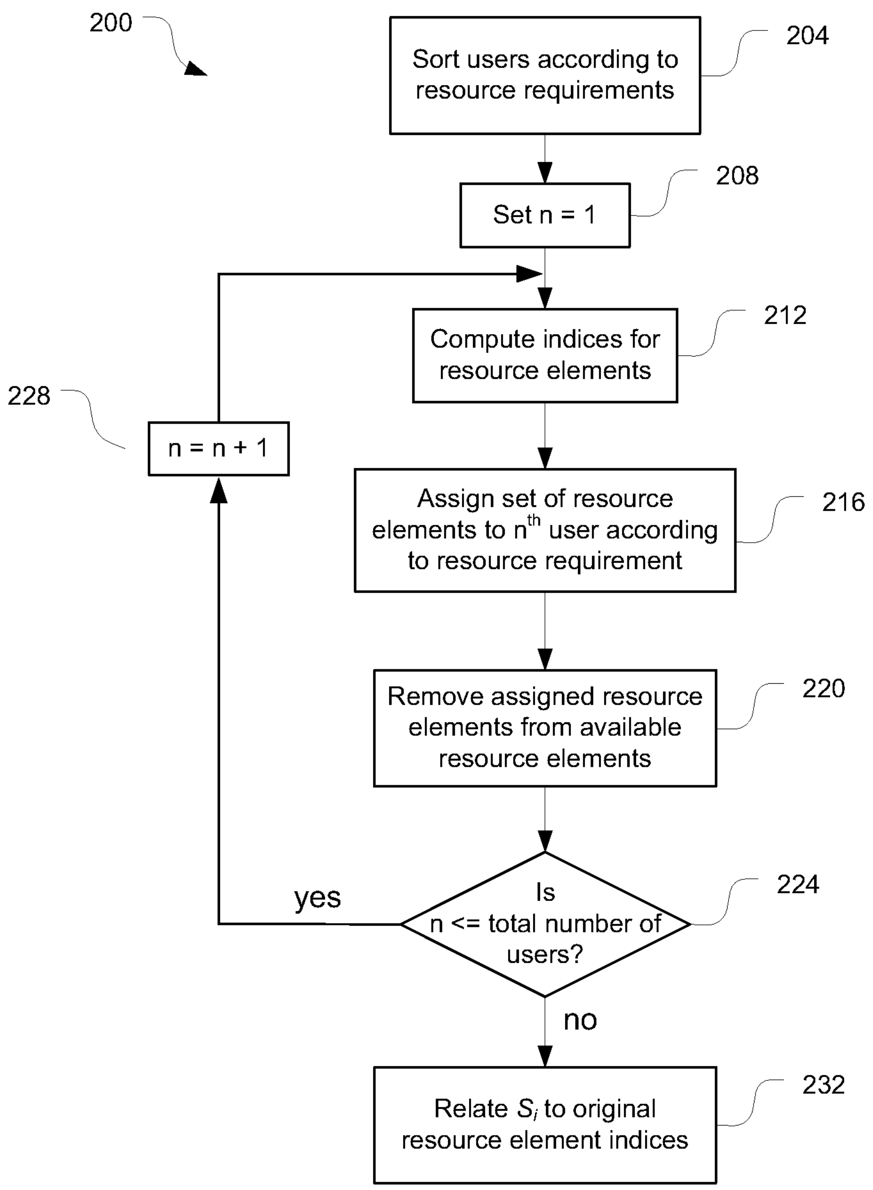
200
Sort users according to resource requirements
204
Set n = 1
208
Compute indices for resource elements
212
228
n = n + 1
Assign set of resource elements to nth user according to resource requirement
216
Remove assigned resource elements from available resource elements
220
Is n <= total number of users?
224
yes
no
Relate Si to original resource element indices
232

FIG. 2

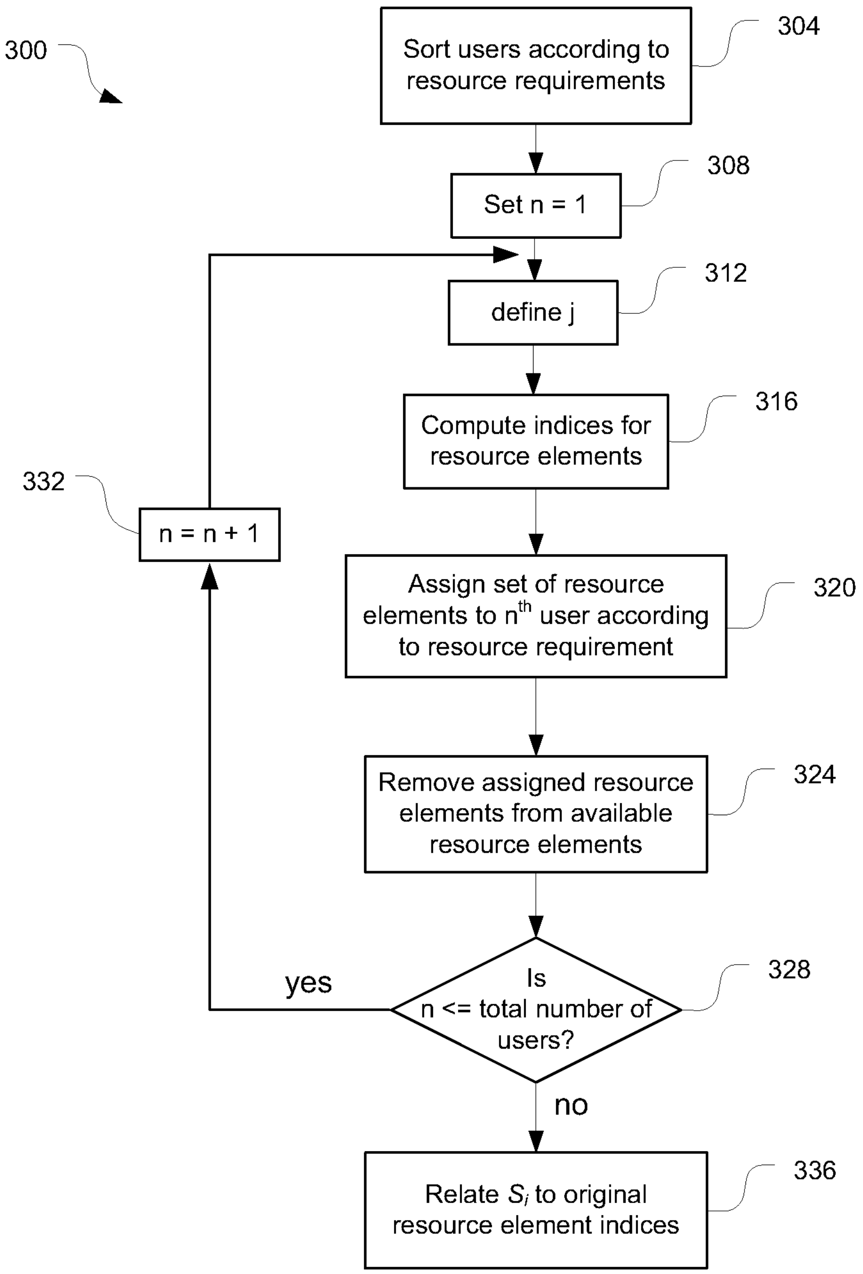
300
Sort users according to resource requirements
304
Set n = 1
308
define j
312
Compute indices for resource elements
316
332
n = n + 1
Assign set of resource elements to nth user according to resource requirement
320
Remove assigned resource elements from available resource elements
324
yes
Is n <= total number of users?
328
no
Relate Si to original resource element indices
336

FIG. 3

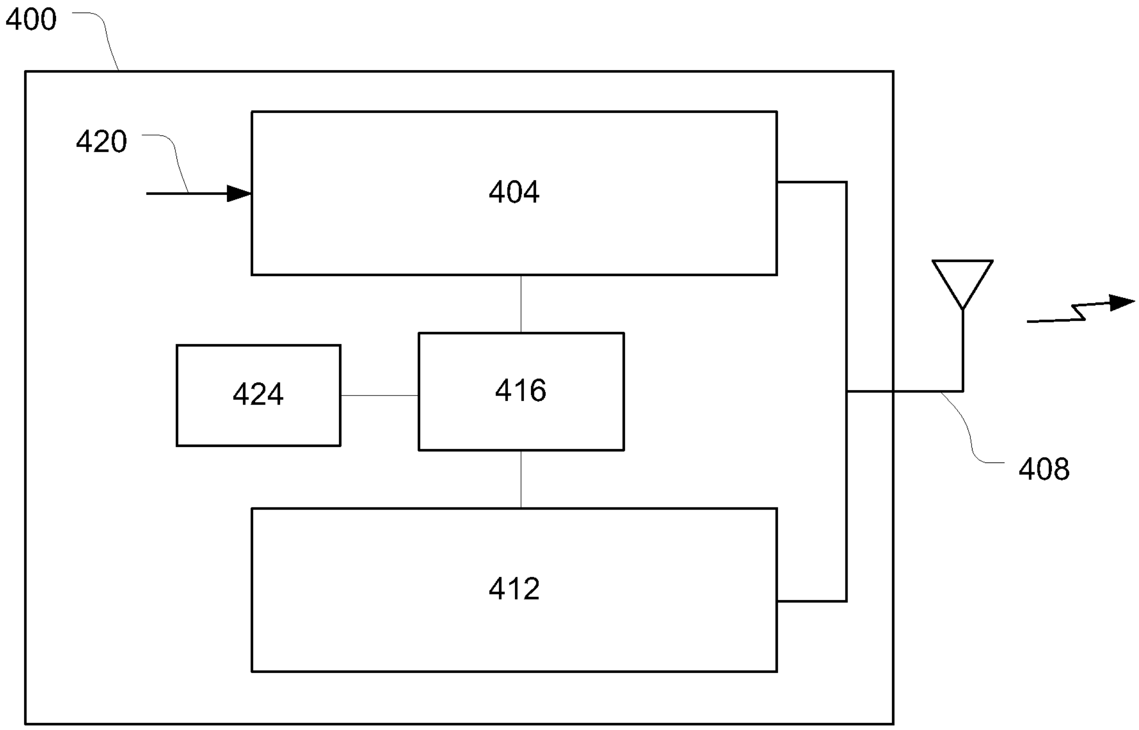

FIG. 4

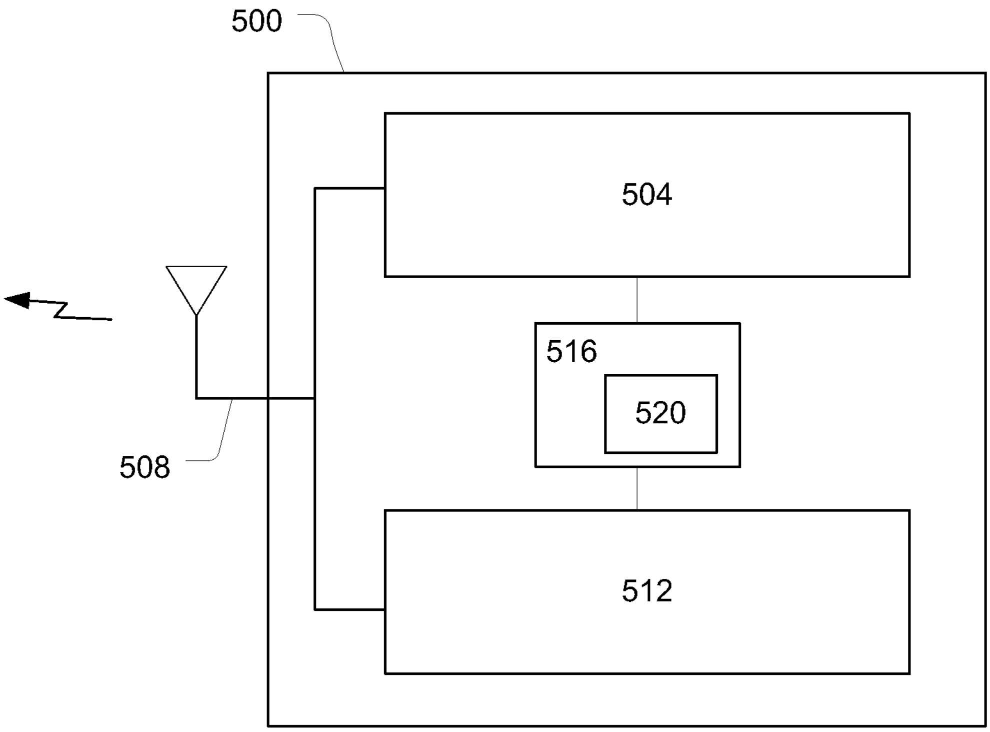

FIG. 5

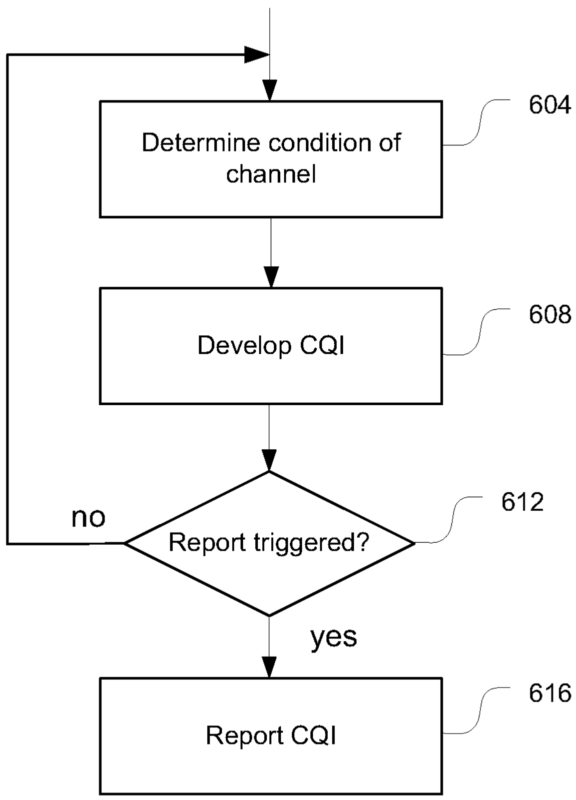
Determine condition of channel
604
Develop CQI
608
no
Report triggered?
612
yes
Report CQI
616

FIG. 6

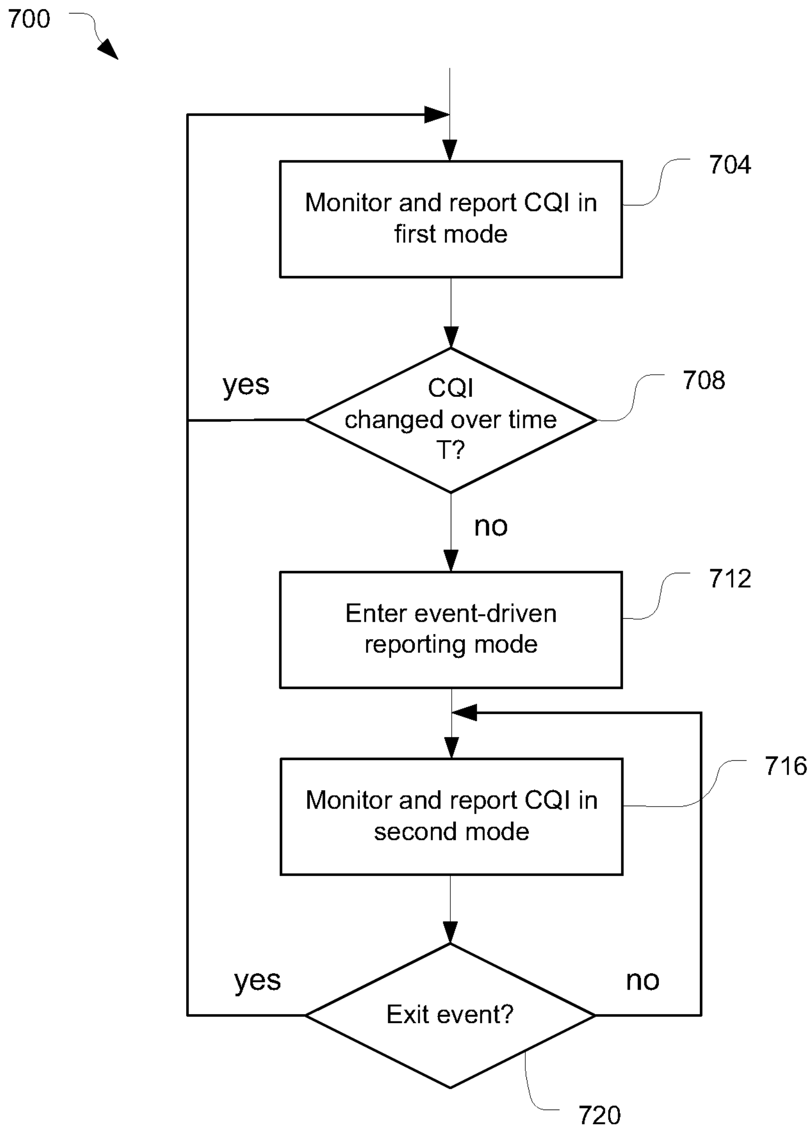
700
704
Monitor and report CQI in first mode
yes
CQI changed over time T?
708
no
712
Enter event-driven reporting mode
716
Monitor and report CQI in second mode
yes
no
Exit event?
720

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/064444

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/26(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC8 H04B 7/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
KOREAN UTILITY MODELS AND APPLICATIONS FOR UTILITY MODELS SINCE 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKIPASS, DELPHION, ESPACENET & Keywords : control feedback, CQI, uplink, downlink and similar terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 2005-21730 A (SAMSUNG ELECTRONICS CO., LTD.) 07.03.2005 * abstract, page 3 line 53 - page 4 line 26, figure 3 *	1-20
A	KR 2004-50756 A (ETRI) 17.06.2004 * abstract, page 3 lines 22 - 52, figures 3-5 *	1-20
A	US 2004/0110473 A1 (RUDOLF et al.) 10.06.2004 * abstract, paragraphs [0028]-[0032], figure 1 *	1-20
A	US 2004/0266358 A1 (PIETRASKI et al.) 30.12.2004 * abstract, paragraphs [0018]-[0024], figure 2 *	1-20

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 JULY 2007 (31.07.2007)	**31 JULY 2007 (31.07.2007)**

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Republic of Korea
Facsimile No. 82-42-472-7140

Authorized officer
JEONG Heon Ju
Telephone No. 82-42-481-8356

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