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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 May 2012 (31.05.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/070672 A1

(51) International Patent Classification:
H04W 24/10 (2009.01) *H04J 99/00* (2009.01)
H04J 1/00 (2006.01) *H04W 72/12* (2009.01)
H04J 11/00 (2006.01)

(21) International Application Number:
PCT/JP2011/077287

(22) International Filing Date:
21 November 2011 (21.11.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/952,114 22 November 2010 (22.11.2010) US
2010-263858 26 November 2010 (26.11.2010) JP

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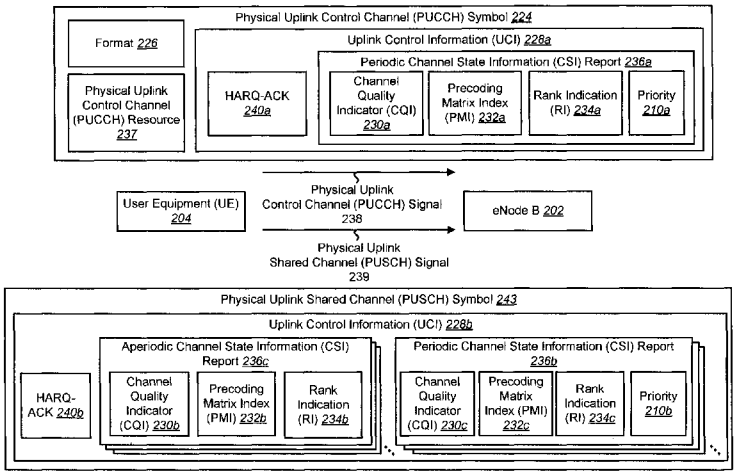
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, KE, KG, KM, 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, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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

(54) **Title**: MULTIPLE CHANNEL STATE INFORMATION (CSI) REPORTING ON THE PHYSICAL UPLINK SHARED CHANNEL (PUSCH) WITH CARRIER AGGREGATION

FIG. 2



(57) **Abstract**: A method for reporting uplink control information (UCI) by a user equipment (UE) is described. It is determined that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH). An aggregated CSI report is generated using two or more of the multiple CSI reports. The aggregated CSI report is transmitted on the PUSCH.

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DESCRIPTION

TITLE OF INVENTION:

MULTIPLE CHANNEL STATE INFORMATION (CSI) REPORTING ON THE PHYSICAL UPLINK SHARED CHANNEL (PUSCH) WITH CARRIER AGGREGATION

TECHNICAL FIELD

The present invention relates generally to radio communications and radio communications-related technology. More specifically, the present invention relates to systems and methods for multiple channel state information (CSI) reporting on the physical uplink shared channel (PUSCH) with carrier aggregation.

BACKGROUND ART

(1) Radio communication devices have become smaller and more powerful in order to meet consumer needs and to improve portability and convenience. Consumers have become dependent upon radio communication devices and have come to expect reliable service, expanded areas of coverage and increased functionality. A radio communication system may provide communication for a number of cells, each of which may be serviced by a base station. A base station may be a fixed station that communicates with mobile

stations.

(2) In another point of view, a radio communication system is described as below.

In mobile radio communication systems in conformity with 3GPP (Third Generation Partnership Project) such as WCDMA (Wideband Code Division Multiple Access), LTE (Long Term Evolution), LTE-A (LTE-Advanced) and WiMAX (Worldwide Interoperability for Microwave Access), communication areas can be expanded by arranging in a cellular manner (cellular configuration) a plurality of areas each covered by a base station device (base station, transmission station, downlink transmission device, uplink receive device, eNodeB) or a transmission station equivalent to a base station. Further, by using different frequencies in adjacent cells or in adjacent sectors, it is possible even for a terminal device (mobile station, receive station, uplink transmission device, downlink receive device, mobile terminal, UE (user equipment)) in a cell edge region or in a sector edge region to carry out communication without interference by transmission signals from a plurality of base stations. However, there has been a problem that use efficiency of frequencies is low. On the other hand, by using the same frequencies in adjacent cells or in adjacent sectors, it is possible to improve use efficiency of frequencies.

However, this necessitates a measure against interference to the terminal device in a cell edge region.

Moreover, by adaptively controlling a modulation and coding scheme (MCS), the number of spatial multiplexing (the number of layers or ranks) and/or a precoder according to the state of a transmission channel between a base station and a terminal device, it is possible to realize more efficient data transmission. Non Patent Literature 1 shows a method of carrying out these controls.

Figure 35 is a view illustrating a base station 3601 and a terminal device 3602 in LTE. In LTE, to adaptively control MCS, the number of spatial multiplexing and/or precoder for a downlink transmission signal 3603 to be transmitted, the terminal device 3602 (i) calculates, by referring to a downlink reference signal (RS: Reference Signal) included in the downlink transmission signal 3603 transmitted from the base station 3601, receiving quality information such as a rank indicator RI specifying the preferred number of spatial multiplexing, a precoding matrix indicator PMI specifying a preferred precoder and a channel quality indicator CQI specifying a preferred transmission rate, and (ii) reports the receiving quality information to the base station 3601 via an uplink channel 3604.

(Citation List)

(Non Patent Literature)

(Non Patent Literature 1)

3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 8), December 2008, 3GPP TS36.213 V8.8.0 (2009-9)

(TECHNICAL PROBLEM)

(1) Various signal processing techniques may be used in radio communication systems to improve efficiency and quality of radio communication. One such technique may include using simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmissions. Benefits may be realized by using different uplink control information (UCI) reporting for simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmissions and non-simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmissions.

(2) Further, in another point of view, as described above, a conventional communication method is capable of reporting only receiving quality information in a single carrier wave, and is difficult to apply to a system that

carries out communication using a plurality of carrier waves. This has inhibited improvement of transmission efficiency.

The present invention has been made in view of the problem, and an object of the present invention is to provide a terminal device, a base station device, a communication system and a communication method each of which is capable of efficiently reporting receiving quality information during communication using a plurality of carrier waves.

SUMMARY of INVENTION

A first aspect of the present invention is described below. A preferred embodiment is a method for reporting uplink control information (UCI) by a user equipment (UE), comprising: determining that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH); generating an aggregated CSI report using two or more of the multiple CSI reports; and transmitting the aggregated CSI report on the PUSCH.

Another preferred embodiment is a user equipment (UE) configured for reporting uplink control information (UCI), comprising: a processor; memory in electronic communication with the processor; instructions stored in the memory, the instructions being executable to: determine that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH); generate an

aggregated CSI report using two or more of the multiple CSI reports; and transmit the aggregated CSI report on the PUSCH.

A second aspect of the present invention is described as below. A preferred embodiment is a terminal device for communicating with a base station device, comprising: means for generating pieces of receiving quality information in respective communication bands; means for concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and means for reporting, to the base station device, the pieces of receiving quality information thus concatenated.

Another preferred embodiment is a terminal device for communicating with a base station device, comprising: means for generating plural types of receiving quality information in respective communication bands; means for concatenating the plural types of receiving quality information in the respective communication bands according to an order configured with respect to the plural types of receiving quality information; and means for reporting, to the base station device, the plural types of receiving quality information thus concatenated.

Yet another preferred embodiment is a base station device for communicating with a terminal device, comprising: means for obtaining concatenated pieces of

receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device; and means for separating the concatenated pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands.

Yet another preferred embodiment is a base station device for communicating with a terminal device, comprising: means for obtaining concatenated plural types of receiving quality information in respective communication bands, the concatenated plural types of receiving quality information having been concatenated by the terminal device; and means for separating the concatenated plural types of receiving quality information in the respective communication bands according to an order configured with respect to the plural types of receiving quality information.

Yet another preferred embodiment is a communication system comprising a base station device and a terminal device which are for communicating with each other, the terminal device generating pieces of receiving quality information in respective communication bands, concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands, and

reporting concatenated pieces of receiving quality information to the base station device, the base station device obtaining the concatenated pieces of receiving quality information in the respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device, and separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

Yet another preferred embodiment is a communication method for use in a terminal device for communicating with a base station device, said method comprising the steps of: generating pieces of receiving quality information in respective communication bands; concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and reporting, to the base station device, the pieces of receiving quality information thus concatenated.

Yet another preferred embodiment is a communication method for use in a base station device for communicating with a terminal device, said method comprising the steps of: obtaining concatenated pieces of receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having

been concatenated by the terminal device; and separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

(ADVANTAGEOUS EFFECTS of INVENTION)

According to the present invention, it is possible to efficiently report receiving quality information during communication using a plurality of carrier waves.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a block diagram illustrating a radio communication system using uplink control information (UCI) multiplexing;

Figure 2 is a block diagram illustrating transmissions from a user equipment (UE) to an eNode B during a subframe;

Figure 3 is a block diagram illustrating the layers used by a user equipment (UE);

Figure 4 is a flow diagram of a method for transmitting periodic channel state information (CSI) reports on the

physical uplink shared channel (PUSCH);

Figure 5 is a flow diagram of a method for transmitting multiple periodic channel state information (CSI) reports on the physical uplink shared channel (PUSCH);

Figure 6 is a flow diagram of a method for concatenating multiple periodic channel state information (CSI) reports that are CQI/PMI to obtain an aggregated CQI/PMI of an aggregated channel state information (CSI) report;

Figure 7 is a flow diagram of a method for concatenating multiple periodic channel state information (CSI) reports that are rank indication (RI) to obtain an aggregated rank indication (RI) of an aggregated channel state information (CSI) report;

Figure 8 is a flow diagram of a method for transmitting aperiodic channel state information (CSI) reports on the physical uplink shared channel (PUSCH);

Figure 9 is a flow diagram of a method for concatenating multiple component carrier (CC) specific aperiodic channel state information (CSI) reports to obtain an aggregated channel state information (CSI) report;

Figure 10 is a flow diagram of a method for transmitting uplink control information (UCI) on the physical uplink shared channel (PUSCH);

Figure 11 is a flow diagram of a method for generating an aggregated channel state information (CSI) report using

combined rank indication (RI) from an instance of aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports;

Figure 12 is a flow diagram of a method for generating an aggregated channel state information (CSI) report using combined CQI/PMI from an instance of aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports;

Figure 13 is a flow diagram of another method for transmitting uplink control information (UCI) on the physical uplink shared channel (PUSCH);

Figure 14 is a flow diagram of a method for generating an aggregated channel state information (CSI) report using combined CQI/PMI from an aperiodic channel state information (CSI) report that is for a specific downlink component carrier (CC) and one or more periodic channel state information (CSI) reports;

Figure 15 is a flow diagram of a method for generating an aggregated channel state information (CSI) report using combined rank indication (RI) from an aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports;

Figure 16 is a flow diagram of a method for transmitting an extended aperiodic channel state information (CSI) report;

Figure 17 is a flow diagram of a method for generating

an extended aperiodic channel state information (CSI) report;

Figure 18 illustrates various components that may be utilized in a user equipment (UE); and

Figure 19 illustrates various components that may be utilized in an eNode B.

Figure 20 is a view illustrating an example of a configuration of a cell in accordance with Embodiment 2-1 of the present invention.

Figure 21 is a view schematically illustrating how a communication system of Embodiment 2-1 is configured.

Figure 22 is a view illustrating an example of a configuration of a radio frame for a downlink in Embodiment 2-1.

Figure 23 is a view illustrating an example of a configuration of a radio frame for an uplink in Embodiment 2-1.

Figure 24 is a view illustrating an example of a block configuration of a base station device of Embodiment 2-1.

Figure 25 is a view illustrating an example of a block configuration of a terminal device of Embodiment 2-1.

Figure 26 is a view illustrating an example of a procedure in a periodic feedback mode in Embodiment 2-1.

Figure 27 is a view illustrating another example of a procedure in a periodic feedback mode in Embodiment 2-1.

Figure 28 is a view illustrating a further example of a procedure in a periodic feedback mode in Embodiment 2-1.

Figure 29 is a view illustrating an example of a procedure in an aperiodic feedback mode in Embodiment 2-1.

Figure 30 is a view illustrating an example of an internal block configuration of a feedback information generation section of Embodiment 2-1.

Figure 31 is a view illustrating an example of an internal block configuration of a feedback information extraction section of Embodiment 2-1.

Figure 32 is a view illustrating another example of an internal block configuration of a feedback information generation section of Embodiment 2-1.

Figure 33 is a view illustrating another example of an internal block configuration of a feedback information extraction section of Embodiment 2-1.

Figure 34 is a view illustrating an example of mapping of feedback information in Embodiment 2-1.

Figure 35 is a view schematically illustrating how a communication system is configured.

DESCRIPTION OF EMBODIMENTS

Embodiment 1:

A method for reporting uplink control information (UCI)

by a user equipment (UE) is disclosed. It is determined that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH). An aggregated CSI report is generated using two or more of the multiple CSI reports. The aggregated CSI report is transmitted on the PUSCH.

The multiple CSI reports may include multiple periodic CSI reports. Generating an aggregated CSI report may include concatenating the multiple periodic CSI reports with component carrier (CC) ordering for each type of CSI report. Transmitting the aggregated CSI report on the PUSCH may include multiplexing multiple aggregated CSI reports on the PUSCH as one composite CSI block. A trigger from an eNode B to generate an aperiodic CSI report may be received. The multiple CSI reports may include multiple aperiodic CSI reports.

Multiple component carrier (CC) specific aperiodic CSI reports may be generated. Generating an aggregated CSI report may include concatenating the multiple CC specific aperiodic CSI reports. Transmitting the aggregated CSI report on the PUSCH may include multiplexing the aggregated aperiodic CSI report on the PUSCH. The aggregated CSI report may include an aggregated channel quality indicator (CQI) and/or precoding matrix indicator (PMI) and aggregated rank information (RI). A trigger from an eNode B to generate

an instance of aperiodic CSI report may be received. The multiple CSI reports may include the instance of aperiodic CSI report and one or more periodic CSI reports.

It may be determined that multiple CSI reports on the PUSCH is supported. The aggregated CSI report may be generated using both the instance of aperiodic CSI report and the one or more periodic CSI reports. It may be determined that multiple CSI reports on the PUSCH is not supported. The aggregated CSI report may be generated using only the instance of aperiodic CSI report on the PUSCH. The method may include determining whether the aperiodic CSI report is for all configured/activated component carriers (CCs). If it is determined that the aperiodic CSI report is for all configured/activated CCs, the aggregated CSI report may be generated using only the instance of aperiodic CSI report. If it is determined that the aperiodic CSI report is not for all configured/activated CCs, the aggregated CSI report may include the instance of aperiodic CSI report and one or more periodic CSI reports.

The one or more periodic CSI reports may correspond to CCs that are not in included in the instance of aperiodic CSI report. The aggregated CSI report may be generated using an aperiodic CSI process to encode the instance of aperiodic CSI report and a periodic CSI process to encode the one or more periodic CSI reports. The aggregated CSI report may include

an extended aperiodic CSI report that includes elements of the instance of aperiodic CSI report and CSI of component carriers that were not represented in the instance of aperiodic CSI report. The UE may be configured for simultaneous physical uplink control channel (PUCCH) and PUSCH transmissions.

A user equipment (UE) configured for reporting uplink control information (UCI) is also disclosed. The UE includes a processor, memory in electronic communication with the processor, and instructions stored in the memory. The instructions are executable to determine that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH). The instructions are also executable to generate an aggregated CSI report using two or more of the multiple CSI reports. The instructions are further executable to transmit the aggregated CSI report on the PUSCH.

The 3rd Generation Partnership Project, also referred to as "3GPP," is a collaboration agreement that aims to define globally applicable technical specifications and technical reports for third and fourth generation radio communication systems. The 3GPP may define specifications for the next generation mobile networks, systems and devices.

3GPP Long Term Evolution (LTE) is the name given to a project to improve the Universal Mobile Telecommunications

System (UMTS) mobile phone or device standard to cope with future requirements. In one aspect, UMTS has been modified to provide support and specification for the Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

At least some aspects of the systems and methods disclosed herein may be described in relation to the 3GPP LTE and LTE-Advanced standards (e.g., Release-8, Release-9 and Release-10). However, the scope of the present disclosure should not be limited in this regard. At least some aspects of the systems and methods disclosed herein may be utilized in other types of radio communication systems.

The term "simultaneous" may be used herein to denote a situation where two or more events occur in overlapping time frames. In other words, two "simultaneous" events may overlap in time to some extent, but are not necessarily of the same duration. Furthermore, simultaneous events may or may not begin or end at the same time.

Figure 1 is a block diagram illustrating a radio communication system 100 using uplink control information (UCI) multiplexing. An eNode B 102 may be in radio communication with one or more user equipments (UEs) 104. An eNode B 102 may be referred to as an access point, a Node B, a base station or some other terminology. Likewise, a user equipment (UE) 104 may be referred to as a mobile station, a

subscriber station, an access terminal, a remote station, a user terminal, a terminal, a handset, a subscriber unit, a radio communication device, or some other terminology.

Communication between a user equipment (UE) 104 and an eNode B 102 may be accomplished using transmissions over a radio link, including an uplink and a downlink. The uplink refers to communications sent from a user equipment (UE) 104 to an eNode B 102. The downlink refers to communications sent from an eNode B 102 to a user equipment (UE) 104. The communication link may be established using a single-input and single-output (SISO), multiple-input and single-output (MISO), single-input and multiple-output (SIMO) or a multiple-input and multiple-output (MIMO) system. A MIMO system may include both a transmitter and a receiver equipped with multiple transmit and receive antennas. Thus, an eNode B 102 may have multiple antennas and a user equipment (UE) 104 may have multiple antennas. In this way, the eNode B 102 and the user equipment (UE) 104 may each operate as either a transmitter or a receiver in a MIMO system. One benefit of a MIMO system is improved performance if the additional dimensionalities created by the multiple transmit and receive antennas are utilized.

The user equipment (UE) 104 communicates with an eNode B 102 using one or more antennas 199a-n. The user

equipment (UE) 104 may include a transceiver 117, a decoder 127, an encoder 131 and an operations module 133. The transceiver 117 may include a receiver 119 and a transmitter 123. The receiver 119 may receive signals from the eNode B 102 using one or more antennas 199a-n. For example, the receiver 119 may receive and demodulate received signals using a demodulator 121. The transmitter 123 may transmit signals to the eNode B 102 using one or more antennas 199a-n. For example, the transmitter 123 may modulate signals using a modulator 125 and transmit the modulated signals.

The receiver 119 may provide a demodulated signal to the decoder 127. The user equipment (UE) 104 may use the decoder 127 to decode signals and make downlink decoding results 129. The downlink decoding results 129 may indicate whether data was received correctly. For example, the downlink decoding results 129 may indicate whether a packet was correctly or erroneously received (i.e., positive acknowledgement, negative acknowledgement or discontinuous transmission (no signal)).

The operations module 133 may be a software and/or hardware module used to control user equipment (UE) 104 communications. For example, the operations module 133 may determine when the user equipment (UE) 104 requires resources to communicate with an eNode B 102.

In 3rd Generation Partnership Project (3GPP) Long Term

Evolution (LTE) – Advanced, additional control feedback will have to be sent on control channels to accommodate MIMO and carrier aggregation. Carrier aggregation refers to transmitting data on multiple component carriers (CC) that are contiguously or separately located. Both the hybrid automatic repeat and request (ARQ) acknowledgement (HARQ-ACK) with positive-acknowledge and negative-acknowledge (ACK/NACK) bits and other control information may be transmitted using the physical uplink control channel (PUCCH). In carrier aggregation (CA), only one uplink component carrier (CC) may be utilized for transmission of control information. In LTE-A, component carriers (CC) are referred to as cells.

The user equipment (UE) 104 may transmit uplink control information (UCI) to an eNode B 102 on the uplink. The uplink control information (UCI) may include a channel quality indicator (CQI), a precoding matrix indicator (PMI), rank indication (RI), a scheduling request (SR) and a hybrid automatic repeat request acknowledgement (HARQ-ACK) 140a. HARQ-ACK 140a means ACK (positive-acknowledgement) and/or NACK (negative-acknowledgement) and/or DTX (discontinuous transmission) responses for HARQ operation, also known as ACK/NACK. If a transmission is successful, the HARQ-ACK 140a may have a logical value of 1 and if the transmission is unsuccessful, the HARQ-ACK 140a may have

a logical value of 0.

In one configuration, the CQI/PMI/RI 141a and the HARQ-ACK 140a may be separately coded. In another configuration, the CQI/PMI/RI 141a and the HARQ-ACK 140a may be jointly coded. Herein, CQI/PMI/RI 141 refers to CQI and/or PMI and/or RI. CQI/PMI/RI 141 may also be referred to as channel state information (CSI). The CQI and/or PMI and/or RI may be reported together or independently based on the physical uplink control channel (PUCCH) reporting modes. ACK/NACK refers to ACK and/or NACK. CQI/PMI/RI 141 and HARQ-ACK 140 refers to ((CQI and/or PMI and/or RI) AND HARQ-ACK 140). CQI/PMI/RI 141 or HARQ-ACK refers to ((CQI and/or PMI and/or RI) OR HARQ-ACK 140). The CQI/PMI/RI 141 may be collectively referred to as channel state information (CSI). A channel state information (CSI) report thus may include a CQI/PMI/RI 141 report. Channel state information (CSI) is discussed in additional detail below in relation to Figure 2.

Channel state information (CSI) reporting from a user equipment (UE) 104 to an eNode B 102 may be periodic or aperiodic. Aperiodic channel state information (CSI) reports may be requested by an eNode B 102. Aperiodic channel state information (CSI) reports are not transmitted on the physical uplink control channel (PUCCH). Periodic channel state information (CSI) reports may be configured by an eNode B

102, so that a user equipment (UE) 104 reports channel state information (CSI) to the eNode B 102 at pre-specified subframes. When periodic channel state information (CSI) reports are scheduled for transmission, if only the physical uplink control channel (PUCCH) is available, one periodic channel state information (CSI) report may be transmitted on the physical uplink control channel (PUCCH). In Rel-8/9, simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is not allowed. Thus, if a physical uplink shared channel (PUSCH) is scheduled, one periodic channel state information (CSI) report may be multiplexed on the physical uplink shared channel (PUSCH). Aperiodic channel state information (CSI) reports are always transmitted on the physical uplink shared channel (PUSCH). Hence, there is a need for a distinction between periodic channel state information (CSI) reports and aperiodic channel state information (CSI) reports.

The CQI/PMI/RI 141a report and the HARQ-ACK 140a may be generated by the uplink control information (UCI) reporting module 114 and transferred to a CQI/PMI/RI and HARQ-ACK encoder 156 that is part of the encoder 131. The CQI/PMI/RI and HARQ-ACK encoder 156 may generate uplink control information (UCI) using backwards compatible physical uplink control channel (PUCCH) formats and physical uplink shared channel (PUSCH) formats. Backwards

compatible physical uplink control channel (PUCCH) formats are those formats that may be used by Release-10 user equipments (UEs) 104 as well as Release-8/9 user equipments (UEs) 104.

The CQI/PMI/RI and HARQ-ACK encoder 156 may include a simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmissions module 157. In Release-8, a user equipment (UE) 104 does not simultaneously transmit on the physical uplink control channel (PUCCH) and the physical uplink shared channel (PUSCH). If the physical uplink shared channel (PUSCH) is available, no periodic channel state information (CSI) reports are transmitted on the physical uplink control channel (PUCCH). Aperiodic channel state information (CSI) reports are always transmitted on the physical uplink shared channel (PUSCH).

One resource of the physical uplink control channel (PUCCH) may be allocated for transmission of the uplink control information (UCI) with collision resolution procedures resolving any collision issues. In general, the resource allocated for the transmission of HARQ-ACK 140a is different from the resource allocated for the transmission of periodic channel state information (CSI) on the physical uplink control channel (PUCCH). If only one of the HARQ-ACK 140a and the periodic channel state information (CSI) is available for

transmission, the corresponding resource is used for transmissions. In case of a collision in the schedule of the transmission of HARQ-ACK 140a and channel state information (CSI), a collision resolution procedure may be used to determine the resource and format used for transmission. If the physical uplink shared channel (PUSCH) is available, the aperiodic channel state information (CSI) reports may take priority over periodic channel state information (CSI) reports and be time and/or frequency shared with the HARQ-ACK 140.

In 3GPP LTE Release-10 (LTE-A or Advanced EUTRAN), simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is introduced and can be configured. A user equipment (UE) 104 may have several transmission modes including physical uplink control channel (PUCCH) only transmission (when no physical uplink shared channel (PUSCH) is scheduled), physical uplink shared channel (PUSCH) only transmission (when simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is not configured and a physical uplink shared channel (PUSCH) is scheduled) and simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission when it is configured. If simultaneous physical uplink shared channel (PUSCH) and physical uplink

control channel (PUCCH) transmission is configured, the physical uplink control channel (PUCCH) is assumed to always be available to send uplink control information (UCI). The physical uplink control channel (PUCCH) for CQI/PMI/RI may be semi-statically scheduled by an eNode B 102 but the physical uplink control channel (PUCCH) for ACK/NACK may be dynamically allocated based on downlink configurations and transmission.

A user equipment (UE) 104 that has multiple uplink control information (UCI) elements for transmission may experience a collision. Some collision resolution procedures have already been defined. For example, when an HARQ-ACK 140 and a channel state information (CSI) report collide, a simultaneousAckNackAndCQI parameter 116 may resolve the collision. The simultaneousAckNackAndCQI parameter 116 is discussed in additional detail below.

The use of simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmissions may be configured by a radio resource control (RRC) configuration based on user equipment (UE) 104 specific RRC signaling. When a user equipment (UE) 104 that is configured for simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is allocated or assigned both the physical uplink shared channel (PUSCH) and the physical

uplink control channel (PUCCH) on a subframe or when the user equipment (UE) 104 is required to transmit on both the physical uplink shared channel (PUSCH) and the physical uplink control channel (PUCCH) on a subframe, the user equipment (UE) 104 may transmit on the physical uplink shared channel (PUSCH) and the physical uplink control channel (PUCCH) simultaneously.

The user equipment (UE) 104 may use the simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmissions module 157 to dynamically switch between simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission and non-simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission.

The user equipment (UE) 104 may also transmit a reference signal (RS) to an eNode B 102. The uplink control information (UCI) may be transmitted using the physical uplink control channel (PUCCH) and/or the physical uplink shared channel (PUSCH). One or more physical uplink control channel (PUCCH) reference signal (RS) symbols are included in a physical uplink control channel (PUCCH) signal transmission on each slot.

The time and frequency resources may be quantized to create a grid known as the Time-Frequency grid. In the time

domain, 10 milliseconds (ms) is referred to as one radio frame. One radio frame may include 10 subframes, each with a duration of 1 ms which is the duration of transmission in the uplink and/or downlink. Every subframe may be divided into two slots, each with a duration of 0.5 ms. Each slot may be divided into 7 symbols. The frequency domain may be divided into bands with a 15 kilohertz (kHz) width referred to as a subcarrier. One resource element has a duration of one symbol in the time domain and the bandwidth of one subcarrier in the frequency domain.

The minimum amount of resource that can be allocated for the transmission of information in the uplink or downlink in any given subframe is two resource blocks (RBs), one RB at each slot. One RB has a duration of 0.5 ms (7 symbols or one slot) in the time domain and a bandwidth of 12 subcarriers (180 kHz) in the frequency domain. At any given subframe, a maximum of two RBs (one RB at each slot) can be used by a given user equipment (UE) 104 for the transmission of uplink control information (UCI) in the physical uplink control channel (PUCCH). However, the eNode B 102 may allocate different RBs for the transmission of HARQ-ACK 140a and periodic channel state information (CSI). In case of a collision, a collision resolution mechanism may decide which RB and what format are used for the transmission of both or one of the HARQ-ACK 140a and the periodic channel state

information (CSI).

In LTE Release-8, only one uplink component carrier (CC) and one downlink component carrier (CC) can be used for transmission to and reception from each user equipment (UE) 104. The uplink control information (UCI) such as ACK/NACK bits for hybrid ARQ (HARQ) 140a and periodic channel quality indicators (CQI), periodic precoding matrix indicator (PMI) and periodic rank indication (RI) can be sent on the physical uplink control channel (PUCCH), on the physical uplink shared channel (PUSCH) or on both. In one configuration where simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is configured, there may be a first uplink control information (UCI) that is scheduled on the physical uplink control channel (PUCCH) and a second uplink control information (UCI) that is scheduled on the physical uplink shared channel (PUSCH). In some conditions, for example in cases when simultaneous physical uplink shared channel (PUSCH) and physical uplink control channel (PUCCH) transmission is not configured, the uplink control information (UCI) that is scheduled on the physical uplink control channel (PUCCH) may be transmitted on the physical uplink shared channel (PUSCH) if a physical uplink shared channel (PUSCH) is scheduled in the subframe.

The physical uplink control channel (PUCCH) may

occupy one resource block (RB) at each slot. Thus, a very limited amount of information can be transmitted on the physical uplink control channel (PUCCH).

In 3GPP Long Term Evolution (LTE) Release-10 (LTE-A or Advanced EUTRAN), carrier aggregation was introduced. Carrier aggregation may also be referred to as cell aggregation. Carrier aggregation is supported in both the uplink and the downlink with up to five component carriers (CCs), also known as cells. Each component carrier (CC) or cell may have a transmission bandwidth of up to one hundred and ten resource blocks (i.e., up to 20 megahertz (MHz)). In carrier aggregation, two or more component carriers (CCs) or cells are aggregated to support wider transmission bandwidths up to 100 megahertz (MHz). A user equipment (UE) 104 may simultaneously receive and/or transmit on one or multiple component carriers (CCs) or cells, depending on the capabilities of the user equipment (UE) 104.

Based on current agreements, cyclic reporting of periodic CQI/PMI/RI 141 of each component carrier (CCs) is supported in Release-10. Thus, the same periodic CQI/PMI/RI payload as in Release-8 can be used. Therefore, a Format 2 based physical uplink control channel (PUCCH) may be reused for periodic CQI/PMI/RI 141 reporting of each component carrier (CC) or cell.

The uplink control information (UCI) generated by the

uplink control information (UCI) reporting module 114 may be dependent on the simultaneousAckNackAndCQI parameter 116. For example, the format used for transmitting the uplink control information (UCI) may be dependent on the simultaneousAckNackAndCQI parameter 116. The simultaneousAckNackAndCQI parameter 116 may be provided by higher layers 118 (e.g., the radio resource control (RRC) layer) on the user equipment (UE) 104. The simultaneousAckNackAndCQI parameter 116 may be used by the user equipment (UE) 104 to determine whether to use periodic CQI/PMI/RI 141 dropping or simultaneous reporting of the periodic CQI/PMI/RI 141 and the HARQ-ACK 140. The choice of periodic CQI/PMI/RI 141 dropping or simultaneous reporting of the periodic CQI/PMI/RI 141 and the HARQ-ACK 140 may be configured by the eNode B 102. For example, simultaneous periodic CQI/PMI/RI 141 and HARQ-ACK 140 reporting should be used if the simultaneousAckNackAndCQI parameter 116 is set to TRUE. Otherwise, the periodic CQI/PMI/RI 141 should be dropped.

A user equipment (UE) 104 may communicate with an eNode B 102 using multiple cells 185 at the same time. For example, a user equipment (UE) 104 may communicate with an eNode B 102 using a primary cell (PCell) 185a while simultaneously communicating with the eNode B 102 using secondary cell(s) (SCell) 185b. Similarly, an eNode B 102 may

communicate with a user equipment (UE) 104 using multiple cells 185 at the same time. For example, an eNode B 102 may communicate with a user equipment (UE) 104 using a primary cell (PCell) 185a while simultaneously communicating with the user equipment (UE) 104 using secondary cell(s) (SCell) 185b.

An eNode B 102 may include a transceiver 107 that includes a receiver 109 and a transmitter 113. An eNode B 102 may additionally include a decoder 103, an encoder 105 and an operations module 194. An eNode B 102 may receive uplink control information (UCI) using its one or more antennas 197a-n and its receiver 109. The receiver 109 may use the demodulator 111 to demodulate the uplink control information (UCI).

The decoder 103 may include an uplink control information (UCI) receiving module 195. An eNode B 102 may use the uplink control information (UCI) receiving module 195 to decode and interpret the uplink control information (UCI) received by the eNode B 102. The eNode B 102 may use the decoded uplink control information (UCI) to perform certain operations, such as retransmit one or more packets based on scheduled communication resources for the user equipment (UE) 104. The uplink control information (UCI) may include a CQI/PMI/RI 141b and/or an HARQ-ACK 140b.

The operations module 194 may include a

retransmission module 196 and a scheduling module 198. The retransmission module 196 may determine which packets to retransmit (if any) based on the uplink control information (UCI). The scheduling module 198 may be used by the eNode B 102 to schedule communication resources (e.g., bandwidth, time slots, frequency channels, spatial channels, etc.). The scheduling module 198 may use the uplink control information (UCI) to determine whether (and when) to schedule communication resources for the user equipment (UE) 104.

The operations module 194 may provide data 101 to the encoder 105. For example, the data 101 may include packets for retransmission and/or a scheduling grant for the user equipment (UE) 104. The encoder 105 may encode the data 101, which may then be provided to the transmitter 113. The transmitter 113 may modulate the encoded data using the modulator 115. The transmitter 113 may transmit the modulated data to the user equipment (UE) 104 using one or more antennas 197a-n.

When carrier aggregation is configured, a user equipment (UE) 104 may have only one Radio Resource Control (RRC) connection with the network. At the RRC connection establishment/re-establishment/handover, one serving cell (i.e., the primary cell (PCell) 185a) provides the non-access stratum (NAS) mobility information (e.g., Tracking

Area Identity (TAI)) and the security input.

In the downlink, the carrier corresponding to the primary cell (PCell) 185a is the downlink primary component carrier (DL PCC) 108a. In the uplink, the carrier corresponding to the primary cell (PCell) 185a is the uplink primary component carrier (UL PCC) 106a. Depending on the capabilities of the user equipment (UE) 104, one or more secondary component carriers (SCC) or secondary cells (SCell) 185b may be configured to form a set of serving cells with the primary cell (PCell) 185a. In the downlink, the carrier corresponding to the secondary cell (SCell) 185b is the downlink secondary component carrier (DL SCC) 108b. In the uplink, the carrier corresponding to the secondary cell (SCell) 185b is the uplink secondary component carrier (UL SCC) 106b. The number of downlink component carriers (CCs) 108 may be different from the number of uplink component carriers (CCs) 106 because multiple cells may share one uplink component carrier (CC) 106.

If carrier aggregation is configured, a user equipment (UE) 104 may have multiple serving cells: a primary cell (PCell) 185a and one or more secondary cells (SCell) 185b. From a network perspective, the same serving cell may be used as the primary cell (PCell) 185a by one user equipment (UE) 104 and used as a secondary cell (SCell) 185b by another user equipment (UE) 104. A primary cell (PCell) 185a that is

operating according to Release-8/9 is equivalent to the Release-8/9 serving cell. When operating according to Release-10, there may be one or more secondary cells (SCell) 185b in addition to the primary cell (PCell) 185a if carrier aggregation is configured.

A number of spatial channels may be available on each serving cell by using multiple antennas at a transmitter and a receiver. Therefore, multiple codewords (up to two codewords) may be transmitted simultaneously. If the user equipment (UE) 104 is configured with five component carriers (CCs) (cells) and two codewords for each of the component carriers (CCs) (cells), ten HARQ-ACK 140 acknowledgement/negative acknowledgement (ACK/NACK) bits for a single downlink subframe may be generated by the user equipment (UE) 104. One benefit of using carrier aggregation is that additional downlink and/or uplink data may be transmitted. As a result of the additional downlink data, additional uplink control information (UCI) may be needed.

It has been agreed that for periodic CQI/PMI/RI 141 reporting for carrier aggregation, the configuration of different (in time) physical uplink control channel (PUCCH) resources for reports for each component carrier (CC) is supported.

Figure 2 is a block diagram illustrating transmissions from a user equipment (UE) 204 to an eNode B 202 during a subframe. The user equipment (UE) 204 may transmit a

physical uplink control channel (PUCCH) symbol 224 via a physical uplink control channel (PUCCH) symbol 238 to the eNode B 202. The user equipment (UE) 204 may also transmit a physical uplink shared channel (PUSCH) symbol 243 via a physical uplink shared channel (PUSCH) signal 239 to the eNode B 202. In one configuration, the user equipment (UE) 204 may simultaneously transmit a physical uplink control channel (PUCCH) symbol 224 and a physical uplink shared channel (PUSCH) symbol 243 to the eNode B 202.

Simultaneous transmission on the physical uplink control channel (PUCCH) and the physical uplink shared channel (PUSCH) is introduced and configurable in Release-10. In Release-8 and Release-9, simultaneous transmission on the physical uplink control channel (PUCCH) and the physical uplink shared channel (PUSCH) is not allowed. Thus, all references to simultaneous transmission on the physical uplink control channel (PUCCH) and the physical uplink shared channel (PUSCH) are related to Release-10, and not to Release-8 or Release-9.

The physical uplink control channel (PUCCH) symbol 224 may include uplink control information (UCI) 228a. The uplink control information (UCI) 228a may include an HARQ-ACK 240a. The uplink control information (UCI) 228a may also include a periodic channel state information (CSI) report 236a. A channel state information (CSI) report 236 refers to

the channel state information (CSI) of each of the downlink component carriers (CC) 108. The periodic channel state information (CSI) report 236a may include a channel quality indicator (CQI) 230a, a precoding matrix indicator (PMI) 232a, and/or a rank indication (RI) 234a. When a user equipment (UE) 204 has data to be transmitted and no physical uplink shared channel (PUSCH) is assigned, the user equipment (UE) 204 may generate a scheduling request (SR). When a physical uplink shared channel (PUSCH) symbol 243 is already scheduled for transmission, the user equipment (UE) 204 does not generate a scheduling request (SR). Thus, the uplink control information (UCI) 228a may include a scheduling request (SR) but the scheduling request (SR) is not a part of channel state information (CSI).

The periodic channel state information (CSI) report 236a may also include a priority 210a. When simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmission is enabled, the HARQ-ACK 240a or the periodic channel state information (CSI) report 236a with the highest priority 210a may be carried on the physical uplink control channel (PUCCH) while the remaining periodic channel state information (CSI) reports 236b are carried on the physical uplink shared channel (PUSCH) (or dropped). The priority of different types of uplink control information (UCI) 228 may be provided by the eNode B

202 or by predefined rules. For example, if an HARQ-ACK 240 and one or more channel state information (CSI) reports 236 needs to be transmitted in a subframe, the most important uplink control information (UCI) 228 (the HARQ-ACK 240 in this case) may be transmitted on the physical uplink control channel (PUCCH) and the dropped channel state information (CSI) reports 236 from the physical uplink control channel (PUCCH) may be carried on the physical uplink shared channel (PUSCH).

In Rel-8/9, only one component carrier (CC) is allocated for a user equipment (UE). Thus, only one periodic channel state information (CSI) report 236a-b is generated (i.e., CQI and/or PMI and/or RI for one component carrier (CC) is reported). For aperiodic channel state information (CSI) reports 236c, the rank indication (RI) is transmitted only if the configured CQI/PMI/RI feedback type supports rank indication (RI) reporting. In cases where both a periodic channel state information (CSI) report 236a-b and an aperiodic channel state information (CSI) report 236c would occur in the same subframe, the user equipment (UE) 204 would only transmit the aperiodic channel state information (CSI) report 236c for that subframe.

In Rel-10 and beyond, multiple component carriers (CCs) or cells may be configured for a user equipment (UE) 204. Thus, multiple periodic channel state information (CSI)

reports 236a-b corresponding to multiple component carriers (CCs) may collide in the same subframe (i.e., the multiple periodic channel state information (CSI) reports 236a-b may have schedules that would force them to be transmitted in the same subframe). Because the periodic channel state information (CSI) reports 236a-b may include valuable control information that is not included in an aperiodic channel state information (CSI) report 236c, it may be beneficial to not drop the periodic channel state information (CSI) reports 236a-b. Therefore, if configured, transmitting both aperiodic channel state information (CSI) reports 236c and periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) may provide system performance benefits.

The CQI/PMI/RI 141 of each component carrier (CC) or cell may be scheduled on the physical uplink control channel (PUCCH) periodically by higher layer 118 signaling (the CQI/PMI/RI 141 is periodic CQI/PMI/RI 141). The eNode B 202 may request periodic channel state information (CSI) 236a-b and aperiodic channel state information (CSI) 236c; the periodic channel state information (CSI) 236a-b may have a periodic reporting schedule while the aperiodic channel state information (CSI) 236c is generated dynamically and not configured by a periodic schedule. The eNode B 102 may also request transmission of CQI/PMI/RI 141. Such a request

may be made through the physical downlink control channel (PDCCH) and the CQI/PMI/RI reported in response to such a request may be referred to as aperiodic CQI/PMI/RI 141. The physical uplink control channel (PUCCH) symbol 224 may be sent only on the primary cell (PCell) 185a. The HARQ-ACK 240a is generated dynamically based on the detection of a physical downlink shared channel (PDSCH). A collision may occur between the schedule for transmission of a periodic CQI/PMI/RI 141 and an HARQ-ACK 240a in the same subframe.

The physical uplink control channel (PUCCH) symbol 224 may further include a format 226 for which the physical uplink control channel (PUCCH) symbol 224 is transmitted. For example, the physical uplink control channel (PUCCH) symbol 224 may be transmitted using Format 1/1a/1b, Format 2/2a/2b, Format 3/3a/3b or any other new formats. As used herein, Format 1/1a/1b represents Format 1 and/or Format 1a and/or Format 1b. Also, as used herein, Format 2/2a/2b represents Format 2 and/or Format 2a and/or Format 2b. Herein, Format 3/3a/3b represents Format 3 and/or Format 3a and/or Format 3b.

Format 3a/3b is not currently defined in the 3GPP specification. Format 3a and 3b are analogues to Format 2a and 2b as defined by 3GPP. In a subframe with Format 3a, additional control information may be carried on one of the

two reference signals of the subframe using Binary Phase Shift Keying (BPSK) modulation. In a subframe with Format 3b, additional control information may be carried on one of the two reference signals of the subframe using Quadrature Phase Shift Keying (QPSK) modulation.

The physical uplink control channel (PUCCH) symbol 224 may also include a physical uplink control channel (PUCCH) resource 237. The physical uplink control channel (PUCCH) resource 237 for the periodic CQI/PMI/RI 141 may be periodically pre-assigned by a higher layer 118, which uses Format 2/2a/2b. The eNode B 202 may dynamically allocate the physical downlink shared channel (PDSCH); the HARQ-ACK 240a is then dynamically generated in a subframe. Therefore, sometimes the periodic CQI/PMI/RI 141 may collide with the HARQ-ACK 240a in the same subframe.

To avoid dropping one of them in collisions between a periodic CQI/PMI/RI 141 and an HARQ-ACK 240a, the periodic CQI/PMI/RI 141 may be multiplexed with the HARQ-ACK 240a on the physical uplink control channel (PUCCH). This is because of the single carrier property for uplink in an LTE system (i.e., a user equipment (UE) 204 should not transmit multiple physical uplink control channels (PUCCHs) simultaneously on one component carrier (CC)). Format 3 may be used for multiplexing the periodic CQI/PMI/RI 141 with the HARQ-ACK 240a. If the periodic CQI/PMI/RI 141

and the HARQ-ACK 240a are not multiplexed, the periodic CQI/PMI/RI 141 may be dropped by the user equipment (UE) 204. Thus, one benefit of using Format 3 is that the CQI/PMI/RI 141 may be multiplexed with the HARQ-ACK 240a, allowing for the uplink transmission of additional data.

A user equipment (UE) 204 that supports up to four ACK/NACK bits can use physical uplink control channel (PUCCH) Format 1a/1b with channel selection for transmission of the HARQ-ACK 240a. A user equipment (UE) 204 that supports more than four ACK/NACK bits is configured by higher layer 118 signaling to use either physical uplink control channel (PUCCH) Format 1a/1b with channel selection or physical uplink control channel (PUCCH) Format 3 for transmission of the HARQ-ACK 240a. A user equipment (UE) 204 may determine the number of HARQ-ACK 240a bits based on the number of configured serving cells and the downlink transmission modes configured for each serving cell. A user equipment (UE) 204 may use two HARQ-ACK 240a bits for a serving cell configured with a downlink transmission mode that supports up to two transport blocks (codewords) and one HARQ-ACK 240a bit otherwise.

For physical uplink control channel (PUCCH) Format 3, a user equipment (UE) 204 may transmit a NACK for a DTX HARQ-ACK 240a response for a transport block (codeword) associated with a configured serving cell. DTX means that

the user equipment (UE) 204 has missed the downlink assignment.

The physical uplink shared channel (PUSCH) symbol 243 may also include uplink control information (UCI) 228b. The uplink control information (UCI) 228b may include the ACK/NACK information corresponding to the transmission of data in the downlink (such as an HARQ-ACK 240b), one or more aperiodic channel state information (CSI) reports 236c and one or more periodic channel state information (CSI) reports 236b. The number of aperiodic channel state information (CSI) reports 236c and the number of periodic channel state information (CSI) reports 236b may be signaled by the eNode B 202 via radio resource control (RRC) signaling.

An eNode B 202 may trigger aperiodic channel state information (CSI) reporting on the physical uplink shared channel (PUSCH) in an on-demand basis. An aperiodic channel state information (CSI) report 236c may collide with one or more periodic channel state information (CSI) reports 236a-b. A collision refers to a subframe where both an aperiodic channel state information (CSI) report 236c is triggered and one or more periodic channel state information (CSI) reports 236a-b are scheduled. Unlike in Rel-8, the aperiodic channel state information (CSI) report 236c in Rel-10 may have channel state information (CSI) for more than one component carrier (CC). The aperiodic channel state

information (CSI) report 236c may include channel state information (CSI) for different component carriers (CCs) than the periodic channel state information (CSI) reports 236a-b.

Each aperiodic channel state information (CSI) report 236c may include channel state information (CSI) for one or more component carriers (CCs). An aperiodic channel state information (CSI) report 236c may include channel state information (CSI) for different component carriers (CCs) from the periodic channel state information (CSI) reports 236a-b. In one configuration, an aperiodic channel state information (CSI) report 236c may include channel state information (CSI) for only one component carrier (CC). In another configuration, an aperiodic channel state information (CSI) report 236c may include channel state information (CSI) for multiple component carriers (CCs). In yet another configuration, an aperiodic channel state information (CSI) report 236c may be a combination of multiple aperiodic channel state information (CSI) reports 236c, each corresponding to one or more component carriers (CCs).

If the aperiodic channel state information (CSI) report 236c and the periodic channel state information (CSI) reports 236a-b are for different component carriers (CCs), it may be beneficial to not drop the periodic channel state information (CSI) reports 236a-b. Dropping periodic channel state information (CSI) reports 236a-b of one component carrier

(CC) may cause a bad channel estimation of the component carrier (CC).

An aperiodic channel state information (CSI) report 236c may include one or more channel quality indicators (CQIs) 230b and/or one or more precoding matrix indicators (PMIs) 232b and/or one or more rank indications (RIs) 234b of one or more component carriers (CCs) or cells. The channel quality indicator (CQI) 230 may be a wideband channel quality indicator (CQI) 230, a subband channel quality indicator (CQI) 230 or a user equipment (UE) 104 selected subband channel quality indicator (CQI) 230. An aperiodic channel state information (CSI) report 236c is always transmitted on the physical uplink shared channel (PUSCH) symbol 243. A periodic channel state information (CSI) report 236b may also include a channel quality indicator (CQI) 230c and/or a precoding matrix indicator (PMI) 232c and/or a rank indication (RI) 234c and a priority 210b. The physical uplink shared channel (PUSCH) symbol 243 may be sent on the primary cell (PCell) 185a and/or on one or more secondary cells (SCell) 185b. The HARQ-ACK 240 is generated dynamically based on the detection of a physical downlink shared channel (PDSCH).

Figure 3 is a block diagram illustrating the layers used by a user equipment (UE) 304. The user equipment (UE) 304 of Figure 3 may be one configuration of the user equipment

(UE) 104 of Figure 1. The user equipment (UE) 304 may include a radio resource control (RRC) layer 347, a radio link control (RLC) layer 342, a medium access control (MAC) layer 344 and a physical (PHY) layer 346. These layers may be referred to as higher layers 118. The user equipment (UE) 304 may include additional layers not shown in Figure 3.

Figure 4 is a flow diagram of a method 400 for transmitting periodic channel state information (CSI) reports 236a-b on the physical uplink shared channel (PUSCH). The method 400 may be performed by a user equipment (UE) 104. The user equipment (UE) 104 may determine 402 that multiple periodic channel state information (CSI) reports 236b and no aperiodic channel state information (CSI) reports 236c are scheduled for the physical uplink shared channel (PUSCH). As discussed above, periodic channel state information (CSI) reports 236b may be generated by a user equipment (UE) 104 at pre-specified subframes while aperiodic channel state information (CSI) reports 236c are generated in response to a request by an eNode B 102.

The user equipment (UE) 104 may determine 404 whether multiple periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) is supported. In Rel-10 and beyond, more than one component carrier (CC) (also referred to herein as a serving cell 185) may be configured by the radio resource control

(RRC) for a user equipment (UE) 104. A component carrier (CC) may be activated or deactivated by the medium access control (MAC) layer 344. A periodic channel state information (CSI) report 236b may be generated for each component carrier (CC).

The periodic channel state information (CSI) reporting for each component carrier (CC) may be configured independently. Thus, multiple periodic channel state information (CSI) reporting schedules may collide in a subframe. If there is no physical uplink shared channel (PUSCH) scheduled in the subframe, a periodic channel state information (CSI) report 236a may be transmitted on the physical uplink control channel (PUCCH). Due to the limited capacity of the physical uplink control channel (PUCCH), only one periodic channel state information (CSI) report 236a may be transmitted on the physical uplink control channel (PUCCH) during a subframe; the other periodic channel state information (CSI) reports 236b may be dropped. Each periodic channel state information (CSI) report 236a-b may have a priority 210a-b that is provided by the eNode B 102 or by predefined rules.

If the physical uplink shared channel (PUSCH) is scheduled, a periodic channel state information (CSI) report 236b may be multiplexed onto the physical uplink shared channel (PUSCH). It has been agreed that only one uplink

physical uplink shared channel (PUSCH) should be used for uplink control information (UCI) 228 reporting, even though multiple uplink physical uplink shared channels (PUSCHs) might be scheduled for transmission. The simplest method is for the user equipment (UE) 104 to transmit only one periodic channel state information (CSI) report 236b on the physical uplink shared channel (PUSCH) and drop the others. However, periodic channel state information (CSI) reports 236b are important control messages and dropping them may cause bad channel estimation and degrade the system performance. Therefore, if configured, multiplexing multiple periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) may provide system performance benefits.

If simultaneous transmission of the physical uplink control channel (PUCCH) and the physical uplink shared channel (PUSCH) is supported, and if no HARQ-ACK 240 is to be transmitted but multiple periodic channel state information (CSI) reports 236b are scheduled in a subframe, the periodic channel state information (CSI) report 236a with the highest priority 210a may be transmitted on the physical uplink control channel (PUCCH). The dropped periodic channel state information (CSI) reports 236b from the physical uplink control channel (PUCCH) may be carried on the physical uplink shared channel (PUSCH). If multiple

periodic channel state information (CSI) reports 236b remain to be transmitted, multiple periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) transmission should be supported to multiplex the multiple periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH).

Periodic channel state information (CSI) reporting is normally on a semi-statically allocated physical uplink control channel (PUCCH) resource. The payload size and the type of the channel state information (CSI) to be reported are decided by the physical uplink control channel (PUCCH) report type and reporting mode. In Rel-8/9, if a physical uplink shared channel (PUSCH) is scheduled in a subframe, the periodic channel state information (CSI) report 236b is multiplexed on the physical uplink shared channel (PUSCH). However, only one channel state information (CSI) report 236 (periodic or aperiodic) can be multiplexed on the physical uplink shared channel (PUSCH). In cases where both a periodic channel state information (CSI) report 236a-b and an aperiodic channel state information (CSI) report 236c occur in the same subframe, the user equipment (UE) 104 only transmits the aperiodic channel state information (CSI) report 236c in that subframe.

In Rel-10, each component carrier (CC) can be configured independently for periodic channel state

information (CSI) reporting. Thus, transmission times of multiple periodic channel state information (CSI) reports 236a-b may collide in the same subframe. With the physical uplink control channel (PUCCH), only one periodic channel state information (CSI) report 236a can be reported. Thus, the periodic channel state information (CSI) report 236a with the highest priority 210a is reported and the other periodic channel state information (CSI) reports 236b are dropped.

If a physical uplink shared channel (PUSCH) is scheduled and simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmission is not allowed, the periodic channel state information (CSI) report 236b may be transmitted on the physical uplink shared channel (PUSCH). If a physical uplink shared channel (PUSCH) is scheduled and simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmission is allowed, the most important uplink control information (UCI) 228 (e.g., the HARQ-ACK 240 or the periodic channel state information (CSI) report 236a with the highest priority 210a when there is no HARQ-ACK 240) may be transmitted on the physical uplink control channel (PUCCH) and the dropped periodic channel state information (CSI) reports 236b may be transmitted on the physical uplink shared channel (PUSCH).

If multiple periodic channel state information (CSI)

reports 236b on the physical uplink shared channel (PUSCH) is not supported, the user equipment (UE) 104 may transmit 406 only the periodic channel state information (CSI) report 236b with the highest priority 210b on the physical uplink shared channel (PUSCH). Other periodic channel state information (CSI) reports 236b may be dropped. If multiple periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) is supported, the user equipment (UE) 104 may generate 408 an aggregated channel state information (CSI) report from the multiple periodic channel state information (CSI) reports 236b. The user equipment (UE) 104 may then transmit 410 the aggregated channel state information (CSI) report on the physical uplink shared channel (PUSCH). An aggregated channel state information (CSI) report may include multiple periodic channel state information (CSI) reports 236b that are concatenated with component carrier (CC) ordering for each type of channel state information (CSI). The channel state information (CSI) may be split into two types, the CQI/PMI channel state information (CSI) and the rank indication (RI) channel state information (CSI). Aggregated channel state information (CSI) reports are discussed in additional detail below in relation to Figure 6 and Figure 7.

Figure 5 is a flow diagram of a method 500 for transmitting multiple periodic channel state information (CSI)

reports 236b on the physical uplink shared channel (PUSCH). The method 500 may be performed by a user equipment (UE) 104. The user equipment (UE) 104 may determine 502 that multiple periodic channel state information (CSI) reports 236b is supported on the physical uplink shared channel (PUSCH). The user equipment (UE) 104 may then concatenate 504 multiple channel state information (CSI) reports 236b with component carrier (CC) ordering for each type of channel state information (CSI) to obtain an aggregated channel state information (CSI) report for each type of channel state information (CSI). The user equipment (UE) 104 may multiplex 506 the aggregated channel state information (CSI) reports on the physical uplink shared channel (PUSCH) as one composite channel state information (CSI) block, following the multiplexing rules of each type of channel state information (CSI).

A periodic channel state information (CSI) report 236 of a component carrier (CC) or cell may be a CQI/PMI report or an RI report, but not both. An aggregated channel state information (CSI) report may be generated from multiple periodic channel state information (CSI) reports 236 in the same subframe. Only one aggregated channel state information (CSI) report is generated in a subframe. An aggregated channel state information (CSI) report may include an aggregated CQI/PMI and/or an aggregated RI. If some CSI

reports are CQI/PMI and some are RI, the aggregated CSI report may contain both an aggregated CQI/PMI and an aggregated RI.

Figure 6 is a flow diagram of a method 600 for concatenating multiple periodic channel state information (CSI) reports 236b that are CQI/PMI to obtain an aggregated CQI/PMI of an aggregated channel state information (CSI) report. The method 600 may be performed by a user equipment (UE) 104. If the periodic channel state information (CSI) reports 236b are CQI/PMI of the corresponding component carriers (CCs), the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ of each periodic channel state information (CSI) report 236b may be concatenated to form an aggregated CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ of the aggregated periodic channel state information (CSI), where N_{CQI}^{PUSCH} is the payload size of the aggregated CQI/PMI of the aggregated channel state information (CSI) report and where l is the length of the CQI/PMI in a periodic channel state information (CSI) report 236a-b of a component carrier (CC), as decided by the physical uplink control channel (PUCCH) report type and reporting mode.

The user equipment (UE) 104 may set 602 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also

set the CQI/PMI bit index j = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may determine 604 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 608 if a periodic channel state information (CSI) report 236a-b is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) report 236a-b is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 610 i = i + 1.

If a periodic channel state information (CSI) report 236a-b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 612 whether the periodic channel state information (CSI) report 236a-b is CQI/PMI. If the periodic channel state information (CSI) report 236a-b is not CQI/PMI, the user equipment (UE) 104 may increment 610 i = i + 1. If the periodic channel state information (CSI) report 236a-b is CQI/PMI, the user equipment (UE) 104 may obtain 614 the CQI/PMI of the cell for the aggregated channel state information (CSI) report. The length of the CQI/PMI report $\{p_0, p_1, \ldots p_{l-1}\}$ is l. The user equipment (UE) 104 may set n = 0. While n < l 616, the user equipment (UE) 104 may set 618 the bit c_j of the aggregated CQI/PMI equal to the bit p_n of the periodic channel state information (CSI), n = n + 1 and j = j + 1. Once n = l, the user equipment (UE) 104 may increment

610 i = i + 1.

After the user equipment (UE) 104 has incremented 610 i = i + 1, the user equipment (UE) 104 may again determine 604 whether $i < N_{cells}^{DL}$. If $i = N_{cells}^{DL}$, the user equipment (UE) 104 may generate 606 an aggregated channel state information (CSI) report with the aggregated CQI/PMI bits $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{\text{PUSCH}} = j$.

Further payload optimization may be applied on the aggregated CQI/PMI to reduce the payload size. A periodic channel state information (CSI) report 236b may be a CQI/PMI report or a rank indication (RI) report, but not both. The aggregated channel state information (CSI) report may include an aggregated CQI/PMI and/or an aggregated rank indication (RI). If some of the periodic channel state information (CSI) reports 236b are CQI/PMI and some are rank indication (RI), the aggregated channel state information (CSI) report may include both an aggregated CQI/PMI and an aggregated rank indication (RI). The reason the CQI/PMI process and the rank indication (RI) process are separated is because each is multiplexed differently on the physical uplink shared channel (PUSCH) and have to be treated separately.

For example, the first CQI/PMI with the lowest cell index that has a CQI/PMI report may be concatenated with a full CQI/PMI report and the others may be coded with different

channel quality indicator (CQI) feedback between the first CQI/PMI. Furthermore, not all CQI/PMI or rank indication (RI) may be transmitted in the same subframe. Depending on the priority, some less important information may be dropped.

If there are multiple physical uplink shared channels (PUSCHs) scheduled for a user equipment (UE) 104, only one physical uplink shared channel (PUSCH) should be selected to carry the uplink control information (UCI) 228. The aggregated CQI/PMI may be multiplexed onto the selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, only one codeword may be selected to carry the aggregated CQI/PMI. The symbol length of the aggregated rank indication (RI) multiplexing may be calculated using the total aggregated CQI/PMI payload size N_{CQI}^{PUSCH}. The aggregated CQI/PMI may be coded with a Reed-Muller code (if the payload is ≤ 11 bits) or a tail biting convolutional code (if the payload > 11 bits), and then rate matched to the desired length. The rate matched output may become the coded CQI/PMI. The coded CQI/PMI may be multiplexed on all layers of the selected codeword. The aggregated CQI/PMI refers to raw information bits.

The CQI/PMI may be measured at the user equipment (UE) 104 and is measured as an integer number. In order to

feedback these integer numbers, a binary representation may be generated. The binary representation of the measured CQI/PMI is referred to as 'raw' information bits. To achieve a level of reliability in transmission, the raw information bits may need to be channel coded. The process of channel coding includes the addition of parities and redundancies that take place in a channel encoder module. The output of the channel encoder module (when the input is raw CQI/PMI bits) is referred to as coded CQI/PMI.

Figure 7 is a flow diagram of a method 700 for concatenating multiple periodic channel state information (CSI) reports 236b that are rank indication (RI) to obtain an aggregated rank indication (RI) of an aggregated channel state information (CSI) report. The method 700 may be performed by a user equipment (UE) 104. The aggregated rank indication (RI) may be channel interleaved on the same selected physical uplink shared channel (PUSCH) as the aggregated CQI/PMI. Furthermore, if the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, the aggregated rank indication (RI) may be channel interleaved across all codewords and all layers with resource element alignment. For the selected physical uplink shared channel (PUSCH), the symbol length of the aggregated rank indication (RI) may be calculated using the

total aggregated rank indication (RI) payload size N_{RI}^{PUSCH}.

If the periodic channel state information (CSI) reports 236b are rank indication (RI) of the corresponding component carriers (CCs), the rank indication (RI) $\{q_0,...q_{m-1}\}$ of each periodic channel state information (CSI) report 236b may be concatenated to an aggregated channel state information (CSI) report $\{r_0,r_1,...r_{N_{RI}^{PUSCH}-1}\}$, where N_{RI}^{PUSCH} is the payload size of the aggregated channel state information (CSI) report and where m is the length of the aggregated channel state information (CSI) report as decided by the physical uplink control channel (PUCCH) report type and reporting mode.

The user equipment (UE) 104 may set 702 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the rank indication (RI) bit index k = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may determine 704 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 708 if a periodic channel state information (CSI) report 236a-b is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) report 236a-b is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 710 i = i + 1.

If a periodic channel state information (CSI) report 236a-b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 712 whether the periodic channel state information (CSI) report 236a-b is rank indication (RI). If the periodic channel state information (CSI) report 236a-b is not rank indication (RI), the user equipment (UE) 104 may increment 710 i = i + 1. If the periodic channel state information (CSI) report 236a-b is rank indication (RI), the user equipment (UE) 104 may obtain 714 the rank indication (RI) of the cell for the aggregated channel state information (CSI) report. The length of the rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 716, the user equipment (UE) 104 may set 718 the bit r_j of the aggregated rank indication (RI) equal to the bit q_n of the rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may increment 710 i = i + 1.

After the user equipment (UE) 104 has incremented 710 i = i + 1, the user equipment (UE) 104 may again determine 704 whether i < N_{cells}^{DL}. If i = N_{cells}^{DL}, the user equipment (UE) 104 may generate 706 an aggregated channel state information (CSI) report with the aggregated rank indication (RI) bits $\{r_0,r_1,...r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH}=k$.

As an alternative to the aggregated CQI/PMI and aggregated rank indication (RI) approach, each CQI/PMI or

rank indication (RI) of each component carrier (CC) can be treated separately. Thus for each periodic CQI/PMI and periodic rank indication (RI), the user equipment (UE) 104 may calculate the length Q' of each uplink control information (UCI) 228 multiplexing on the physical uplink shared channel (PUSCH) and then multiplex them following the component carrier (CC) ordering. Thus, multiple symbol length calculations may be used and coding and multiplexing may be performed independently.

In yet another alternative, the aggregated CQI/PMI and the aggregated rank indication (RI) may each be treated as one report block. Thus, one length calculation may be used to decide the number of symbols for each type of channel state information (CSI) on each layer. The aggregated channel state information (CSI) report can normally obtain a better coding gain because aggregated channel state information (CSI) reports have a higher payload than independent channel state information (CSI) reports. For example, for 1 or 2 bits of rank indication (RI), simple repetition or simplex coding may be used. If the aggregated rank indication (RI) payload is great than 2, the Reed Muller code (e.g., (32, O) code) can be employed to get better coding performance.

If some periodic channel state information (CSI) reports 236b are CQI/PMI and some periodic channel state information (CSI) reports 236b are rank indication (RI) of the

corresponding component carriers (CCs), the CQI/PMI of those periodic channel state information (CSI) reports 236b may be concatenated to an aggregated CQI/PMI and the rank indication (RI) of those periodic channel state information (CSI) reports 236b may be concatenated to an aggregated rank indication (RI). There may be no dependency between the aggregated CQI/PMI and the aggregated rank indication (RI). The payload of the aggregated CQI/PMI, N_{CQI}^{PUSCH}, may be the sum of all CQI/PMI of all the component carriers (CCs) reporting CQI/PMI. The payload of the aggregated rank indication (RI), N_{RI}^{PUSCH}, may be the sum of all rank indication (RI) of all component carriers (CCs) reporting periodic rank indication (RI). This is different from the periodic channel state information (CSI) reporting of Rel-8/9 where either CQI/PMI or rank indication (RI) is reported, but not both. This is also different from Rel-8/9 aperiodic channel state information (CSI) reporting, where both CQI/PMI and rank indication (RI) are reported, and the CQI/PMI payload size depends on the rank indication (RI) value.

Figure 8 is a flow diagram of a method 800 for transmitting aperiodic channel state information (CSI) reports 236c on the physical uplink shared channel (PUSCH). The method 800 may be performed by a user equipment (UE) 104. The user equipment (UE) 104 may receive 802 a trigger from an eNode B 102 to generate one or more aperiodic channel

state information (CSI) reports 236c. Aperiodic channel state information (CSI) reporting may be triggered by an eNode B 102 in a subframe. An aperiodic channel state information (CSI) report 236c may include both the CQI/PMI and the rank indication (RI) and is always carried on the physical uplink shared channel (PUSCH). In Rel-8/9, only one component carrier (CC) is used. Thus, the aperiodic channel state information (CSI) report 236c and a periodic channel state information (CSI) report 236b are for the same component carrier (CC). In cases where both periodic and aperiodic reporting occur in the same subframe, the user equipment (UE) 104 only transmits the aperiodic channel state information (CSI) report 236c on the physical uplink shared channel (PUSCH) in that subframe.

In Rel-10 and beyond, multiple component carriers (CCs) may be configured for a user equipment (UE) 104. Thus, several types of aperiodic channel state information (CSI) reports 236c may be available. A component carrier (CC) specific aperiodic channel state information (CSI) report 236c, also known as a cell-specific aperiodic channel state information (CSI) report, is an aperiodic channel state information (CSI) report 236c for one specific component carrier (CC). A component carrier (CC) specific aperiodic channel state information (CSI) report 236c may include both CQI/PMI and rank indication (RI). The CQI/PMI in an

aperiodic channel state information (CSI) report 236c may be a wideband channel quality indicator (CQI) report, one or more subband channel quality indicator (CQI) reports and/or a user equipment (UE) 104 selected subband CQI/PMI/RI report. For aperiodic channel quality indicator (CQI) reporting, the rank indication (RI) reporting is transmitted only if the configured CQI/PMI/RI feedback type supports rank indication (RI) reporting. If the rank indication (RI) is reported, the payload of the channel quality indicator (CQI) depends on the corresponding rank indication (RI).

An aperiodic channel state information (CSI) report 236c of multiple component carriers (CCs) may include both CQI/PMI and rank indication (RI) for multiple component carriers (CCs). The CQI/PMI may be one or more wideband channel quality indicator (CQI) reports, one or more subband channel quality indicator (CQI) reports of multiple component carriers (CCs) and/or of one or more user equipment (UE) 104 selected component carriers (CCs) and/or one or more user equipment (UE) 104 selected subband CQI/PMI/RI reports. For example, an aperiodic channel state information (CSI) report 236c of multiple component carriers (CCs) may be an aperiodic channel state information (CSI) report 236c for all configured or activated component carriers (CC). In one configuration, multiple aperiodic channel state information (CSI) reports 236c may be generated.

The user equipment (UE) 104 may determine 804 whether there are multiple aperiodic channel state information (CSI) reports 236c for transmission. For component carrier (CC) specific aperiodic channel state information (CSI) reports 236c and aperiodic channel state information (CSI) reports 236c of multiple component carriers (CCs) when there is only one aperiodic channel state information (CSI) report 236 for transmission, only one block of channel state information (CSI) for the component carrier (CC) (or component carriers (CCs)) may be generated 806 for the aperiodic channel state information (CSI) report 236c. The user equipment (UE) 104 may then transmit 808 the aperiodic channel state information (CSI) report 236c in a subframe.

If there are multiple aperiodic channel state information (CSI) reports 236c for transmission, the user equipment (UE) 104 may generate 810 multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c. The user equipment (UE) 104 may then concatenate 812 the aperiodic channel state information (CSI) reports 236c into an aggregated aperiodic channel state information (CSI) report. The user equipment (UE) 104 may multiplex 814 the aggregated aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH).

Figure 9 is a flow diagram of a method 900 for

concatenating multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c to obtain an aggregated channel state information (CSI) report. The method 900 may be performed by a user equipment (UE) 104. The CQI/PMI of each component carrier (CC) specific aperiodic channel state information (CSI) report 236c may be concatenated to form an aggregated channel state information (CSI) report with aggregated aperiodic CQI/PMI bits $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$, where N_{CQI}^{PUSCH} is the number of aggregated aperiodic CQI/PMI bits. The rank indication (RI) of each component carrier (CC) specific aperiodic channel state information (CSI) report 236c may be concatenated to form an aggregated channel state information (CSI) report with aggregated aperiodic rank indication (RI) bits $\{r_0, r_1, \ldots r_{N_{RI}^{PUSCH}-1}\}$, where N_{RI}^{PUSCH} is the number of aggregated aperiodic rank indication (RI) bits.

The user equipment (UE) 104 may set 902 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the CQI/PMI bit index j = 0. The user equipment (UE) 104 may further set the rank indication (RI) bit index k = 0. The user equipment (UE) 104 may also set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user

equipment (UE) 104. The user equipment (UE) 104 may determine 904 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 908 if a component carrier (CC) specific aperiodic channel state information (CSI) report 236c is triggered for the i^{th} downlink cell. If a component carrier (CC) specific aperiodic channel state information (CSI) report 236c is not triggered for the i^{th} downlink cell, the user equipment (UE) 104 may increment 910 i = i + 1.

If a component carrier (CC) specific aperiodic channel state information (CSI) report 236c is triggered for the i^{th} downlink cell, the user equipment (UE) 104 may obtain 912 the aperiodic CQI/PMI of the cell for the aggregated channel state information (CSI) report. The length of the CQI/PMI report $\{p_0, p_1, \ldots p_{l-1}\}$ is l. The user equipment (UE) 104 may set n = 0. While n < l 914, the user equipment (UE) 104 may set 916 the bit c_j of the aggregated CQI/PMI equal to the bit p_n of the aperiodic CQI/PMI, n = n + 1 and j = j + 1.

Once n = l, the user equipment (UE) 104 may determine 918 whether the rank indication (RI) is reported in the aperiodic channel state information (CSI) report 236c. If the rank indication (RI) is not reported in the aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may increment 910 i = i + 1. If the rank indication (RI) is reported in the aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may obtain 920 the

aperiodic rank indication (RI) of the cell for the aggregated channel state information (CSI) report. The length of the rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 922, the user equipment (UE) 104 may set 924 the bit r_j of the aggregated aperiodic rank indication (RI) equal to the bit q_n of the rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may increment 910 i = i + 1.

After the user equipment (UE) 104 has incremented 910 i = i + 1, the user equipment (UE) 104 may again determine 904 whether i < N_{cells}^{DL}. If i = N_{cells}^{DL}, the user equipment (UE) 104 may generate 906 an aggregated channel state information (CSI) report with the aggregated CQI/PMI bits $\{c_0,c_1,...c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{\text{PUSCH}} = j$ and the aggregated aperiodic rank indication (RI) bits $\{r_0,r_1,...r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH} = k$.

With the concatenation of multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c, only one aggregated aperiodic channel state information (CSI) report is multiplexed on the physical uplink shared channel (PUSCH). The uncoded CQI/PMI payload of the aggregated aperiodic channel state information (CSI) report is the sum of the uncoded CQI/PMI payload of the component

carrier (CC) specific aperiodic channel state information (CSI) reports 236c. The uncoded rank indication (RI) payload of the aggregated periodic channel state information (CSI) report is the sum of the uncoded rank indication (RI) payload of the component carrier (CC) specific aperiodic channel state information (CSI) reports 236c.

An "instance of aperiodic channel state information (CSI) report" may refer to a component carrier (CC) specific aperiodic channel state information (CSI) report 236c, an aperiodic channel state information (CSI) report 236c from multiple component carriers (CCs), or an aggregated aperiodic channel state information (CSI) report from multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c. An instance of aperiodic channel state information (CSI) report may be generated when any type and number of aperiodic channel state information (CSI) reports 236c are triggered. An instance of aperiodic channel state information (CSI) report may also be referred to as "an aperiodic channel state information (CSI) reporting."

The uncoded CQI/PMI payload of an instance of aperiodic channel state information (CSI) report may be the number of uncoded CQI/PMI payload of a component carrier (CC) specific aperiodic channel state information (CSI) report 236c, the number of uncoded CQI/PMI payload of an aperiodic channel state information (CSI) report 236c for

multiple component carriers (CCs) or the number of uncoded CQI/PMI payload of an aggregated aperiodic channel state information (CSI) report from multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c. The uncoded rank indication (RI) payload of an instance of aperiodic channel state information (CSI) report may be the number of uncoded rank indication (RI) payload of a component carrier (CC) specific aperiodic channel state information (CSI) report 236c, the number of uncoded rank indication (RI) payload of an aperiodic channel state information (CSI) report 236c for multiple component carriers (CCs) or the number of uncoded rank indication (RI) payload of an aggregated aperiodic channel state information (CSI) report from multiple component carrier (CC) specific aperiodic channel state information (CSI) reports 236c.

If there are multiple physical uplink shared channels (PUSCHs) scheduled for the user equipment (UE) 104, only one physical uplink shared channel (PUSCH) should be selected to carry the uplink control information (UCI) 228. The CQI/PMI may be multiplexed before data and the rank indication (RI) may be channel interleaved on the same selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, the

CQI/PMI may be multiplexed on all layers of one selected codeword and the rank indication (RI) may be channel interleaved across all codewords and all layers with resource element alignment.

Figure 10 is a flow diagram of a method 1000 for transmitting uplink control information (UCI) 228 on the physical uplink shared channel (PUSCH). The method 1000 may be performed by a user equipment (UE) 104. In Rel-10 and beyond, an instance of aperiodic channel state information (CSI) report may collide with one or multiple periodic channel state information (CSI) reports 236b. The instance of aperiodic channel state information (CSI) report may have channel state information (CSI) for one component carrier (CC) or multiple component carriers (CCs). The instance of aperiodic channel state information (CSI) report may or may not include channel state information (CSI) for the component carrier (CC) corresponding to the periodic channel state information (CSI) report 236b that it collides with.

When simultaneous physical uplink control channel (PUCCH) and physical uplink shared channel (PUSCH) transmission is not configured, the user equipment (UE) 104 may need to transmit one or more periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH). If simultaneous physical uplink control

channel (PUCCH) and physical uplink shared channel (PUSCH) transmission is configured, the user equipment (UE) 104 may transmit the HARQ-ACK 240a (if present) on the physical uplink control channel (PUCCH). One or more periodic channel state information (CSI) reports 236b may be dropped from the physical uplink control channel (PUCCH) to be transmitted on the physical uplink shared channel (PUSCH). If the HARQ-ACK 240a is not present, multiple periodic channel state information (CSI) reports 236b may be scheduled in the same subframe.

The user equipment (UE) 104 may generate 1002 one or more periodic channel state information (CSI) reports 236b in a subframe. The user equipment (UE) 104 may receive 1004 a trigger from an eNode B 102 to generate an instance of aperiodic channel state information (CSI) report in the same subframe as the generated one or more periodic channel state information (CSI) reports 236b. The user equipment (UE) 104 may then generate 1006 the instance of aperiodic channel state information (CSI) report. The instance of aperiodic channel state information (CSI) report may or may not include channel state information (CSI) corresponding to the component carrier (CC) of the periodic channel state information (CSI) report 236a with the highest priority 210a (i.e., the periodic channel state information (CSI) report 236a transmitted on the physical uplink control channel (PUCCH)).

The user equipment (UE) 104 may determine 1008 whether multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is supported. If multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is supported, simultaneous aperiodic channel state information (CSI) and periodic channel state information (CSI) reporting may be allowed. If simultaneous aperiodic channel state information (CSI) and periodic channel state information (CSI) reporting is supported by the user equipment (UE) 104 and configured by the eNode B 102, the user equipment (UE) 104 may multiplex 1012 both the instance of aperiodic channel state information (CSI) report and the one or more periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH).

If multiple channel state information (CSI) reporting on the physical uplink shared channel (PUSCH) is not supported, the user equipment (UE) 104 may multiplex 1010 only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH). If there are multiple physical uplink shared channels (PUSCHs) scheduled for the user equipment (UE) 104, only one physical uplink shared channel (PUSCH) should be selected to carry uplink control information (UCI) 228. Thus, the aperiodic CQI/PMI should be multiplexed on the selected physical uplink shared

channel (PUSCH) and the aperiodic rank indication (RI) should be channel interleaved on the same selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, only one codeword may be selected to carry the aperiodic CQI/PMI. The coded CQI/PMI may be multiplexed on all layers of the selected codeword. The aperiodic rank indication (RI) may be channel interleaved across all codewords and all layers with resource element alignment.

Figure 11 is a flow diagram of a method 1100 for generating an aggregated channel state information (CSI) report using combined rank indication (RI) from an instance of aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports 236b. The method 1100 may be performed by a user equipment (UE) 104. An aggregated channel state information (CSI) report may include a combined CQI/PMI and/or a combined rank indication (RI) from an instance of aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports 236a-b. If some of the channel state information (CSI) reports are CQI/PMI and some are rank indication (RI), the aggregated channel state information (CSI) report may include both a combined CQI/PMI and a

combined rank indication (RI).

The combined rank indication (RI) may be channel interleaved on the selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, the combined rank indication (RI) may be channel interleaved across all codewords and all layers with resource element alignment. For the selected physical uplink shared channel (PUSCH), the symbol length of the combined rank indication (RI) may be calculated using the total combined rank indication (RI) payload size N_{RI}^{PUSCH}.

The user equipment (UE) 104 may set 1102 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the rank indication (RI) bit index k = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may then use an aperiodic channel state information (CSI) process 1141 and a periodic channel state information (CSI) process 1143 to obtain an aggregated channel state information (CSI) report.

In the method 1100, the aperiodic channel state information (CSI) report 236c is concatenated before the periodic channel state information (CSI) reports 236b. By

switching the order of the aperiodic channel state information (CSI) process 1141 and the periodic channel state information (CSI) process 1143, the aperiodic channel state information (CSI) report 236c can be concatenated after the periodic channel state information (CSI) reports 236b.

In the aperiodic channel state information (CSI) process 1141, the user equipment (UE) 104 may determine 1104 whether the rank indication (RI) is reported in the instance of aperiodic channel state information (CSI) report. If the rank indication (RI) is not reported in the instance of aperiodic channel state information (CSI) report, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1143. If the rank indication (RI) is reported in the instance of aperiodic channel state information (CSI) report, the user equipment (UE) 104 may obtain 1106 the aggregated rank indication (RI) of the cell for the aggregated channel state information (CSI) report, if available. The length of the aperiodic rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 1108, the user equipment (UE) 104 may set 1110 the bit r_k of the combined rank indication (RI) equal to the bit q_k of the aperiodic rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1143.

In the periodic channel state information (CSI) process

1143, the user equipment (UE) 104 may determine 1112 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 1114 if a periodic channel state information (CSI) is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 1116 i = i + 1.

If a periodic channel state information (CSI) report 236a-b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 1118 whether the component carrier (CC) is included in the instance of aperiodic channel state information (CSI) report. If the component carrier (CC) is included in the instance of aperiodic channel state information (CSI) report, the user equipment (UE) 104 may increment 1116 i = i + 1. If the component carrier (CC) is not included in the instance of aperiodic channel state information (CSI) report, the user equipment (UE) 104 may determine 1120 whether the periodic channel state information (CSI) report 236b is rank indication (RI). If the periodic channel state information (CSI) report 236b is not rank indication (RI), the user equipment (UE) 104 may increment 1116 i = i + 1. If the periodic channel state information (CSI) report 236b is rank indication (RI), the user equipment (UE) 104 may obtain 1122 the rank indication (RI) of this cell for the combined rank indication (RI). The length

of the rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 1124, the user equipment (UE) 104 may set 1126 the bit r_k of the combined rank indication (RI) equal to the bit q_k of the aperiodic rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may increment 1116 i = i + 1.

After the user equipment (UE) 104 has incremented 1116 i = i + 1, the user equipment (UE) 104 may again determine 1112 whether i < N_{cells}^{DL}. If i = N_{cells}^{DL}, the user equipment (UE) 104 may obtain 1128 the combined rank indication (RI) from the aperiodic channel state information (CSI) process 1141 and the periodic channel state information (CSI) process 1143. The user equipment (UE) 104 may then generate 1130 an aggregated channel state information (CSI) report using the combined rank indication (RI) $\{r_0,r_1,...r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH}=k$.

Figure 12 is a flow diagram of a method 1200 for generating an aggregated channel state information (CSI) report using combined CQI/PMI from an instance of aperiodic channel state information (CSI) report and one or more periodic channel state information (CSI) reports 236b. The method 1200 may be performed by a user equipment (UE) 104. The combined CQI/PMI may be multiplexed on the selected

physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, only one codeword should be selected to carry the combined CQI/PMI. The coded CQI/PMI should be multiplexed on all layers of the selected codeword. For the selected codeword and physical uplink shared channel (PUSCH), the symbol length of the combined CQI/PMI may be calculated using the total combined CQI/PMI payload size N_{CQI}^{PUSCH}.

The user equipment (UE) 104 may set 1202 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the CQI/PMI bit index j = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may then use an aperiodic channel state information (CSI) process 1241 and a periodic channel state information (CSI) process 1243 to obtain an aggregated channel state information (CSI) report.

In the method 1200, for the concatenation of CQI/PMI bits for different cells, the instance of aperiodic channel state information (CSI) report is concatenated before the periodic channel state information (CSI) reports 236b. By switching the order of the aperiodic channel state information (CSI)

process 1241 and the periodic channel state information (CSI) process 1243, the instance of aperiodic channel state information (CSI) report can be concatenated after the periodic channel state information (CSI) reports 236b.

In the aperiodic channel state information (CSI) process 1241, the user equipment (UE) 104 may obtain 1204 the aperiodic CQI/PMI for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l. The user equipment (UE) 104 may set n = 0. While n < l 1206, the user equipment (UE) 104 may set 1208 the bit c_j of the combined CQI/PMI equal to the bit p_n of the aperiodic CQI/PMI, n = n + 1 and j = j + 1. Once n = l, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1243.

In the periodic channel state information (CSI) process 1243, the user equipment (UE) 104 may determine 1210 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 1214 if a periodic channel state information (CSI) is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 1212 i = i + 1.

If a periodic channel state information (CSI) is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 1216 whether the component carrier (CC) is included in the aperiodic channel state information (CSI)

report 236c. If the component carrier (CC) is included in the aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may increment 1212 i = i + 1. If the component carrier (CC) is not included in the aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may determine 1218 whether the periodic channel state information (CSI) report 236b is CQI/PMI. If the periodic channel state information (CSI) report 236b is not CQI/PMI, the user equipment (UE) 104 may increment 1212 i = i + 1. If the periodic channel state information (CSI) report 236b is CQI/PMI, the user equipment (UE) 104 may obtain 1220 the CQI/PMI of this cell for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l. The user equipment (UE) 104 may set n = 0. While n < l 1222, the user equipment (UE) 104 may set 1224 the bit c_j of the combined CQI/PMI equal to the bit p_n of the aperiodic CQI/PMI, n = n + 1 and j = j + 1. Once n = m, the user equipment (UE) 104 may increment 1212 i = i + 1.

After the user equipment (UE) 104 has incremented 1212 i = i + 1, the user equipment (UE) 104 may again determine 1210 whether i < N_{cells}^{DL}. If i = N_{cells}^{DL}, the user equipment (UE) 104 may obtain 1226 the combined CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process 1241 and the periodic channel state

information (CSI) process 1243. The user equipment (UE) 104 may then generate 1228 an aggregated channel state information (CSI) report using the combined CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{\text{PUSCH}} = j$.

Figure 13 is a flow diagram of another method 1300 for transmitting uplink control information (UCI) 228 on the physical uplink shared channel (PUSCH). The method 1300 may be performed by a user equipment (UE) 104. The user equipment (UE) 104 may include a configuration parameter that indicates whether the user equipment (UE) 104 sends an instance of aperiodic channel state information (CSI) report for all configured/activated downlink cells or whether the user equipment (UE) 104 sends an instance of aperiodic channel state information (CSI) report for a specific downlink cell. The configuration parameter may be linked to the periodic channel state information (CSI) configuration.

If the user equipment (UE) 104 is configured to send an instance of aperiodic channel state information (CSI) report for all configured/activated downlink cells, when an instance of aperiodic channel state information (CSI) report collides with one or more periodic channel state information (CSI) reports 236b all the periodic channel state information (CSI) reports 236b are dropped. If the user equipment (UE) 104 is configured to send an instance of aperiodic channel state

information (CSI) report for a specific downlink cell, when a component carrier (CC) specific aperiodic channel state information (CSI) report 236c collides with one or more periodic channel state information (CSI) reports 236b, all the periodic channel state information (CSI) reports 236b may be transmitted on the physical uplink shared channel (PUSCH) together with the component carrier (CC) specific aperiodic channel state information (CSI) report 236c.

The user equipment (UE) 104 may generate 1302 one or more periodic channel state information (CSI) reports 236b. The user equipment (UE) 104 may receive 1304 a trigger from an eNode B 102 to generate an instance of aperiodic channel state information (CSI) report 236c. The user equipment (UE) 104 may then generate 1306 an instance of aperiodic channel state information (CSI) report. The user equipment (UE) 104 may determine 1308 whether multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is supported. If multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is not supported, the user equipment (UE) 104 may transmit 1314 only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH). If multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is supported, the user equipment (UE) 104 may determine 1310

whether the instance of aperiodic channel state information (CSI) report is for all configured/activated component carriers (CCs).

If the instance of aperiodic channel state information (CSI) report is for all configured/activated component carriers (CCs), the user equipment (UE) 104 may transmit 1314 only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH). If the instance of aperiodic channel state information (CSI) report is not for all configured/activated component carriers (CCs), the user equipment (UE) 104 may transmit 1312 both the instance of aperiodic channel state information (CSI) report and the one or more periodic channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH).

In one configuration that may be configured by the eNode B 102, the instance of aperiodic channel state information (CSI) report and the periodic channel state information (CSI) reports 236b of the component carriers (CCs) that are not included in the instance of aperiodic channel state information (CSI) report may be reported together on the physical uplink shared channel (PUSCH). For a periodic channel state information (CSI) report 236b of one component carrier (CC), the user equipment (UE) 104 may first check if the channel state information (CSI) of the same component carrier (CC) is included in the instance of

aperiodic channel state information (CSI) report. If the periodic channel state information (CSI) report 236b is for the same component carrier (CC) as that reported in the instance of aperiodic channel state information (CSI) report, the periodic channel state information (CSI) report 236b for that particular component carrier (CC) may be dropped. Otherwise, the periodic channel state information (CSI) report 236b and the instance of aperiodic channel state information (CSI) report may be transmitted together.

One way to multiplex one or more periodic channel state information (CSI) reports 236b and an instance of aperiodic channel state information (CSI) report is to treat them separately. The one or more periodic channel state information (CSI) reports 236b may be multiplexed before the instance of aperiodic channel state information (CSI) report. A periodic CQI/PMI report may be multiplexed before the instance of aperiodic channel state information (CSI) report because the periodic CQI/PMI size is already known to the eNode B 102. The aperiodic CQI/PMI may be multiplexed after the periodic CQI/PMI. Similarly, the rank indication (RI) from the periodic channel state information (CSI) may be channel interleaved on the rank indication (RI) location first because the size of the rank indication (RI) is already known to the eNode B 102. The aperiodic rank indication (RI) may be channel interleaved after the rank indication (RI) from the

periodic channel state information (CSI).

At the eNode B 102, the aperiodic CQI/PMI payload size may be obtained after the aperiodic rank indication (RI) is decoded. Thus, more complexity may be introduced when the one or more periodic channel state information (CSI) reports 236b and an instance of aperiodic channel state information (CSI) report are treated separately because separate length calculations may be necessary for periodic and aperiodic channel state information (CSI) reports 236. However, treating the one or more periodic channel state information (CSI) reports 236b and an instance of aperiodic channel state information (CSI) report separately allows separate detection and decoding of the periodic and aperiodic channel state information (CSI). Thus, the miss detection of an aperiodic rank indication (RI) may not cause problems with the periodic channel state information (CSI) reporting.

The periodic channel state information (CSI) reports 236b and the instance of aperiodic channel state information (CSI) report may instead be concatenated together. The periodic channel state information (CSI) reports 236b of the component carriers (CCs) that are not included in the instance of aperiodic channel state information (CSI) report may be grouped together first, and then concatenated with the instance of aperiodic channel state information (CSI) report. The aperiodic CQI/PMI may be put after the

aggregated CQI/PMI from the periodic channel state information (CSI) report 236b to form a combined CQI/PMI. The aperiodic rank indication (RI) may be put after the aggregated rank indication (RI) from the periodic channel state information (CSI) reports 236b to form a combined rank indication (RI). Alternatively, the aperiodic CQI/PMI may be put before the aggregated CQI/PMI from the periodic channel state information (CSI) reports 236b to form a combined CQI/PMI and the aperiodic rank indication (RI) may be put before the aggregated rank indication (RI) from the periodic channel state information (CSI) reports 236b to form a combined rank indication (RI). Unlike the separate coding and multiplexing discussed above, the combined CQI/PMI is jointly coded. Thus, the order of the instance of aperiodic channel state information (CSI) report and the periodic channel state information (CSI) report 236b has no impact on the performance but must be defined. Once defined, the same rule may also apply to the combined rank indication (RI).

The uncoded payload of the combined CQI/PMI, N_{CQI}^{PUSCH}, is the sum of the uncoded CQI/PMI payload of the instance of the aperiodic channel state information (CSI) report and the aggregated CQI/PMI of all the periodic CQI/PMI reports of the component carriers (CCs) that are not included in the instance of aperiodic channel state information (CSI) report. The uncoded payload of the combined rank indication (RI),

N_{RI}^{PUSCH}, is the sum of the uncoded rank indication (RI) payload of the instance of the aperiodic channel state information (CSI) report and the aggregated rank indication (RI) of all the periodic rank indication (RI) reports of the component carriers (CCs) that are not included in the instance of aperiodic channel state information (CSI) report. The length of the aperiodic CQI/PMI part may depend on the aperiodic rank indication (RI) part only if the rank indication (RI) is reported in the instance of aperiodic channel state information (CSI) report.

Figure 14 is a flow diagram of a method 1400 for generating an aggregated channel state information (CSI) report using combined CQI/PMI from an aperiodic channel state information (CSI) report 236c that is for a specific downlink component carrier (CC) and one or more periodic channel state information (CSI) reports 236b. The method 1400 may be performed by a user equipment (UE) 104. The combined CQI/PMI may be multiplexed on the selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, only one codeword should be selected to carry the combined CQI/PMI. The coded CQI/PMI should be multiplexed on all layers of the selected codeword. For the selected codeword and physical uplink

shared channel (PUSCH), the symbol length of the combined CQI/PMI may be calculated using the total combined CQI/PMI payload size N_{CQI}^{PUSCH}.

In the method 1400, for the concatenation of CQI/PMI bits for different cells, the aperiodic channel state information (CSI) report 236c is concatenated before the periodic channel state information (CSI) reports 236b. By switching the order of the aperiodic channel state information (CSI) process 1441 and the periodic channel state information (CSI) process 1443, the aperiodic channel state information (CSI) report 236c can be concatenated after the periodic channel state information (CSI) reports 236b.

The user equipment (UE) 104 may set 1402 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the CQI/PMI bit index j = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may use an aperiodic channel state information (CSI) process 1441 and a periodic channel state information (CSI) process 1443 to obtain an aggregated channel state information (CSI) report.

In the aperiodic channel state information (CSI) process 1441, the user equipment (UE) 104 may obtain 1404 the aperiodic CQI/PMI for the combined CQI/PMI. The length of

the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is 1. The user equipment (UE) 104 may set n = 0. While n < l 1406, the user equipment (UE) 104 may set 1408 the bit c_j of the combined CQI/PMI equal to the bit p_n of the aperiodic CQI/PMI, n = n + 1 and j = j + 1. Once n = l, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1443.

In the periodic channel state information (CSI) process 1443, the user equipment (UE) 104 may determine 1410 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 1412 if a periodic channel state information (CSI) is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 1414 i = i + 1.

If a periodic channel state information (CSI) report 236b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 1416 whether the periodic channel state information (CSI) report 236b is CQI/PMI. If the periodic channel state information (CSI) report 236b is not CQI/PMI, the user equipment (UE) 104 may increment 1414 i = i + 1. If the periodic channel state information (CSI) report 236b is CQI/PMI, the user equipment (UE) 104 may obtain 1418 the CQI/PMI of the cell for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l. The user equipment (UE) 104 may set n = 0. While n < l 1420, the user equipment (UE) 104

may set 1422 the bit c_j of the combined CQI/PMI equal to the bit p_n of the aperiodic CQI/PMI, n = n + 1 and j = j + 1. Once n = m, the user equipment (UE) 104 may increment 1414 i = i + 1.

After the user equipment (UE) 104 has incremented 1414 i = i + 1, the user equipment (UE) 104 may again determine 1410 whether $i < N_{cells}^{DL}$. If $i = N_{cells}^{DL}$, the user equipment (UE) 104 may obtain 1424 the combined CQI/PMI $\{c_0, c_1, ...c_{N_{CQI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process 1441 and the periodic channel state information (CSI) process 1443. The user equipment (UE) 104 may then generate 1426 an aggregated channel state information (CSI) report using the combined CQI/PMI $\{c_0, c_1, ...c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{\text{PUSCH}} = j$.

Figure 15 is a flow diagram of a method 1500 for generating an aggregated channel state information (CSI) report using combined rank indication (RI) from an aperiodic channel state information (CSI) report 236c and one or more periodic channel state information (CSI) reports 236b. The method 1500 may be performed by a user equipment (UE) 104. The combined rank indication (RI) may be channel interleaved on the selected physical uplink shared channel (PUSCH). If the selected physical uplink shared channel (PUSCH) is

configured with single-user multiple-input and multiple-output (SU-MIMO) with multiple codewords and layers, the combined rank indication (RI) may be channel interleaved across all codewords and all layers with resource element alignment. For the selected physical uplink shared channel (PUSCH), the symbol length of the combined rank indication (RI) may be calculated using the total combined rank indication (RI) payload size N_{RI}^{PUSCH}.

In the method 1500, the aperiodic channel state information (CSI) report 236c is concatenated before the periodic channel state information (CSI) reports 236b. By switching the order of the aperiodic channel state information (CSI) process 1541 and the periodic channel state information (CSI) process 1543, the aperiodic channel state information (CSI) report 236c can be concatenated after the periodic channel state information (CSI) reports 236b.

The user equipment (UE) 104 may set 1502 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set the rank indication (RI) bit index k = 0. The user equipment (UE) 104 may further set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104. The user equipment (UE) 104 may then use an aperiodic channel state information (CSI) process 1541 and a periodic channel state information (CSI) process 1543

to obtain an aggregated channel state information (CSI) report.

In the aperiodic channel state information (CSI) process 1541, the user equipment (UE) 104 may determine 1504 whether the rank indication (RI) is reported in an aperiodic channel state information (CSI) report 236c. If the rank indication (RI) is not reported in the aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1543. If the rank indication (RI) is reported in the aperiodic channel state information (CSI) report, the user equipment (UE) 104 may obtain 1506 the aperiodic rank indication (RI) of the cell for the aggregated rank indication (RI), if available. The length of the rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 1508, the user equipment (UE) 104 may set 1510 the bit r_k of the combined rank indication (RI) equal to the bit q_n of the aperiodic rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may switch to the periodic channel state information (CSI) process 1543.

In the periodic channel state information (CSI) process 1543, the user equipment (UE) 104 may determine 1512 whether i < N_{cells}^{DL}. If i < N_{cells}^{DL}, the user equipment (UE) 104 may determine 1514 if a periodic channel state information (CSI) report 236b is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) report 236b is not

scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 1516 i = i + 1.

If a periodic channel state information (CSI) report 236b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 1518 whether the periodic channel state information (CSI) report 236b is rank indication (RI). If the periodic channel state information (CSI) report 236b is not rank indication (RI), the user equipment (UE) 104 may increment 1516 i = i + 1. If the periodic channel state information (CSI) report 236b is rank indication (RI), the user equipment (UE) 104 may obtain 1520 the rank indication (RI) report of this cell for the combined rank indication (RI). The length of the rank indication (RI) $\{q_0,...q_{m-1}\}$ is m. The user equipment (UE) 104 may set n = 0. While n < m 1522, the user equipment (UE) 104 may set 1524 the bit r_k of the combined rank indication (RI) equal to the bit q_n of the aperiodic rank indication (RI), n = n + 1 and k = k + 1. Once n = m, the user equipment (UE) 104 may increment 1516 i = i + 1.

After the user equipment (UE) 104 has incremented 1516 i = i + 1, the user equipment (UE) 104 may again determine 1512 whether i < N_{cells}^{DL}. If i = N_{cells}^{DL}, the user equipment (UE) 104 may obtain 1526 the combined rank indication (RI) from the aperiodic channel state information (CSI) process 1543 and the periodic channel state information (CSI) process 1543.

The user equipment (UE) 104 may then generate 1528 an aggregated channel state information (CSI) report using the combined rank indication (RI) $\{r_0, r_1, ..r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH} = k$.

Figure 16 is a flow diagram of a method 1600 for transmitting an extended aperiodic channel state information (CSI) report. The method 1600 may be performed by a user equipment (UE) 104. When one or more periodic channel state information (CSI) reports 236b are scheduled at the same subframe where an instance of aperiodic channel state information (CSI) report is also triggered, an extended channel state information (CSI) report may be generated and transmitted while all the periodic channel state information (CSI) reports 236b are dropped.

The user equipment (UE) 104 may generate 1602 one or more periodic channel state information (CSI) reports 236b for a subframe. The user equipment (UE) 104 may receive 1604 a trigger from an eNode B 102 to generate an instance of aperiodic channel state information (CSI) report for the same subframe. The user equipment (UE) 104 may then generate 1606 an instance of aperiodic channel state information (CSI) report 236c.

The user equipment (UE) 104 may determine 1608 whether multiple channel state information (CSI) reports 236b

on the physical uplink shared channel (PUSCH) is supported. If multiple channel state information (CSI) reports 236b on the physical uplink shared channel (PUSCH) is not supported, the user equipment (UE) 104 may transmit 1610 only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH). If multiple channel state information (CSI) reports 236 on the physical uplink shared channel (PUSCH) is supported, the user equipment (UE) 104 may generate 1614 an extended aperiodic channel state information (CSI) report that includes the instance of aperiodic channel state information (CSI) report elements and new channel state information (CSI) elements from the component carriers (CCs) that were not represented in the instance of aperiodic channel state information (CSI) report. The user equipment (UE) 104 may then transmit 1616 the extended aperiodic channel state information (CSI) report.

As an example, if the periodic channel state information (CSI) report 236b of a component carrier (CC) is scheduled in the same subframe as an instance of aperiodic channel state information (CSI) report, the user equipment (UE) 104 may first check if the component carrier (CC) is already represented in the instance of aperiodic channel state information (CSI) report. If the component carrier (CC) is already represented in the instance of aperiodic channel state information (CSI) report, the periodic channel state

information (CSI) report 236b corresponding to the component carrier (CC) should be dropped. If the component carrier (CC) is not represented in the instance of aperiodic channel state information (CSI) report, the information in the periodic channel state information (CSI) report 236b corresponding to the component carrier (CC) should be added to the extended aperiodic channel state information (CSI) report.

If the periodic channel state information (CSI) report 236b of the component carrier (CC) is a CQI/PMI, the extended aperiodic channel state information (CSI) report may include the CQI/PMI of the periodic channel state information (CSI) report 236b of the component carrier (CC). If the periodic channel state information (CSI) report 236b of the component carrier (CC) is a rank indication (RI), the extended aperiodic channel state information (CSI) report may include both the periodic rank indication (RI) report and the periodic channel state information (CSI) report 236b of the component carrier (CC). This is because in an aperiodic channel state information (CSI) report 236c, if the rank indication (RI) of a component carrier (CC) is transmitted, the CQI/PMI of the component carrier (CC) should also be transmitted, and the CQI/PMI payload depends on the rank indication (RI) value. On the other hand, a periodic channel state information (CSI) report 236b has either CQI/PMI or rank indication (RI), but not both.

Figure 17 is a flow diagram of a method 1700 for generating an extended aperiodic channel state information (CSI) report 236c. The method 1700 may be performed by a user equipment (UE) 104. The user equipment (UE) 104 may obtain 1702 the channel state information (CSI) for the original aperiodic channel state information (CSI) report 236c. The user equipment (UE) 104 may set 1704 the cell index i = 0. Lower indices correspond to lower RRC indices of the corresponding cell. The user equipment (UE) 104 may also set N_{cells}^{DL} as the number of configured or activated cells by higher layers for the user equipment (UE) 104.

The user equipment (UE) 104 may determine 1706 whether $i < N_{cells}^{DL}$. If $i < N_{cells}^{DL}$, the user equipment (UE) 104 may determine 1708 if a periodic channel state information (CSI) report 236b is scheduled for the i^{th} downlink cell. If a periodic channel state information (CSI) report 236b is not scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may increment 1714 i = i + 1. If a periodic channel state information (CSI) report 236b is scheduled for the i^{th} downlink cell, the user equipment (UE) 104 may determine 1710 whether the i^{th} cell is included in the original aperiodic channel state information (CSI) report 236c. If the i^{th} cell is included in the original aperiodic channel state information (CSI) report, the user equipment (UE) 104 may increment 1714 i = i + 1. If the i^{th} cell is not included in the original

aperiodic channel state information (CSI) report 236c, the user equipment (UE) 104 may add 1712 the channel state information (CSI) of the i^{th} cell into the aperiodic channel state information (CSI) report 236c. The user equipment (UE) 104 may then increment 1714 i = i + 1.

After the user equipment (UE) 104 has incremented 1714 i = i + 1, the user equipment (UE) 104 may again determine 1706 whether $i < N_{cells}^{DL}$. If $i = N_{cells}^{DL}$, the user equipment (UE) 104 may generate 1716 an extended aperiodic channel state information (CSI) report 236c with the original aperiodic channel state information (CSI) report 236c and the obtained channel state information (CSI) of the added component carriers (CCs). Thus, only the extended aperiodic channel state information (CSI) report is multiplexed on the physical uplink shared channel (PUSCH). The payload size may be decided by the corresponding aperiodic channel state information (CSI) report 236c format with all the requested information. The length of the symbols Q' for multiplexing on the physical uplink shared channel (PUSCH) may be calculated with the payload of the extended aperiodic channel state information (CSI) report 236c.

Figure 18 illustrates various components that may be utilized in a user equipment (UE) 1804. The user equipment (UE) 1804 may be utilized as the user equipment (UE) 104 illustrated previously. The user equipment (UE) 1804

includes a processor 1854 that controls operation of the user equipment (UE) 104 1804. The processor 1854 may also be referred to as a CPU. Memory 1874, which may include both read-only memory (ROM), random access memory (RAM) or any type of device that may store information, provides instructions 1856a and data 1858a to the processor 1854. A portion of the memory 1874 may also include non-volatile random access memory (NVRAM). Instructions 1856b and data 1858b may also reside in the processor 1854. Instructions 1856b and/or data 1858b loaded into the processor 1854 may also include instructions 1856a and/or data 1858a from memory 1874 that were loaded for execution or processing by the processor 1854. The instructions 1856b may be executed by the processor 1854 to implement the systems and methods disclosed herein.

The user equipment (UE) 1804 may also include a housing that contains a transmitter 1872 and a receiver 1873 to allow transmission and reception of data. The transmitter 1872 and receiver 1873 may be combined into a transceiver 1871. One or more antennas 1806a-n are attached to the housing and electrically coupled to the transceiver 1871.

The various components of the user equipment (UE) 1804 are coupled together by a bus system 1877 which may include a power bus, a control signal bus, and a status signal bus, in addition to a data bus. However, for the sake of

clarity, the various buses are illustrated in Figure 18 as the bus system 1877. The user equipment (UE) 1804 may also include a digital signal processor (DSP) 1875 for use in processing signals. The user equipment (UE) 1804 may also include a communications interface 1876 that provides user access to the functions of the user equipment (UE) 1804. The user equipment (UE) 1804 illustrated in Figure 18 is a functional block diagram rather than a listing of specific components.

Figure 19 illustrates various components that may be utilized in an eNode B 1902. The eNode B 1902 may be utilized as the eNode B 102 illustrated previously. The eNode B 1902 may include components that are similar to the components discussed above in relation to the user equipment (UE) 1804, including a processor 1978, memory 1986 that provides instructions 1979a and data 1980a to the processor 1978, instructions 1979b and data 1980b that may reside in or be loaded into the processor 1978, a housing that contains a transmitter 1982 and a receiver 1984 (which may be combined into a transceiver 1981), one or more antennas 1908a-n electrically coupled to the transceiver 1981, a bus system 1992, a DSP 1988 for use in processing signals, a communications interface 1990 and so forth.

Unless otherwise noted, the use of '/' above represents the phrase "and/or".

The functions described herein may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions on a computer-readable medium. The term "computer-readable medium" refers to any available medium that can be accessed by a computer or a processor. The term "computer-readable medium," as used herein, may denote a computer- and/or processor-readable medium that is non-transitory and tangible. By way of example, and not limitation, a computer-readable or processor-readable medium may comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer or processor. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

Each of the methods disclosed herein comprises one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another and/or combined into a single step without departing from the scope of the claims. In other words,

unless a specific order of steps or actions is required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

As used herein, the term "determining" encompasses a wide variety of actions and, therefore, "determining" can include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Also, "determining" can include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, "determining" can include resolving, selecting, choosing, establishing and the like.

The phrase "based on" does not mean "based only on," unless expressly specified otherwise. In other words, the phrase "based on" describes both "based only on" and "based at least on."

The term "processor" should be interpreted broadly to encompass a general purpose processor, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a controller, a microcontroller, a state machine and so forth. Under some circumstances, a "processor" may refer to an application specific integrated circuit (ASIC), a programmable logic device (PLD), a field programmable gate array (FPGA), etc. The term "processor" may refer to a combination of

processing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core or any other such configuration.

The term "memory" should be interpreted broadly to encompass any electronic component capable of storing electronic information. The term memory may refer to various types of processor-readable media such as random access memory (RAM), read-only memory (ROM), non-volatile random access memory (NVRAM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable PROM (EEPROM), flash memory, magnetic or optical data storage, registers, etc. Memory is said to be in electronic communication with a processor if the processor can read information from and/or write information to the memory. Memory may be integral to a processor and still be said to be in electronic communication with the processor.

The terms "instructions" and "code" should be interpreted broadly to include any type of computer-readable statement(s). For example, the terms "instructions" and "code" may refer to one or more programs, routines, sub-routines, functions, procedures, etc. "Instructions" and "code" may comprise a single computer-readable statement or many computer-readable statements.

Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL) or radio technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or radio technologies such as infrared, radio and microwave are included in the definition of transmission medium.

It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the systems, methods, and apparatus described herein without departing from the scope of the claims.

Embodiment 2

Embodiment 2 described as below relates to a terminal device, a base station device, a communication system and a communication method.

Embodiment 2-1

The following description discusses a second embodiment of the present invention with reference to the drawings.

Figure 20 illustrates an example of a configuration of a

cell in accordance with Embodiment 2-1 of the present invention. A terminal device is connected with cells (Cell#0 and Cell#1) covered by CC#0 and CC#1 which are two different downlink component carriers (CC, downlink communication bands), and reports pieces of receiving quality information in the respective cells Cell#0 and Cell#1 by using a single uplink component carrier (CC#1, uplink communication band).

Figure 21 is a view schematically illustrating a configuration of a communication system of the present embodiment. It is assumed in Figure 21 that the communication system is an LTE-A system. The communication system shown in Figure 21 includes a base station device (base station, transmission station, downlink transmission device, uplink receive device, eNodeB) 2201 which forms a cell and a terminal device (mobile station, receive station, uplink transmission device, downlink receive device, mobile terminal, UE (User Equipment)) 2202. To adaptively control transmission parameters such as a MCS (Modulation and Coding Scheme), rank and/or precoder for a downlink transmission signal 2203 to be transmitted in each of the cells Cell#0 and Cell#1, the terminal device 2202 (i) calculates, for each cell, by referring to a downlink reference signal (RS: Reference Signal) included in the downlink transmission signal 2203 transmitted from the base station

device 2201 on each of the component carriers CC#0 and CC#1, receiving quality information such as a rank indicator RI which specifies the preferred number of spatial multiplexing, partial precoder information PI which specifies a preferred precoder, and a channel quality indicator CQI which specifies a preferred transmission rate (modulation method, coding rate and the length of transport block etc.) and (ii) reports the receiving quality information to the base station 2201 via an uplink channel 2204 in one of the CCs. The explanation here is given to the case where the partial precoder information PI to be reported is partial precoder information 1 (PI1, first partial precoder information) and partial precoder information 2 (PI2, second partial precoder information). For example, an index i that can be represented by m bits is used as PI1 and an index j that can be represented by n bits is used as PI2 to specify a preferred precoder W(i, j). Alternatively, a rank r is further used to specify a preferred precoder $W^{(r)}(i, j)$. Note, however, that W(i, j) is a matrix determined uniquely by i and j, and a method of determining the matrix is shared between the base station device and the terminal device. Further, the preferred precoder can be calculated for example by a method of calculating, in consideration of a downlink propagation channel, a precoder so that a received signal strength indicator is high in the downlink.

Figure 22 illustrates an example of a configuration of a downlink radio frame in accordance with the present embodiment. The downlink used here is an OFDM (Orthogonal Frequency Division Multiplex) access mode. In the downlink, a physical downlink control channel (PDCCH) and a physical downlink shared channel (PDSCH) etc. is allocated. Further, a downlink reference signal (RS) is multiplexed on part of the PDSCH. The downlink radio frame includes a pair of downlink resource blocks (RB). This downlink RB pair is a unit of allocation of a downlink radio resource etc., and is defined by a frequency band of a predetermined width (RB bandwidth) and a time band of a predetermined width (2 slots = one subframe). One downlink RB pair is constituted by two consecutive downlink RBs (RB bandwidth × 2 slots) in the time domain. One downlink RB is constituted by 12 subcarriers in the frequency domain, and is constituted by 7 OFDM symbols in the time domain. A physical downlink control channel is a physical channel which transmits downlink control information such as a terminal device identifier, schedule information for a downlink shared channel, schedule information for an uplink channel, modulation method, coding rate, and resend parameters. It should be noted that, although the downlink subframe on a single CC is described here, a downlink subframe is specified for each CC and downlink subframes on the respective CCs

are substantially synchronized with each other.

Figure 23 illustrates an example of a configuration of an uplink radio frame in accordance with the present embodiment. The uplink used here is a SC-FDMA (Single Carrier-Frequency Division Multiple Access) mode. In the uplink, a physical uplink shared channel (PUSCH) and a physical uplink control channel (PUCCH) etc. is allocated. Further, an uplink reference signal is allocated to part of PUSCH and the PUCCH. The uplink radio frame includes a pair of uplink RB. This uplink RB pair is a unit for allocation of an uplink radio resource etc., and is defined by a frequency band of a predetermined width (RB bandwidth) and a time band of a predetermined width (2 slots = one subframe). One uplink RB pair is constituted by two consecutive uplink RBs (RB bandwidth × 2 slots) in the time domain. One uplink RB is constituted by 12 subcarriers in the frequency domain, and is constituted by 7 SC-FDMA symbols in the time domain.

Figure 24 is a view schematically illustrating an example of a block configuration of a base station device in accordance with the present embodiment. The base station device includes a downlink subframe generation section 2501, an OFDM signal transmission section 2504, a transmission antenna (base station transmission antenna) 2505, a receiving antenna (base station receiving antenna) 2506, an SC-FDMA signal receive section 2507, a filter section 2508, a

codeword process section 2510, and a higher layer 2511. The downlink subframe generation section 2501 includes a physical downlink control channel generation section 2502 and a downlink reference signal generation section 2503. The filter section 2508 includes a feedback information extraction section 2509.

Figure 25 is a view schematically illustrating an example of a block configuration of a terminal device in accordance with the present embodiment. The terminal device includes a receiving antenna (terminal receiving antenna) 2601, an OFDM signal receive section 2602, a downlink subframe process section 2603, a higher layer 2606, a feedback information generation section 2607, a codeword generation section 2608, an uplink subframe generation section 2609, an SC-FDMA signal transmission section 2611, and a transmission antenna (terminal transmission antenna) 2612. The downlink subframe process section 2603 includes a downlink reference signal extraction section 2604 and a physical downlink control channel extraction section 2605. The uplink subframe generation section 2609 includes an uplink reference signal generation section 2610.

The following description discusses, with reference to Figs. 5 and 6, how transmission and reception over a downlink are carried out. In the base station device, the downlink subframe generation section 2501 carries out

modulation such as error-correction coding, rate matching, PSK (phase shift keying) modulation and QAM (quadrature amplitude modulation) with respect to transmission data (also referred to as transport block) in each codeword (transmission data sequence in a physical layer) transmitted from the higher layer 2511, thereby converting the transmission data into a modulation symbol sequence. The modulation symbol sequence is mapped to a resource element (RE) which is a unit of mapping of modulation symbol sequence, and is subjected to precoding by a precoder indicated by the higher layer. Note that the RE on a downlink is defined in such a way as to correspond to each subcarrier on each OFDM symbol. Here, the transmission data sequence transmitted from the higher layer 2511 includes control data for RRC (Radio Resource Control) signaling. Further, the physical downlink control channel generation section 2502 generates a physical downlink control channel in response to instructions from the higher layer 2511. Here, control information included in the physical downlink control channel includes a transmission parameter for a downlink and information such as resource allocation on an uplink, a transmission parameter for an uplink, and/or CQI request. The downlink reference signal generation section 2503 generates a downlink reference signal DLRS. The downlink subframe generation section 2501 maps the physical downlink control channel and DLRS to REs

in a downlink subframe. The downlink subframe generated in the downlink subframe generation section 2501 is modulated to an OFDM signal in the OFDM signal transmission section 2504, and is transmitted via the transmission antenna 2505.

In the terminal device, the OFDM signal receive section 2602 receives the OFDM signal via the receiving antenna 2601 and carries out OFDM demodulation with respect to the OFDM signal. The downlink subframe process section 2603 extracts receive data from a received downlink subframe, and transmits the receive data to the higher layer 2606. More specifically, demodulation, rate matching and error correction decoding corresponding to the modulation, rate matching and error correction coding carried out in the downlink subframe generation section 2501, respectively, etc., are carried out with respect to the OFDM signal. The downlink reference signal extraction section 2604 extracts the DLRS which has been generated in the downlink reference signal generation section 2503 and mapped in the downlink subframe generation section 2501, and transmits the DLRS to the feedback information generation section 2607. The physical downlink control channel extraction section 2605 extracts the control information included in the physical downlink control channel which is generated in the physical downlink control channel generation section 2502 and is mapped in the downlink subframe generation section 2501, and transmits

the control information to the higher layer 2606.

Note here that the processes carried out by the downlink subframe generation section 2501, the OFDM signal transmission section 2504 and the transmission antenna 2505 of the base station device, and the processes carried out by the receiving antenna 2601, the OFDM signal receive section 2602 and the downlink subframe process section 2603 of the terminal device, are carried out for each downlink cell. Further, the feedback information generation section 2607 generates pieces of receiving quality information (feedback information) in a plurality of downlink cells.

The following description discusses, with reference to Figs. 5 and 6, how transmission and reception over an uplink are carried out. In the terminal device, the codeword generation section 2608 carries out processes such as error correction coding and rate matching with respect to transmission data (also referred to as a transport block) in each codeword transmitted from the higher layer 2606, thereby converting the transmission data into a codeword CW. In accordance with instructions from the higher layer 2606, the feedback information generation section 2607 converts RI, PI1, PI2, CQI etc. into codes with use of the DLRS extracted by the downlink reference signal extraction section 2604, thereby generating feedback information. The uplink reference signal generation section 2610 generates an uplink reference

signal ULRS. The uplink subframe generation section 2609 rearranges a codeword modulation symbol sequence and the feedback information in a predetermined manner, and thereafter maps them to an uplink subframe together with the uplink reference signal. The SC-FDMA signal transmission section 2611 carries out SC-FDMA modulation with respect to the uplink subframe to generate an SC-FDMA signal, and transmits the SC-FDMA signal via the transmission antenna 2612.

In the base station, the SC-FDMA signal receive section 2507 receives the SC-FDMA signal via the receiving antenna 2506, and carries out SC-FDMA demodulation with respect to the SC-FDMA signal. The filter section 2508 extracts a codeword from a received uplink subframe and transmits the codeword to the codeword process section 2510. The codeword process section extracts receive data from the codeword and transmits the receive data to the higher layer 2511. More specifically, rate matching and error correction decoding corresponding to the rate matching and the error correction coding carried out in the codeword generation section 2608, respectively, etc., are carried out to extract the receive data. In accordance with instructions from the higher layer, the feedback information extraction section 2509 in the filter section 2508 extracts and decodes the feedback information which has been generated in the feedback information

generation section 2607 and mapped in the uplink subframe generation section 2609, and transmits this feedback information to the higher layer 2511. Note here that the filtering, which is carried out by the filter section 2508 with respect to a signal received via each receive antenna 2506, uses a method such as ZF (Zero Forcing), MMSE (Minimum Mean Square Error), MLD (Maximum Likelihood Detection) or the like to detect a signal for each codeword.

Here, the feedback information generation section 2607 of the terminal device generates pieces of receiving quality information (feedback information) in a plurality of downlink cells. Further, the feedback information extraction section 2509 of the base station device extracts pieces of receiving quality information (feedback information) in a plurality of downlink cells.

Figure 26 illustrates an example of a procedure in a periodic feedback mode in accordance with the present embodiment. The procedure shown in Figure 26 is an example of a procedure in a periodic feedback mode (first feedback mode) in which RI, PI1, PI2 and W-CQI (Wideband CQI) in a single cell are fed back periodically. Note that the W-CQI is CQI which represents a system bandwidth (component carrier bandwidth). Further, note that the feedback mode as used herein includes setting of a combination of content of receiving quality information to be fed back from the terminal

device to the base station, a method of measuring or generating each content, and a method of feedback of each content or a resource to be used for feedback etc. First, the base station sets a parameter for feedback in the terminal device and indicates the first feedback mode via RRC signaling (step S701). Upon receiving instructions of periodic feedback, the terminal device reports periodically RI and PI1 (step S702) and reports periodically PI2 and W-CQI (step S703) to the base station device via a physical uplink control channel in accordance with the set feedback parameter. Hereinafter, the report in step S702 is referred to as a feedback type 1A and the report in step S703 is referred to as a feedback type 1B.

Figure 27 illustrates another example of a procedure in a periodic feedback mode in accordance with the present embodiment. The procedure shown in Figure 27 is an example of a procedure in a periodic feedback mode (second feedback mode) in which RI, PTI (Precoder Type Indication), PI1, PI2, W-CQI and S-CQI (Subband-CQI) in a single cell are fed back periodically. In a case of a feedback mode which periodically feedbacks S-CQI (Subband-CQI), the S-CQI is further reported periodically. Note here that the S-CQI is CQI which represents a band BP (Bandwidth Part) which is one of a plurality of narrow bands into which a system bandwidth (component carrier bandwidth) is divided. More specifically, the S-CQI is

CQI on one of one or more subband(s) (bandwidths into which BP is subdivided) included in the BP. Further, as described later, the PTI is an index for switching between contents that are to be fed back. First, the base station sets a parameter for feedback in the terminal device and indicates the second feedback mode via RRC signaling (step S801). Upon receiving instructions of periodic feedback, the terminal device reports periodically RI and PTI (step S802) to the base station device via a physical uplink control channel in accordance with the set feedback parameter. In a case where the PTI reported in step S802 is indicative of a precoder type such as those for reporting PI2 for each subband, the terminal device reports periodically PI1 and W-CQI (step S803) and reports periodically PI2 and S-CQI (step S804) to the base station device via a physical uplink control channel in accordance with the set feedback parameter. Note here that the PI2 is PI2 calculated in a subband corresponding to the S-CQI to be transmitted simultaneously with the PI2. On the other hand, in a case where the PTI reported in step S802 is indicative of a precoder type such as those for reporting PI2 in a system waveband (component carrier waveband), the terminal device reports periodically PI2 and W-CQI (step S805) and reports periodically S-CQI (step S806) to the base station device via a physical uplink control channel in accordance with the set feedback parameter. Note here that, in this case, the terminal

device does not report PI1, and uses a codebook such as those for specifying a preferred precoder only with PI2. Hereinafter, the report in step S802 is referred to as a feedback type 2A, the report in step S803 is referred to as a feedback type 2B, the report in step S804 is referred to as a feedback type 2C, the report in step S805 is referred to as a feedback type 2D, and the report in step S806 is referred to as a feedback type 2E. Note that the feedback type 2D may be the same report as the feedback type 1B. Further, the feedback type 2D is the one for which methods of calculating PI2 and W-CQI etc. can be each individually set.

Figure 28 illustrates a further example of a procedure in a periodic feedback mode in accordance with the present embodiment. The procedure shown in Figure 28 is an example of a procedure in a periodic feedback mode (third feedback mode) in which RI, PI1, PI2, W-CQI and S-CQI in a single cell are fed back periodically. First, the base station sets a parameter for feedback in the terminal device and indicates the third feedback mode via RRC signaling (step S901). Upon receiving instructions of periodic feedback, the terminal device reports periodically RI (step S902) to the base station device via a physical uplink control channel in accordance with the set feedback parameter. Next, the terminal device reports periodically PI1, PI2 and W-CQI (step S903) and reports periodically S-CQI (step S904) to the base station

device via a physical uplink control channel in accordance with the set feedback parameter. Hereinafter, the report in step S902 is referred to as a feedback type 3A, the report in step S903 is referred to as a feedback type 3B, and the report in step S904 is referred to as a feedback type 3C. Note that the feedback type 3C may be the same report as the feedback type 2E. Further, the feedback type 3C is the one for which a method of calculating S-CQI can be each individually set.

Figure 29 illustrates an example of a procedure in accordance with the present embodiment. The procedure shown in Figure 29 is an example of a procedure in an aperiodic feedback mode (fourth feedback mode) in which RI, PI1, PI2 and W-CQI are fed back aperiodically. First, the base station sets a parameter for feedback in the terminal device via RRC signaling (step S1001). Next, the base station notifies the terminal device of a CQI request, which is information indicating aperiodic feedback (step S1002). Further, the base station allocates a resource (e.g., physical uplink shared channel) via which pieces of feedback information are reported simultaneously. Upon receiving instructions of the aperiodic feedback, the terminal device simultaneously (at the same time) reports RI, PI1, PI2 and W-CQI to the base station device in accordance with the set feedback parameter (step S1003). In a case of an aperiodic feedback mode which feedbacks S-CQI, the S-CQI is further reported

simultaneously. Here, the terminal device simultaneously reports S-CQIs in a plurality of band BPs. It should be noted that, although the description here discusses an example in which the notification of the CQI request in the terminal device (step S1002) is carried out through dynamic signaling via a physical downlink control channel, this does not imply any limitation. For example, it is possible to achieve the same effect by giving instructions of aperiodic feedback through semi-static signaling via RRC signaling. In such a case, it is preferable to further specify a subframe to be reported.

In the periodic feedback mode, the report of any of feedback information (step S702, step S703, step S802, step S803, step S804, step S805, step S806, step S902, step S903, or step S904) is carried out via a physical uplink control channel, which is a channel which usually reports control information in a physical layer. However, in a case where a physical uplink shared channel, which is a channel which transmits data in a physical layer, is allocated at a time when the report of any of those feedback information is carried out, the feedback information is reported via a physical uplink shared channel. Note that operation of reporting the control information in a physical layer via a physical uplink shared channel is called piggyback.

In the aperiodic feedback mode, usually, the CQI request in step S1002 is included in an uplink grant, which is

downlink control information specifying allocation of a physical uplink shared channel (triggering transmission of a physical uplink shared channel). Further, part of a physical uplink shared channel allocated is used to report the feedback information in step S1003.

It is sometimes the case that pieces of feedback information in a plurality of downlink CCs are reported via a single physical uplink shared channel. An example of such a case is the case where a physical uplink shared channel to be transmitted at the same time as the report of feedback information (step S702, step S703, step S802, step S803, step S804, step S805, step S806, step S902, step S903, or step S904) in a periodic feedback mode in a single cell is triggered by an uplink grant including a CQI request of S1002 in another single cell. In other words, an example of the above case is the case where report of any of the feedback information in a periodic feedback mode in Cell#0 coincides with report of feedback information in an aperiodic feedback mode in Cell#1.

Another example of the foregoing case is the case where the physical uplink shared channel is triggered by an uplink grant including CQI requests in S1002 in a plurality of cells. In other words, another example of the foregoing case is the case where report of any of those feedback information in an aperiodic feedback mode in Cell#0 coincides with report of

feedback information in an aperiodic feedback mode in Cell#1.

The following description discusses an example of processes of generating and extracting feedback information (receiving quality information) in a plurality of cells. Figure 30 is a view illustrating an example of an inside block configuration of the feedback information generation section 2607 for reporting pieces of feedback information in a plurality of cells on a single physical channel. The feedback information generation section 2607 includes a concatenating section 3101 and a coding section (feedback information coding section) 3102.

The concatenating section 3101 concatenates serially a bit sequence which represents receiving quality information (feedback information) for Cell#0 and a bit sequence which represents receiving quality information (feedback information) for Cell#1. The coding section 3102 carries out error correction coding with respect to a bit sequence thus concatenated in the concatenating section 3101.

Figure 31 is a view illustrating an example of an inside block configuration of the feedback information extraction section 2509 for reporting pieces of feedback information in a plurality of cells on a single physical channel. The feedback information extraction section 2509 includes a decoding section (feedback information decoding section) 3201 and a separating section 3202.

The decoding section 3201 carries out decoding corresponding to the error correction coding carried out in the coding section 3102. The separating section 3202 carries out a process that is opposite to the concatenating process carried out in the concatenating section 3101. That is, the separating section 3202 separates a decoded bit sequence into a bit sequence which represents the receiving quality information (feedback information) for Cell#0 and a bit sequence which represents the receiving quality information (feedback information) for Cell#1.

This increases the number of input bits dealt with in a single coding process. Accordingly, significant coding benefits can be achieved.

The following description discusses another example of processes of generating and extracting pieces of feedback information (receiving quality information) on a plurality of cells. Figure 32 is a view illustrating another example of an inside block configuration of the feedback information generation section 2607 for reporting pieces of feedback information in a plurality of cells on a single physical channel. The feedback information generation section 2607 includes coding sections 3301 and 3302 and a concatenating section 3303.

The coding sections 3301 and 3302 carry out error correction coding with respect to a bit sequence which

represents receiving quality information (feedback information) for Cell#0 and a bit sequence which represents receiving quality information for Cell#1, respectively. It is preferable that the coding section 3301 and the coding section 3302 share a circuit. The concatenating section 3303 concatenates serially a coded bit sequence obtained by coding the bit sequence which represents the receiving quality information (feedback information) for Cell#0 and a coded bit sequence obtained by coding the bit sequence which represents the receiving quality information (feedback information) for Cell#1.

Figure 33 is a view illustrating another example of an inside block configuration of the feedback information extraction section 2509 for reporting pieces of feedback information in a plurality of cells on a single physical channel. The feedback information extraction section 2509 includes a separating section 3401 and decoding sections 3402 and 3403.

The separating section 3401 carries out a process opposite to the concatenating process carried out in the concatenating section 3303. That is, the separating section 3401 separates the coded bit sequence which represents the receiving quality information (feedback information) for Cell#0 and the coded bit sequence which represents the receiving quality information (feedback information) for Cell#1. The decoding sections 3402 and 3403 carry out decoding

processes corresponding to the error correction coding processes carried out in the respective coding sections 3301 and 3302. It is preferable that the decoding section 3402 and the decoding section 3403 share a circuit.

The following description discusses mapping of feedback information which has been subjected to coding and concatenating. Figure 34 illustrates an example of mapping of feedback information. The rearrangement and mapping shown in Figure 34 are examples for the case where a plurality of CWs (CW0 and CW1) are transmitted on an uplink. The explanation here is made on the assumption that CW0 and CW1 are transmitted using a layer 1 and a layer 2, respectively. Note here that a layer is an index for spatial multiplexing, and the number of layer(s) is indicative of the number of spatial multiplexing. ULRS is mapped to the fourth and eleventh SC-FDMA symbols in each layer. The feedback information including RI or PTI and the other feedback information (e.g., feedback information including CQI or PI2) are each rearranged as shown in Figure 34. Needless to say, the parameters here are examples, and other parameters can be used alternatively. For example, in a case of transmitting only CW0, it is only necessary to carry out mapping in the same way as in the layer 1 of Figure 34.

More specifically, feedback information including CQI or PI2 is first concatenated with the CW0. Here, the feedback

information including CQI or PI2 and the CW0 are concatenated so that they are arranged in the order named. After that, this concatenated symbol sequence is rearranged from its top so as to be mapped to the SC-FDMA symbols sequentially from the foremost portion of each SC-FDMA symbol on a layer which transmits the CW0, in order of for example the foremost portion of the first SC-FDMA symbol in the layer 1, the foremost portion of the second SC-FDMA symbol in the layer 1, ... , the foremost portion of the fourteenth SC-FDMA symbol in the layer 1, the second foremost portion of the first SC-FDMA symbol in the layer 1, and so on. On the other hand, the CW1 is rearranged from its top so as to be mapped to the SC-FDMA symbols sequentially from the foremost portion of each SC-FDMA symbol on a layer which transmits the CW1, in order of for example the foremost portion of the first SC-FDMA symbol in the layer 2, the foremost portion of the second SC-FDMA symbol in the layer 2, ..., the foremost portion of the fourteenth SC-FDMA symbol in the layer 2, the second foremost portion of the first SC-FDMA symbol in the layer 2, and so on. Feedback information including RI or PTI is rearranged so as to be mapped to part or all (e.g., as shown in Figure 34, back portion of each of the second, sixth, ninth, and thirteenth SC-FDMA symbols in each of the layers 1 and 2) of SC-FDMA symbols near ULRS in each layer. That is, RI and PI2, or RI

and CQI, are transmitted (reported) with the different numbers of spatial multiplexing.

These rearrangement and mapping are carried out in the uplink subframe generation section 2609 in accordance with instructions from the higher layer 2606. On the other hand, the feedback information extraction section 2509 in the base station device carries out, in accordance with instructions from the higher layer 513, demapping corresponding to mapping carried out in the uplink subframe generation section 2609 and rearrangement for restoring the state that is before the arrangement carried out in the uplink subframe generation section 2609, thereby obtaining feedback information.

Note here that the feedback information including RI or PTI is feedback information obtained by carrying out concatenating and coding as shown in Figure 30 or Figure 32 with respect to (i) feedback information in the feedback type 1A, feedback type 2A or feedback type 3A in a single cell and RI in an aperiodic feedback mode in another single cell or (ii) RI in an aperiodic feedback mode in a single cell and RI in an aperiodic feedback mode in another single cell. Further, the feedback information including PI2 or CQI is feedback information obtained by carrying out concatenating and coding as shown in Figure 30 or Figure 32 with respect to (a) feedback information in the feedback type 1B, feedback type

2B, feedback type 2C, feedback type 2D, feedback type 2E, feedback type 3B or feedback type 3C in a single cell and PI1, PI2 or CQI in an aperiodic feedback mode in another single cell or (b) PI1, PI2 or CQI in an aperiodic feedback mode in a single cell and PI1, PI2 or CQI in an aperiodic feedback mode in another single cell. That is, concatenating and coding are carried out with respect to feedback information including RI, and carried out separately with respect to other feedback information. This makes it possible to carry out coding processes suitable for respective pieces of feedback information targeting different quality levels.

This makes it possible to improve accuracy of detection of highly important information such as RI and RTI, and thus possible to improve receive quality. Further, it is possible to improve effect of interleaving large-volume information such as PI2 and CQI (effect of reducing burst error due to rearrangement), and thus possible to improve receive quality.

This makes it possible to carry out coding for each cell. Accordingly, it is possible to prevent a so-called burst error such as simultaneous errors in pieces of feedback information in a plurality of cells.

The following description discusses the order of concatenation in the concatenating section 3101 or the concatenating section 3303. The order of concatenation in accordance with the present embodiment is the order

determined in such a way as to correspond to cells. This order is uniquely determined with use of for example the following information.

(1) Frequency of downlink CC corresponding to a cell

(2) Cell identifier (cell index, CC index)

(3) Whether a cell is a cell (PCell) which is subject to monitoring of broadcast information by a terminal device or a cell (SCell) other than PCell

(4) Priority configured beforehand with respect to each cell by signaling such as RRC signaling in a higher layer (e.g., the same priority as a priority that determines which cell's feedback information is to be transmitted when reports of feedback information in a periodic feedback mode in a plurality of cells coincide with each other)

Note that the order of cells can be specific to a base station device, thereby difficulty of scheduling can be reduced. Alternatively, the order of cells can be specific to a terminal device, thereby scheduling with a high degree of freedom can be achieved.

As described above, the order is configured with respect to a plurality of cells beforehand and, in a case where reports of pieces of feedback information in a plurality of cells overlap in time, the terminal device concatenates the pieces of feedback information in the configured order and reports it to the base station device. This makes it possible to eliminate

ambiguity of the order in which pieces of feedback information are concatenated in the base station device and the terminal device, and thus possible to efficiently report and extract receiving quality information.

It should be noted that, although the foregoing descriptions discussed the case where PI1 is reported in each feedback mode, this does not imply any limitation. For example, PI1 may not be reported in a case where the number of transmission antennas of the base station device is small. If this is the case, a codebook such as that uniquely determined only from PI2 may be used in a preferred precoder. Further, the feedback type including PI1 may be the feedback type that reports content other than the PI1.

Embodiment 2-2

Embodiment 2-1 discussed the case where the order is configured beforehand with respect to a plurality of cells. Embodiment 2-2 of the present invention discusses the case where the order is configured beforehand with respect to types of feedback information. Note that present embodiment and Embodiment 2-1 are different from each other in terms of the order of concatenation in the concatenating section 3101 and the separating section 3202 or in the concatenating section 3303 and the separating section 3401. The other processes and effects are the same between the present

embodiment and Embodiment 2-1.

The order of concatenation in accordance with the present embodiment is the order determined in such a way as to correspond to types of feedback information. This order is determined uniquely with use of for example the following information.

(1) Whether feedback information is the feedback information in a periodic feedback mode or the feedback information in an aperiodic feedback mode

(2) Feedback mode index (e.g., first feedback mode, second feedback mode)

(3) Whether feedback information includes predetermined content (e.g., PTI, W-CQI, PI1)

(4) Priority given to feedback type

As described above, the order is configured with respect to types of plural pieces of feedback information beforehand and, in a case where reports of pieces of feedback information in a plurality of cells overlap in time, the terminal device concatenates the pieces of feedback information in the configured order and reports it to the base station device. This makes it possible to eliminate ambiguity of the order in which pieces of feedback information are concatenated in the base station device and the terminal device, and thus possible to efficiently report and extract receiving quality information.

Note here that, although Example 1 and Example 2

discussed the respective different methods of order specification, the order can be specified based on a combination of both of these methods. For example, the order can be specified by (i) first, determining an order according to types of feedback information and (ii) if the types of feedback information are the same, determining an order according to the order of cells.

Further, although the foregoing embodiments discussed the case where pieces of receiving quality information in a plurality of cells corresponding to different component carriers are reported, this does not imply any limitation. The present invention is applicable also to a plurality of cells specified in some other way (e.g., specified based on transmission point). Furthermore, although the foregoing embodiments discussed the case where receiving quality information is reported on a single uplink, this does not imply any limitation. The present invention is applicable even to a case where receiving quality information is reported on two or more uplinks, by focusing on one of these uplinks.

Moreover, although the foregoing embodiments discussed the case where pieces of receiving quality information in two cells are reported, this does not imply any limitation. The present invention is applicable also to three or more cells. If this is the case, the number of pieces of feedback information that are concatenated in the concatenating section and the

number of pieces of feedback information separated in the separating section may be increased.

Note that a process in each section can be accomplished by recording a program for achieving a function of all or part of the base station device or a function of all or part of the terminal device onto a computer-readable storage medium and causing a computer system to read and execute the program recorded on the storage medium. As used herein, the "computer system" includes OS and hardware such as peripheral devices.

Further, in a case where a WWW system is used, the "computer system" includes also an environment which provides homepages (or an environment which displays homepages).

Further, the "computer-readable storage medium" refers to a storage device such as a transportable medium inducing a flexible disc, magneto-optical disk, ROM or CD-ROM etc., or hard disk provided within a computer system. The "computer-readable storage medium" further includes those dynamically retain a program for a short period of time, such as a communication line (e.g., Internet network or telephone line) which transmits a program, and those retain a program for a predetermined period of time, such as a volatile memory in a computer system which memory serves as a server or client in the above case. Moreover, the program can be the one for

achieving part of the foregoing function or can be the one that can operate in combination with a program already recorded on a computer system to achieve the foregoing function.

Moreover, a function of all or part of the base station device and a function of all or part of the terminal device may be achieved by an integrated circuit. Each functional block of the base station device and the terminal device may be individually provided on a chip, or part or all of the functional blocks may be integrated and provided on a chip. The integrated circuit is not limited to LSI, and may be a dedicated circuit or a general-purpose processor. Furthermore, in a case where a technique of making an integrated circuit alternative to the LSI becomes available as the semiconductor technology develops, such a technique can be used to make an integrated circuit.

The foregoing descriptions discussed the embodiments of the present invention with reference to the drawings. A specific configuration of the present invention is not limited to those described in the embodiments, and a design modification within the gist of the present invention is also encompassed in the present invention. Further, the present invention may be altered within the scope of the claims. An embodiment based on a proper combination of technical means disclosed in different embodiments is encompassed in the technical scope of the present invention. Furthermore, the

present invention encompasses also a configuration in which constituents described in the foregoing embodiments and bring about the same effect are substituted with each other.

The present invention can also be expressed as below.

(1) The present invention has been made to attain the above object. In one aspect of the present invention, a terminal device is a terminal device for communicating with a base station device, including: means for generating pieces of receiving quality information in respective communication bands; means for concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and means for reporting, to the base station device, the pieces of receiving quality information thus concatenated.

(2) Further, in one aspect of the present invention, a terminal device is the terminal device configured such that priorities configured with respect to the communication bands are obtained and the order is configured according to the priories.

(3) Further, in one aspect of the present invention, a terminal device is a terminal device for communicating with a base station device, including: means for generating plural types of receiving quality information in respective

communication bands; means for concatenating the plural types of receiving quality information in the respective communication bands according to an order configured with respect to the plural types of receiving quality information; and means for reporting, to the base station device, the plural types of receiving quality information thus concatenated.

(4) Further, in one aspect of the present invention, a terminal device is the terminal device configured such that the plural types of receiving quality information include receiving quality information in a periodic feedback mode and receiving quality information in an aperiodic feedback mode.

(5) Further, in one aspect of the present invention, a base station device is a base station device for communicating with a terminal device, including: means for obtaining concatenated pieces of receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device; and means for separating the concatenated pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands.

(6) Further, in one aspect of the present invention, a base station device is the base station device configured such that priorities are configured with respect to the communication bands and the order is configured according to the priorities.

(7) Further, in one aspect of the present invention, a base station device is a base station device for communicating with a terminal device, including: means for obtaining concatenated plural types of receiving quality information in respective communication bands, the concatenated plural types of receiving quality information having been concatenated by the terminal device; and means for separating the concatenated plural types of receiving quality information in the respective communication bands according to an order configured with respect to the plural types of receiving quality information.

(8) Further, in one aspect of the present invention, a base station device is the base station device configured such that the plural types of receiving quality information include receiving quality information in a periodic feedback mode and receiving quality information in an aperiodic feedback mode.

(9) Further, in one aspect of the present invention, a communication system is a communication system including a base station device and a terminal device which are for

communicating with each other, the terminal device generating pieces of receiving quality information in respective communication bands, concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands, and reporting concatenated pieces of receiving quality information to the base station device, the base station device obtaining the concatenated pieces of receiving quality information in the respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device, and separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

(10) Further, in one aspect of the present invention, a communication method is a communication method for use in a terminal device for communicating with a base station device, said method including the steps of: generating pieces of receiving quality information in respective communication bands; concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and reporting, to the base station

device, the pieces of receiving quality information thus concatenated.

(11) Further, in one aspect of the present invention, a communication method is a communication method for use in a base station device for communicating with a terminal device, said method including the steps of: obtaining concatenated pieces of receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device; and separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

The present invention can be expressed as below. That is, the present invention provides a terminal device, a base station device, a communication system and a communication method each of which is capable of efficiently reporting receiving quality information during communication using a plurality of carrier waves.

To this end, in a communication system including a base station device and a terminal device which are for communicating with each other, the terminal device generates pieces of receiving quality information in respective communication bands, concatenates the pieces of

receiving quality information in the respective communication bands according to an order configured with respect to the communication bands, and reports concatenated pieces of receiving quality information to the base station device, and the base station device obtains the concatenated pieces of receiving quality information in the respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device, and separates the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

(INDUSTRIAL APPLICABILITY)

The present invention is suitable for use in a radio base station device, a radio terminal device, a radio communication system or a radio communication method.

(REFERENCE SIGNS LIST)

2201, 3601 Base station device

2202, 3602 Terminal device

2203, 3603 Downlink transmission signal

2204, 3604 Feedback information

2501 Downlink subframe generation section

2502 Physical downlink control channel generation section

2503 Downlink reference signal generation section

2504 OFDM signal transmission section

2505 Transmission antenna

2506 Receiving antenna

2507 SC-FDMA signal receive section

2508 Filter section

2509 Feedback information extraction section

2510 Codeword process section

2511 Higher layer

2601 Receiving antenna

2602 OFDM signal receive section

2603 Downlink subframe process section

2604 Downlink reference signal extraction section

2605 Physical downlink control channel extraction section

2606 Higher layer

2607 Feedback information generation section

2608 Codeword generation section

2609 Uplink subframe generation section

2610 Uplink reference signal generation section

2611 SC-FDMA signal transmission section

2612 Transmission antenna

3101, 3303 Concatenating section

3102, 3301, 3202 Coding section

3201, 3402, 3403 Decoding section

3202, 3401 Separating section

CLAIMS

1. A method for reporting uplink control information (UCI) by a user equipment (UE), comprising:

determining that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH);

generating an aggregated CSI report using two or more of the multiple CSI reports; and

transmitting the aggregated CSI report on the PUSCH.

2. The method of claim 1, wherein the multiple CSI reports comprise multiple periodic CSI reports.

3. The method of claim 2, wherein generating an aggregated CSI report comprises concatenating the multiple periodic CSI reports with component carrier (CC) ordering for each type of CSI report, and wherein transmitting the aggregated CSI report on the PUSCH comprises multiplexing multiple aggregated CSI reports on the PUSCH as one composite CSI block.

4. The method of claim 1, further comprising receiving a trigger from an eNode B to generate an aperiodic CSI report, wherein the multiple CSI reports comprise multiple aperiodic CSI reports.

5. The method of claim 4, further comprising generating multiple component carrier (CC) specific aperiodic CSI reports, wherein generating an aggregated CSI report comprises concatenating the multiple CC specific aperiodic CSI reports, and wherein transmitting the aggregated CSI report on the PUSCH comprises multiplexing the aggregated aperiodic CSI report on the PUSCH.

6. The method of claim 5, wherein the aggregated CSI report comprises an aggregated channel quality indicator (CQI) and/or precoding matrix indicator (PMI) and aggregated rank information (RI).

7. The method of claim 1, further comprising receiving a trigger from an eNode B to generate an instance of aperiodic CSI report, wherein the multiple CSI reports comprise the instance of aperiodic CSI report and one or more periodic CSI reports.

8. The method of claim 7, wherein it is determined that multiple CSI reports on the PUSCH is supported, and wherein the aggregated CSI report is generated using both the instance of aperiodic CSI report and the one or more periodic CSI reports.

9. The method of claim 7, wherein it is determined that multiple CSI reports on the PUSCH is not supported, and wherein the aggregated CSI report is generated using only the instance of aperiodic CSI report on the PUSCH.

10. The method of claim 7, wherein it is determined that multiple CSI reports on the PUSCH is supported, and further comprising determining whether the aperiodic CSI report is for all configured/activated component carriers (CCs).

11. The method of claim 10, wherein it is determined that the aperiodic CSI report is for all configured/activated CCs, and wherein the aggregated CSI report is generated using only the instance of aperiodic CSI report.

12. The method of claim 10, wherein it is determined that the aperiodic CSI report is not for all configured/activated CCs, and wherein the aggregated CSI report comprises the instance of aperiodic CSI report and one or more periodic CSI reports.

13. The method of claim 12, wherein the one or more periodic CSI reports correspond to CCs that are not in

included in the instance of aperiodic CSI report.

14. The method of 12, wherein the aggregated CSI report is generated using an aperiodic CSI process to encode the instance of aperiodic CSI report and a periodic CSI process to encode the one or more periodic CSI reports.

15. The method of claim 1, further comprising receiving a trigger from an eNode B to generate an instance of aperiodic CSI report, wherein the aggregated CSI report comprises an extended aperiodic CSI report, and wherein the extended aperiodic CSI report comprises elements of the instance of aperiodic CSI report and CSI of component carriers that were not represented in the instance of aperiodic CSI report.

16. The method of claim 1, wherein the UE is configured for simultaneous physical uplink control channel (PUCCH) and PUSCH transmissions.

17. A user equipment (UE) configured for reporting uplink control information (UCI), comprising:

a processor;

memory in electronic communication with the processor;

instructions stored in the memory, the instructions being executable to:

determine that multiple channel state information (CSI) reports are scheduled on a physical uplink shared channel (PUSCH);

generate an aggregated CSI report using two or more of the multiple CSI reports; and

transmit the aggregated CSI report on the PUSCH.

18. The UE of claim 17, wherein the multiple CSI reports comprise multiple periodic CSI reports.

19. The UE of claim 18, wherein the instructions executable to generate an aggregated CSI report comprise instructions executable to concatenate the multiple periodic CSI reports with component carrier (CC) ordering for each type of CSI report, and wherein the instructions executable to transmit the aggregated CSI report on the PUSCH comprise instructions executable to multiplex multiple aggregated CSI reports on the PUSCH as one composite CSI block.

20. The UE of claim 17, wherein the instructions are further executable to receive a trigger from an eNode B to generate an aperiodic CSI report, wherein the multiple CSI reports comprise multiple aperiodic CSI reports.

21. The UE of claim 20, wherein the instructions are

further executable to generate multiple component carrier (CC) specific aperiodic CSI reports, wherein the instructions executable to generate an aggregated CSI report comprise instructions executable to concatenate the multiple CC specific aperiodic CSI reports, and wherein the instructions executable to transmit the aggregated CSI report on the PUSCH comprise instructions executable to multiplex the aggregated aperiodic CSI report on the PUSCH.

22. The UE of claim 21, wherein the aggregated CSI report comprises an aggregated channel quality indicator (CQI) and/or precoding matrix indicator (PMI) and aggregated rank information (RI).

23. The UE of claim 17, wherein the instructions are further executable to receive a trigger from an eNode B to generate an instance of aperiodic CSI report, wherein the multiple CSI reports comprise the instance of aperiodic CSI report and one or more periodic CSI reports.

24. The UE of claim 23, wherein it is determined that multiple CSI reports on the PUSCH is supported, and wherein the aggregated CSI report is generated using both the instance of aperiodic CSI report and the one or more periodic CSI reports.

25. The UE of claim 23, wherein it is determined that multiple CSI reports on the PUSCH is not supported, and wherein the aggregated CSI report is generated using only the instance of aperiodic CSI report on the PUSCH.

26. The UE of claim 23, wherein it is determined that multiple CSI reports on the PUSCH is supported, and wherein the instructions are further executable to determine whether the aperiodic CSI report is for all configured/activated component carriers (CCs).

27. The UE of claim 26, wherein it is determined that the aperiodic CSI report is for all configured/activated CCs, and wherein the aggregated CSI report is generated using only the instance of aperiodic CSI report.

28. The UE of claim 26, wherein it is determined that the aperiodic CSI report is not for all configured/activated CCs, and wherein the aggregated CSI report comprises the instance of aperiodic CSI report and one or more periodic CSI reports.

29. The UE of claim 28, wherein the one or more periodic CSI reports correspond to CCs that are not in

included in the instance of aperiodic CSI report.

30. The UE of 28, wherein the aggregated CSI report is generated using an aperiodic CSI process to encode the instance of aperiodic CSI report and a periodic CSI process to encode the one or more periodic CSI reports.

31. The UE of claim 17, wherein the instructions are further executable to receive a trigger from an eNode B to generate an instance of aperiodic CSI report, wherein the aggregated CSI report comprises an extended aperiodic CSI report, and wherein the extended aperiodic CSI report comprises elements of the instance of aperiodic CSI report and CSI of component carriers (CC) that were not represented in the instance of aperiodic CSI report.

32. The UE of claim 17, wherein the UE is configured for simultaneous physical uplink control channel (PUCCH) and PUSCH transmissions.

33. A terminal device for communicating with a base station device, comprising:

means for generating pieces of receiving quality information in respective communication bands;

means for concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and

means for reporting, to the base station device, the pieces of receiving quality information thus concatenated.

34. A base station device for communicating with a terminal device, comprising:

means for obtaining concatenated pieces of receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device; and

means for separating the concatenated pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands.

35. A communication system comprising a base station device and a terminal device which are for communicating with each other,

the terminal device

generating pieces of receiving quality information in respective communication bands,

concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands, and

reporting concatenated pieces of receiving quality information to the base station device, and

the base station device

obtaining the concatenated pieces of receiving quality information in the respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device, and

separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

36. A communication method for use in a terminal device for communicating with a base station device, said method comprising the steps of:

generating pieces of receiving quality information in respective communication bands;

concatenating the pieces of receiving quality information in the respective communication bands according to an order configured with respect to the communication bands; and

reporting, to the base station device, the pieces of receiving quality information thus concatenated.

37. A communication method for use in a base station device for communicating with a terminal device, said method comprising the steps of:

obtaining concatenated pieces of receiving quality information in respective communication bands, the concatenated pieces of receiving quality information having been concatenated by the terminal device; and

separating the concatenated pieces of receiving quality information in the respective communication bands according to the order configured with respect to the communication bands.

FIG. 1

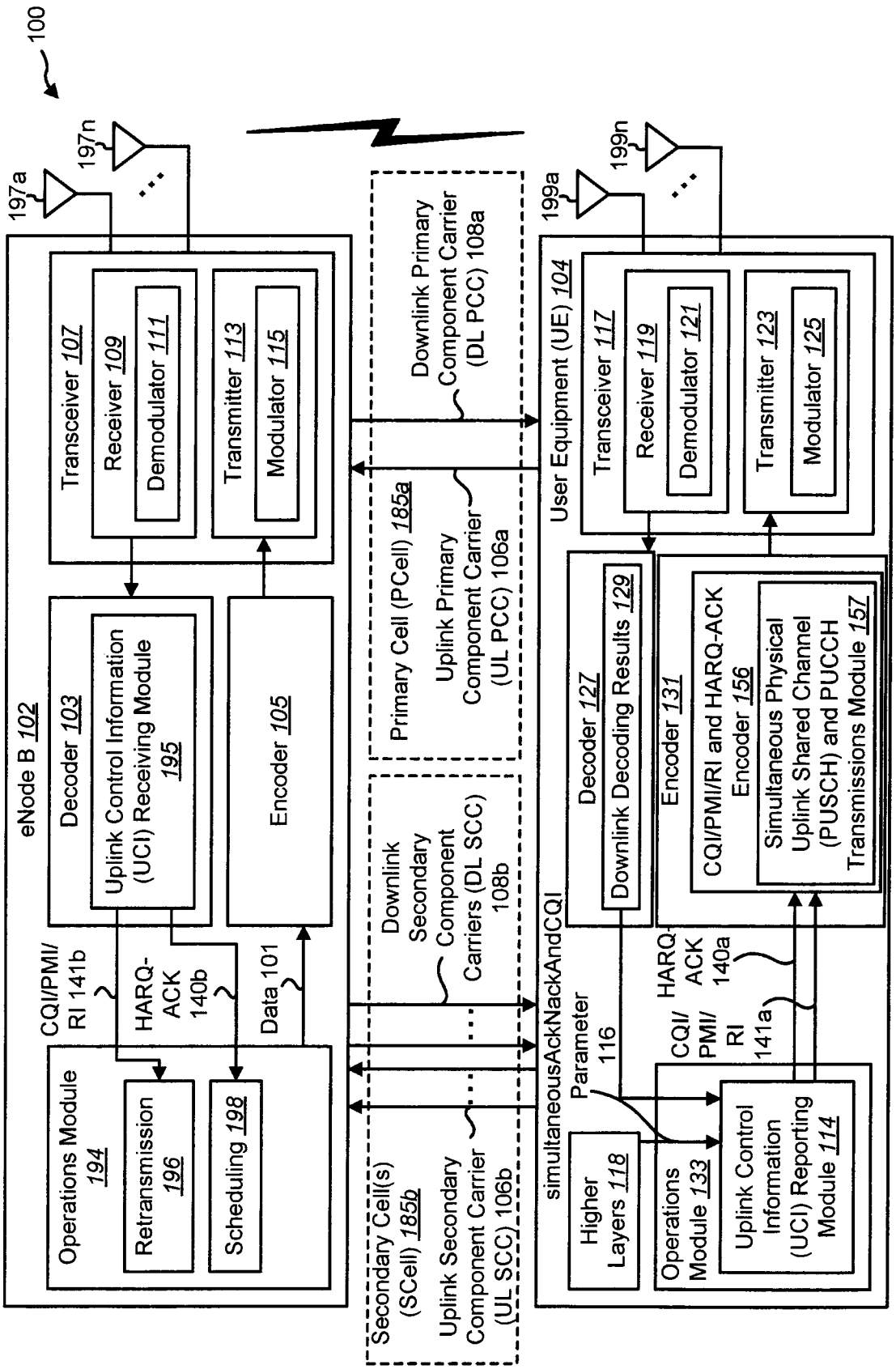
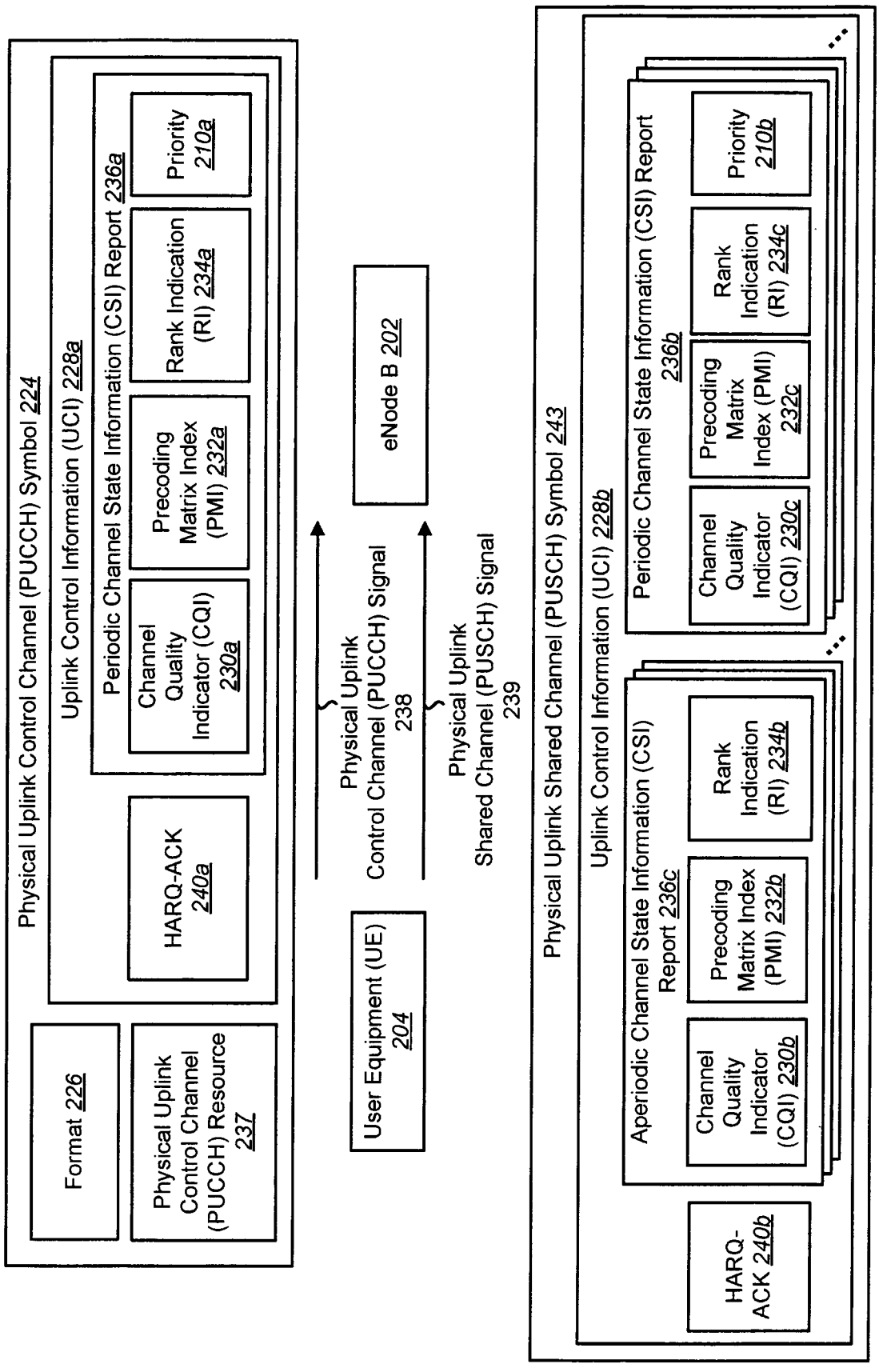

100
197a
197n
199a
199n
eNode B 102
Transceiver 107
Receiver 109
Demodulator 111
Transmitter 113
Modulator 115
Decoder 103
Uplink Control Information (UCI) Receiving Module 195
Encoder 105
Operations Module 194
Retransmission 196
Scheduling 198
CQI/PMI/RI 141b
HARQ-ACK 140b
Data 101
Downlink Primary Component Carrier (DL PCC) 108a
Primary Cell (PCell) 185a
Uplink Primary Component Carrier (UL PCC) 106a
Downlink Secondary Component Carriers (DL SCC) 108b
Secondary Cell(s) (SCell) 185b
Uplink Secondary Component Carrier (UL SCC) 106b
User Equipment (UE) 104
Transceiver 117
Receiver 119
Demodulator 121
Transmitter 123
Modulator 125
Decoder 127
Downlink Decoding Results 129
Encoder 131
CQI/PMI/RI and HARQ-ACK Encoder 156
Simultaneous Physical Uplink Shared Channel (PUSCH) and PUCCH Transmissions Module 157
simultaneousAckNackAndCQI
Higher Layers 118
Parameter 116
Operations Module 133
Uplink Control Information (UCI) Reporting Module 114
CQI/PMI/RI 141a
HARQ-ACK 140a

FIG. 2


Physical Uplink Control Channel (PUCCH) Symbol 224
Format 226
Physical Uplink Control Channel (PUCCH) Resource 237
Uplink Control Information (UCI) 228a
HARQ-ACK 240a
Periodic Channel State Information (CSI) Report 236a
Channel Quality Indicator (CQI) 230a
Precoding Matrix Index (PMI) 232a
Rank Indication (RI) 234a
Priority 210a
User Equipment (UE) 204
Physical Uplink Control Channel (PUCCH) Signal 238
eNode B 202
Physical Uplink Shared Channel (PUSCH) Signal 239
Physical Uplink Shared Channel (PUSCH) Symbol 243
Uplink Control Information (UCI) 228b
HARQ-ACK 240b
Aperiodic Channel State Information (CSI) Report 236c
Channel Quality Indicator (CQI) 230b
Precoding Matrix Index (PMI) 232b
Rank Indication (RI) 234b
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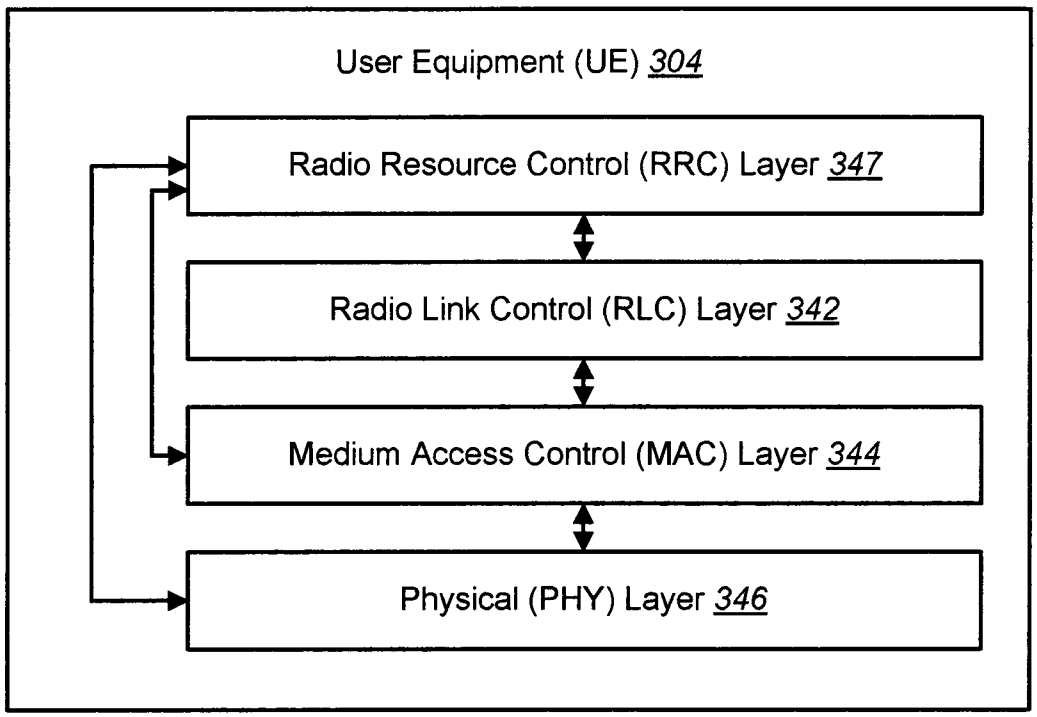
Precoding Matrix Index (PMI) 232c
Rank Indication (RI) 234c
Priority 210b

FIG. 3


User Equipment (UE) 304
Radio Resource Control (RRC) Layer 347
Radio Link Control (RLC) Layer 342
Medium Access Control (MAC) Layer 344
Physical (PHY) Layer 346

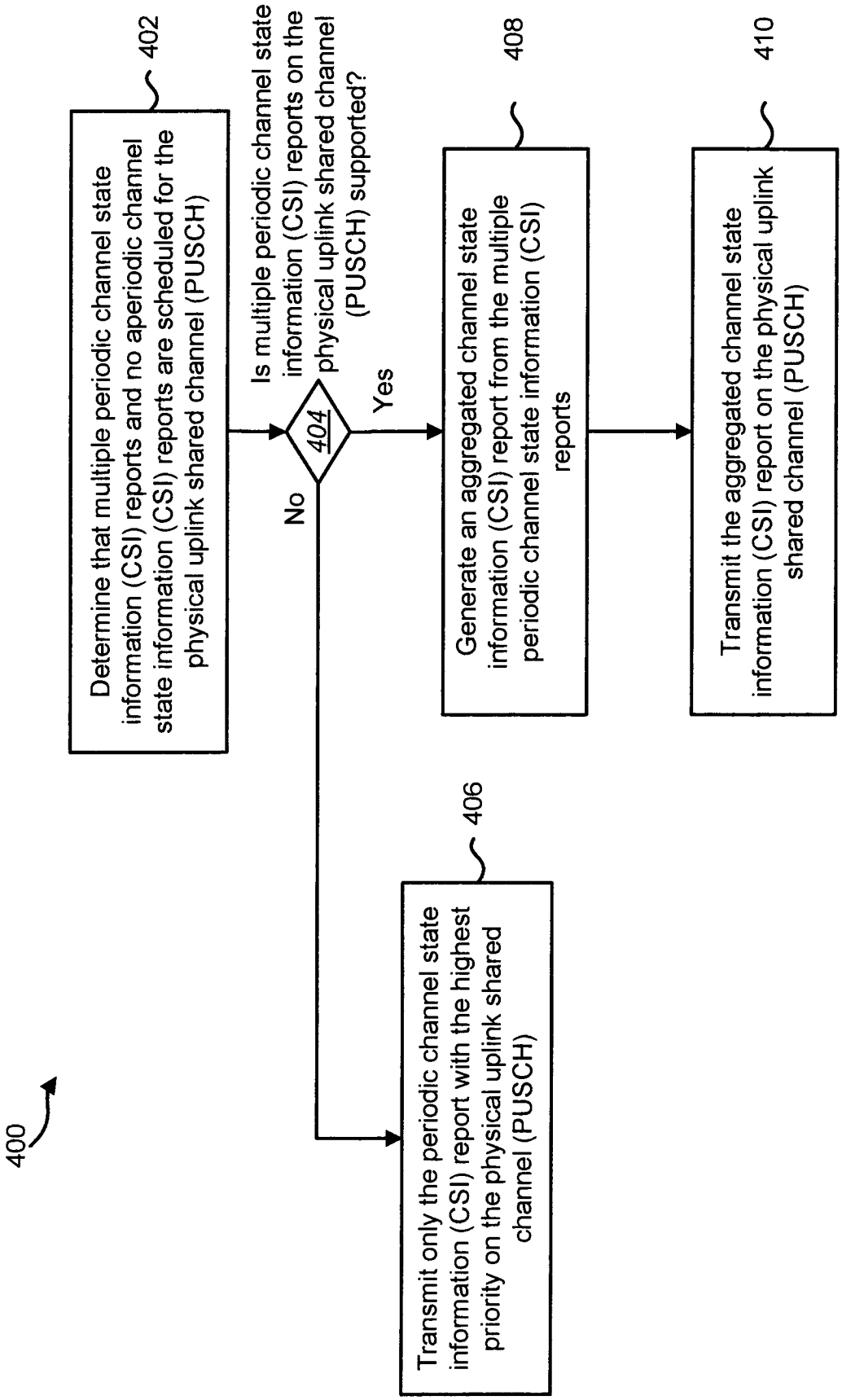

400
Determine that multiple periodic channel state information (CSI) reports and no aperiodic channel state information (CSI) reports are scheduled for the physical uplink shared channel (PUSCH)
402
Is multiple periodic channel state information (CSI) reports on the physical uplink shared channel (PUSCH) supported?
404
Yes
No
Generate an aggregated channel state information (CSI) report from the multiple periodic channel state information (CSI) reports
408
Transmit the aggregated channel state information (CSI) report on the physical uplink shared channel (PUSCH)
410
Transmit only the periodic channel state information (CSI) report with the highest priority on the physical uplink shared channel (PUSCH)
406

FIG. 4

FIG. 5

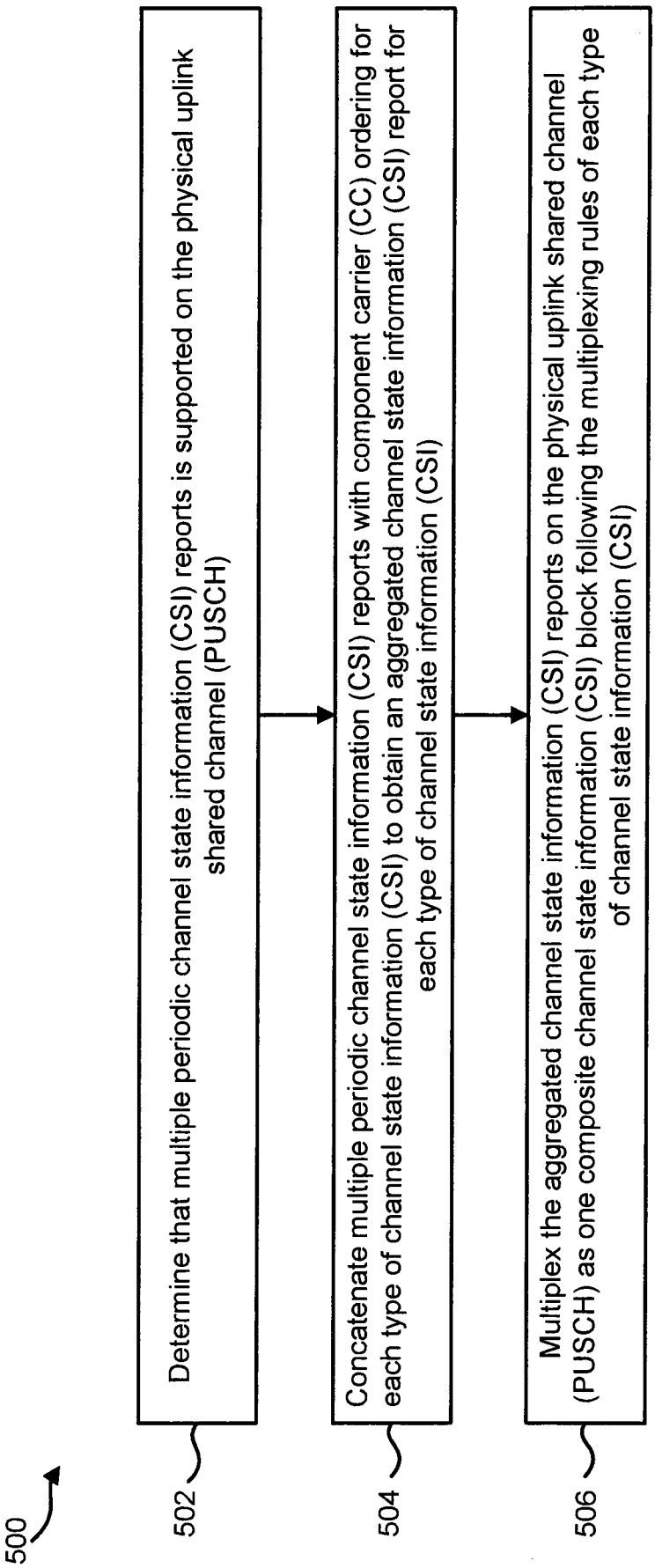

500
502
Determine that multiple periodic channel state information (CSI) reports is supported on the physical uplink shared channel (PUSCH)
504
Concatenate multiple periodic channel state information (CSI) reports with component carrier (CC) ordering for each type of channel state information (CSI) to obtain an aggregated channel state information (CSI) report for each type of channel state information (CSI)
506
Multiplex the aggregated channel state information (CSI) reports on the physical uplink shared channel (PUSCH) as one composite channel state information (CSI) block following the multiplexing rules of each type of channel state information (CSI)

FIG. 6

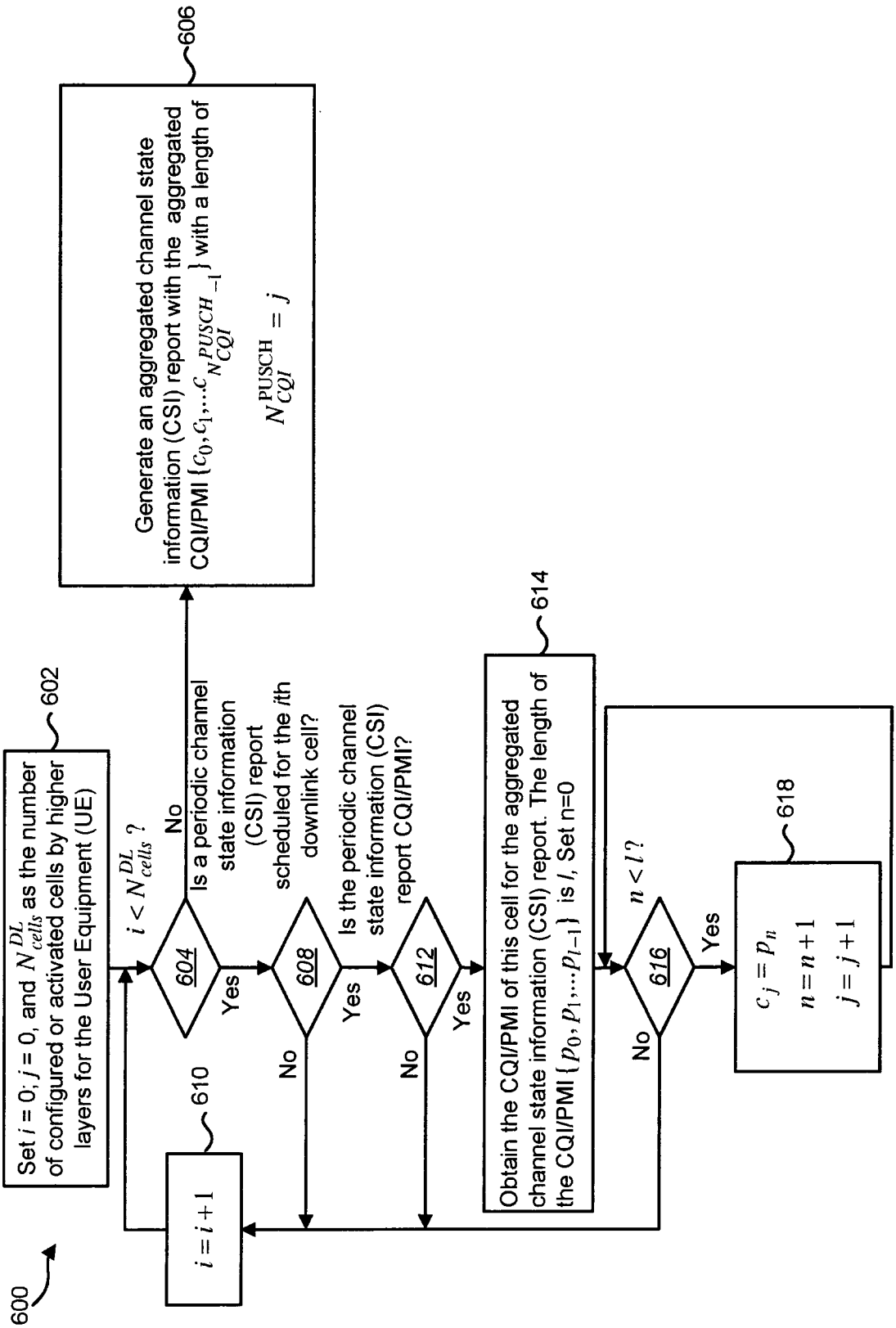

600
Set $i = 0$; $j = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the User Equipment (UE)
602
$i < N_{cells}^{DL}$?
604
No
Yes
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
608
No
Yes
Is the periodic channel state information (CSI) report CQI/PMI?
612
No
Yes
$i = i + 1$
610
Generate an aggregated channel state information (CSI) report with the aggregated CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{PUSCH} = j$
606
Obtain the CQI/PMI of this cell for the aggregated channel state information (CSI) report. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l, Set n=0
614
$n < l$?
616
No
Yes
$c_j = p_n$
$n = n + 1$
$j = j + 1$
618

FIG. 7

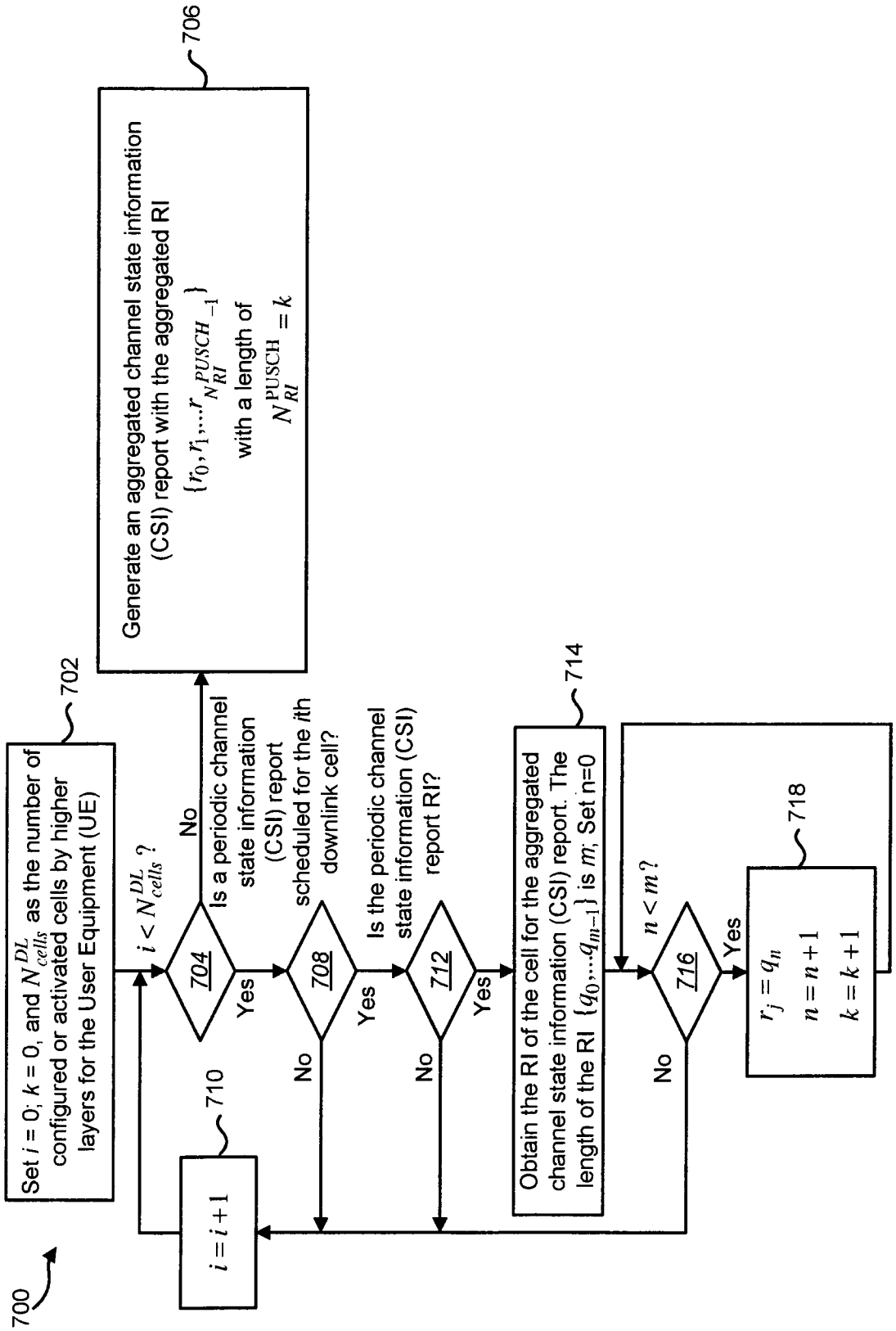

700
Set $i = 0$; $k = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the User Equipment (UE)
702
$i < N_{cells}^{DL}$?
704
No
Yes
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
706
Generate an aggregated channel state information (CSI) report with the aggregated RI $\{r_0, r_1, \ldots r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH} = k$
708
No
Yes
Is the periodic channel state information (CSI) report RI?
712
No
Yes
Obtain the RI of the cell for the aggregated channel state information (CSI) report. The length of the RI $\{q_0, \ldots q_{m-1}\}$ is m; Set n=0
714
$n < m$?
716
No
Yes
$r_j = q_n$
$n = n + 1$
$k = k + 1$
718
$i = i + 1$
710

FIG. 8

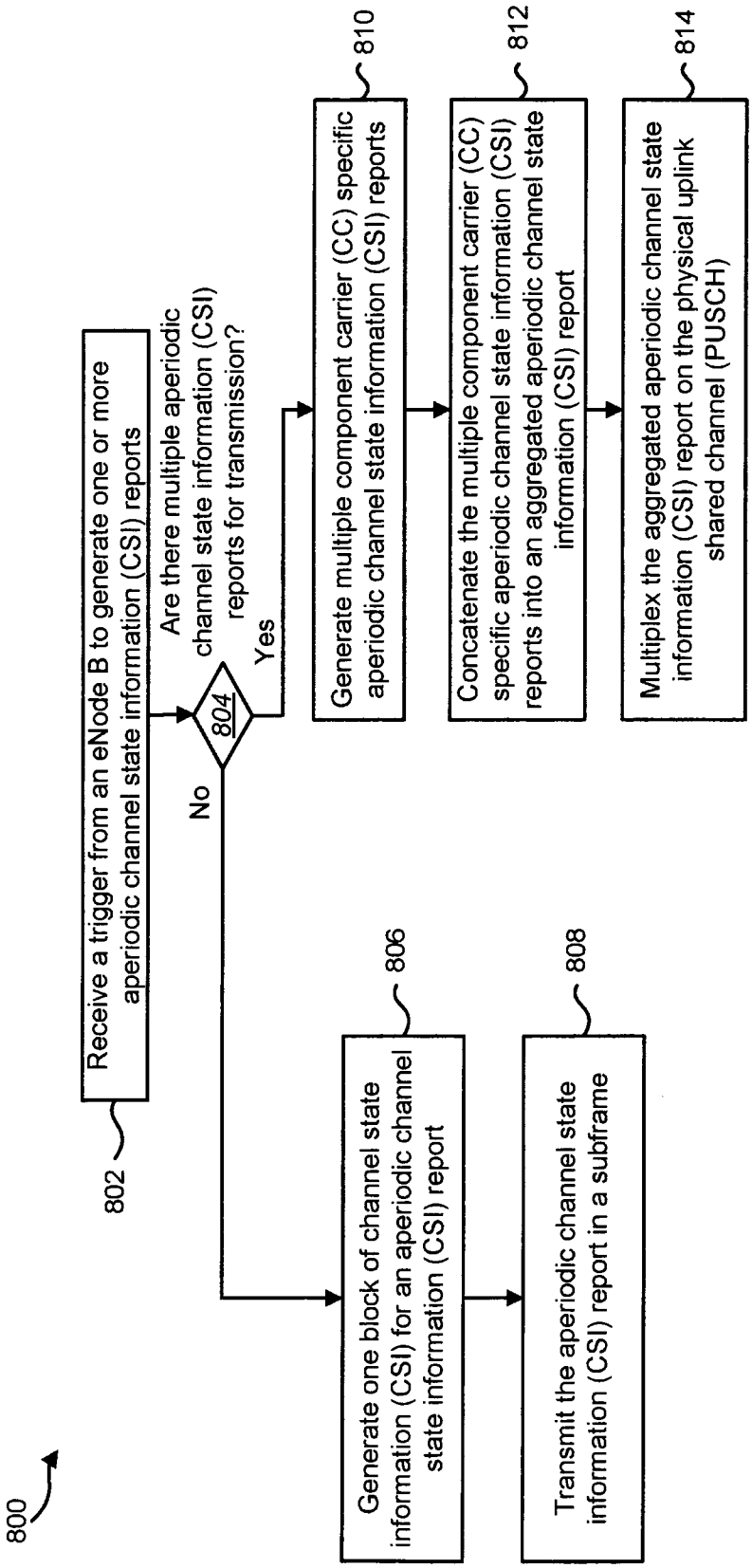

800
802
Receive a trigger from an eNode B to generate one or more aperiodic channel state information (CSI) reports
804
Are there multiple aperiodic channel state information (CSI) reports for transmission?
Yes
No
806
Generate one block of channel state information (CSI) for an aperiodic channel state information (CSI) report
808
Transmit the aperiodic channel state information (CSI) report in a subframe
810
Generate multiple component carrier (CC) specific aperiodic channel state information (CSI) reports
812
Concatenate the multiple component carrier (CC) specific aperiodic channel state information (CSI) reports into an aggregated aperiodic channel state information (CSI) report
814
Multiplex the aggregated aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH)

FIG. 9

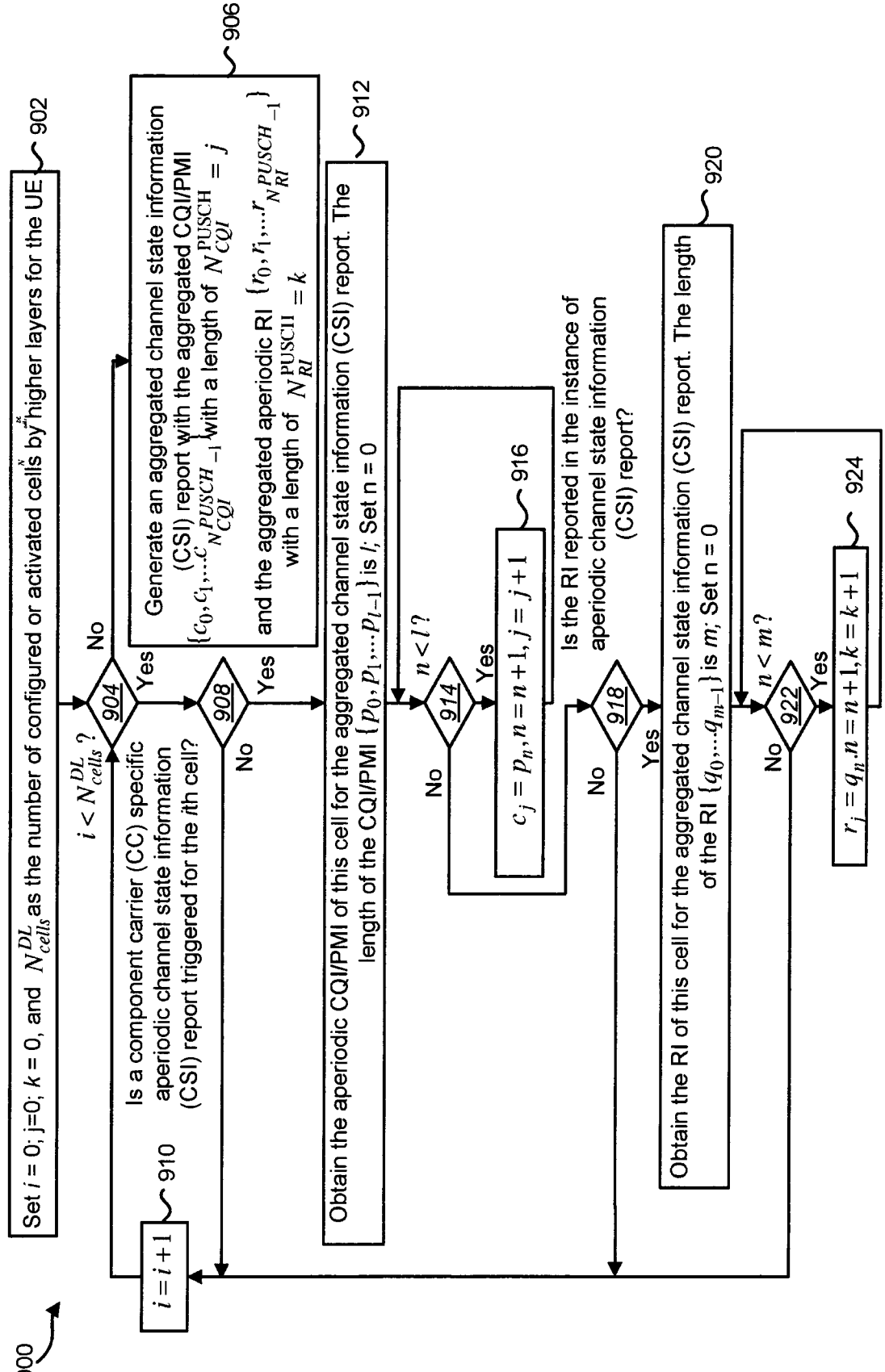

900
Set i = 0; j=0; k = 0, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
902
$i < N_{cells}^{DL}$?
904
No
Yes
Is a component carrier (CC) specific aperiodic channel state information (CSI) report triggered for the ith cell?
908
No
Yes
Generate an aggregated channel state information (CSI) report with the aggregated CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ with a length of $N_{CQI}^{PUSCH} = j$ and the aggregated aperiodic RI $\{r_0, r_1, \ldots r_{N_{RI}^{PUSCH}-1}\}$ with a length of $N_{RI}^{PUSCH} = k$
906
$i = i + 1$
910
Obtain the aperiodic CQI/PMI of this cell for the aggregated channel state information (CSI) report. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l; Set n = 0
912
$n < l$?
914
No
Yes
$c_j = p_n, n = n+1, j = j+1$
916
Is the RI reported in the instance of aperiodic channel state information (CSI) report?
918
No
Yes
Obtain the RI of this cell for the aggregated channel state information (CSI) report. The length of the RI $\{q_0, \ldots q_{m-1}\}$ is m; Set n = 0
920
$n < m$?
922
No
Yes
$r_j = q_n, n = n+1, k = k+1$
924

FIG. 10

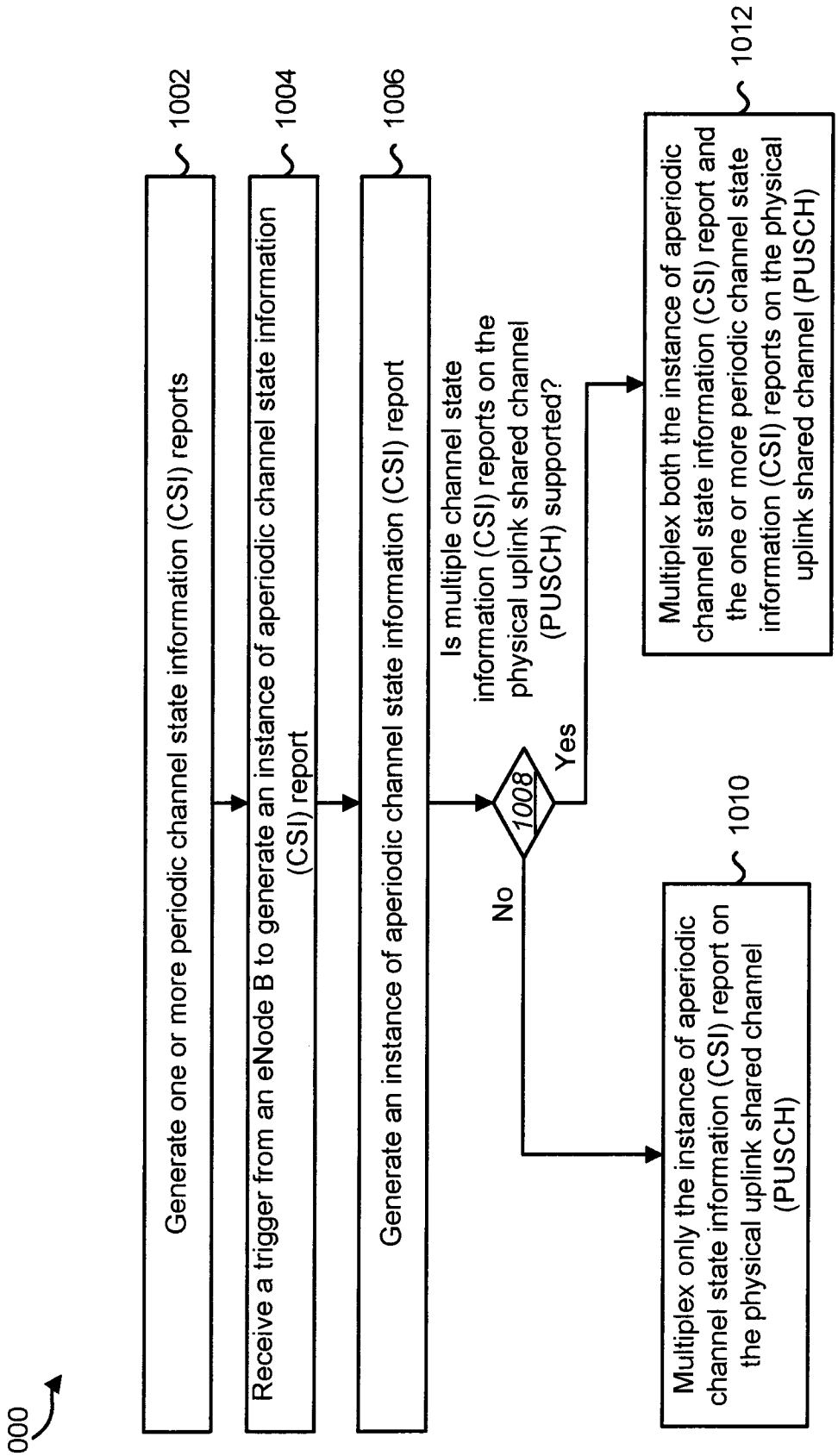

1000
Generate one or more periodic channel state information (CSI) reports
1002
Receive a trigger from an eNode B to generate an instance of aperiodic channel state information (CSI) report
1004
Generate an instance of aperiodic channel state information (CSI) report
1006
Is multiple channel state information (CSI) reports on the physical uplink shared channel (PUSCH) supported?
1008
Yes
No
Multiplex both the instance of aperiodic channel state information (CSI) report and the one or more periodic channel state information (CSI) reports on the physical uplink shared channel (PUSCH)
1012
Multiplex only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH)
1010

FIG. 11

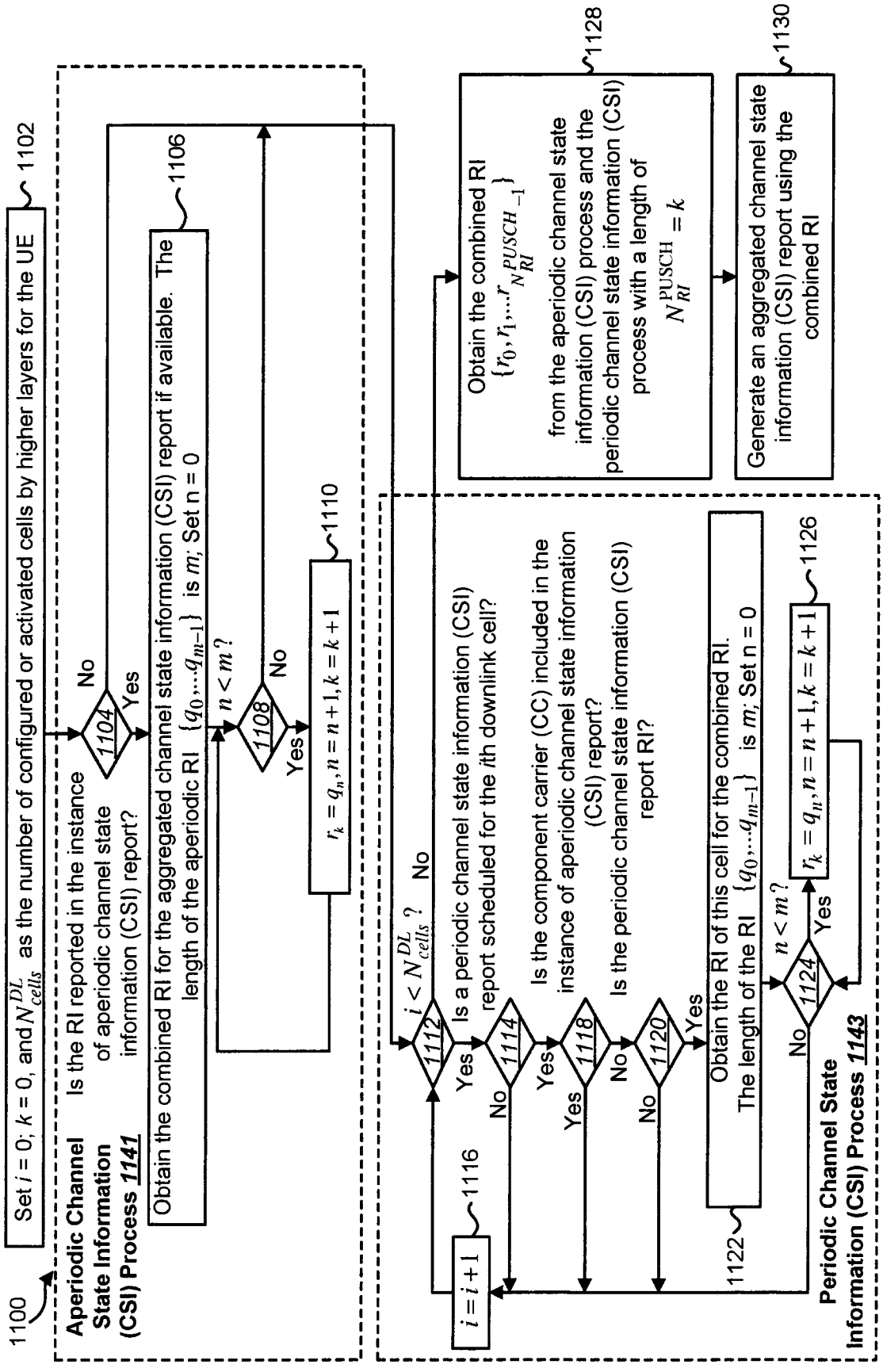

1100
Aperiodic Channel State Information (CSI) Process 1141
Set $i = 0$; $k = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
1102
Is the RI reported in the instance of aperiodic channel state information (CSI) report?
1104
No
Yes
Obtain the combined RI for the aggregated channel state information (CSI) report if available. The length of the aperiodic RI $\{q_0,...q_{m-1}\}$ is m; Set n = 0
1106
$n < m$?
1108
No
Yes
$r_k = q_n, n = n+1, k = k+1$
1110
Periodic Channel State Information (CSI) Process 1143
$i < N_{cells}^{DL}$?
1112
No
Yes
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
1114
No
Yes
Is the component carrier (CC) included in the instance of aperiodic channel state information (CSI) report?
1118
No
Yes
Is the periodic channel state information (CSI) report RI?
1120
No
Yes
$i = i+1$
1116
Obtain the RI of this cell for the combined RI. The length of the RI $\{q_0,...q_{m-1}\}$ is m; Set n = 0
1122
$n < m$?
1124
No
Yes
$r_k = q_n, n = n+1, k = k+1$
1126
Obtain the combined RI $\{r_0, r_1,...r_{N_{RI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process and the periodic channel state information (CSI) process with a length of $N_{RI}^{PUSCH} = k$
1128
Generate an aggregated channel state information (CSI) report using the combined RI
1130

FIG. 12

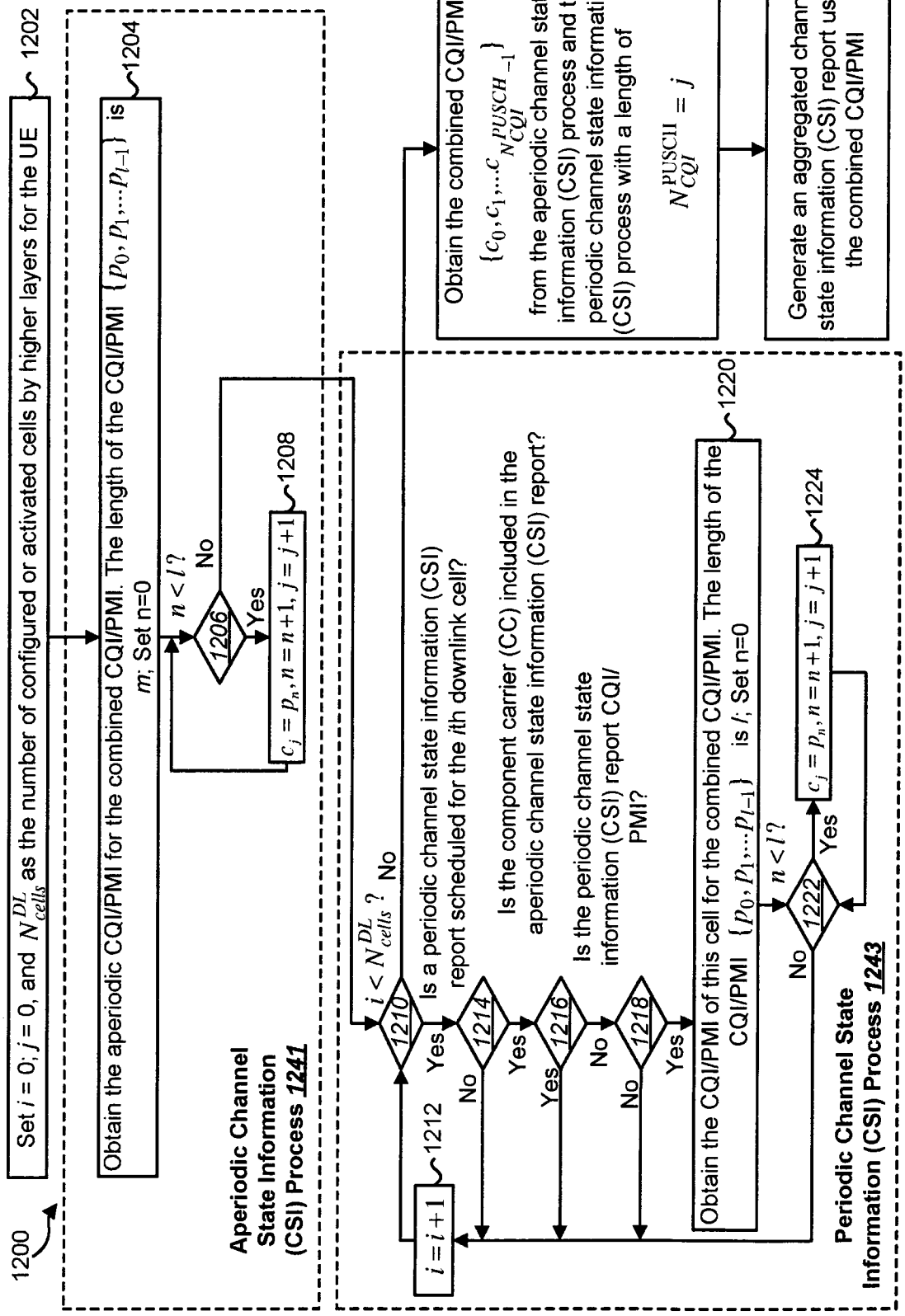

1200
Set $i = 0$; $j = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
1202
Obtain the aperiodic CQI/PMI for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is m; Set n=0
1204
$n < l$?
No
1206
Yes
$c_j = p_n, n = n+1, j = j+1$
1208
Aperiodic Channel State Information (CSI) Process 1241
$i < N_{cells}^{DL}$?
No
1210
Yes
$i = i+1$
1212
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
No
1214
Yes
Is the component carrier (CC) included in the aperiodic channel state information (CSI) report?
No
1216
Yes
Is the periodic channel state information (CSI) report CQI/PMI?
No
1218
Yes
Obtain the CQI/PMI of this cell for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l; Set n=0
1220
$n < l$?
No
1222
Yes
$c_j = p_n, n = n+1, j = j+1$
1224
Periodic Channel State Information (CSI) Process 1243
Obtain the combined CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process and the periodic channel state information (CSI) process with a length of $N_{CQI}^{PUSCH} = j$
1226
Generate an aggregated channel state information (CSI) report using the combined CQI/PMI
1228

FIG. 13

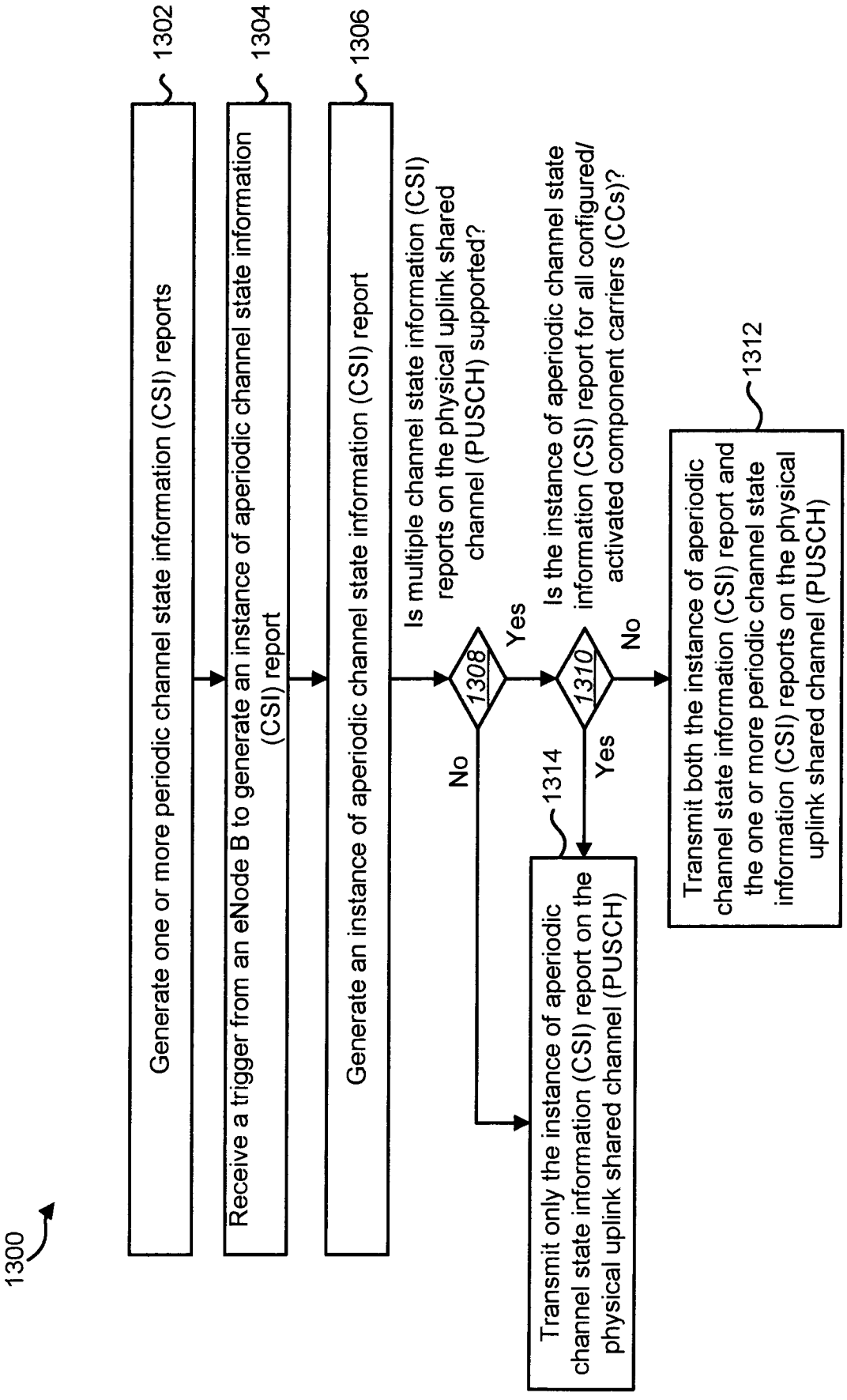

1300
Generate one or more periodic channel state information (CSI) reports
1302
Receive a trigger from an eNode B to generate an instance of aperiodic channel state information (CSI) report
1304
Generate an instance of aperiodic channel state information (CSI) report
1306
Is multiple channel state information (CSI) reports on the physical uplink shared channel (PUSCH) supported?
1308
Yes
No
Is the instance of aperiodic channel state information (CSI) report for all configured/ activated component carriers (CCs)?
1310
Yes
No
Transmit only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH)
1314
Transmit both the instance of aperiodic channel state information (CSI) report and the one or more periodic channel state information (CSI) reports on the physical uplink shared channel (PUSCH)
1312

FIG. 14

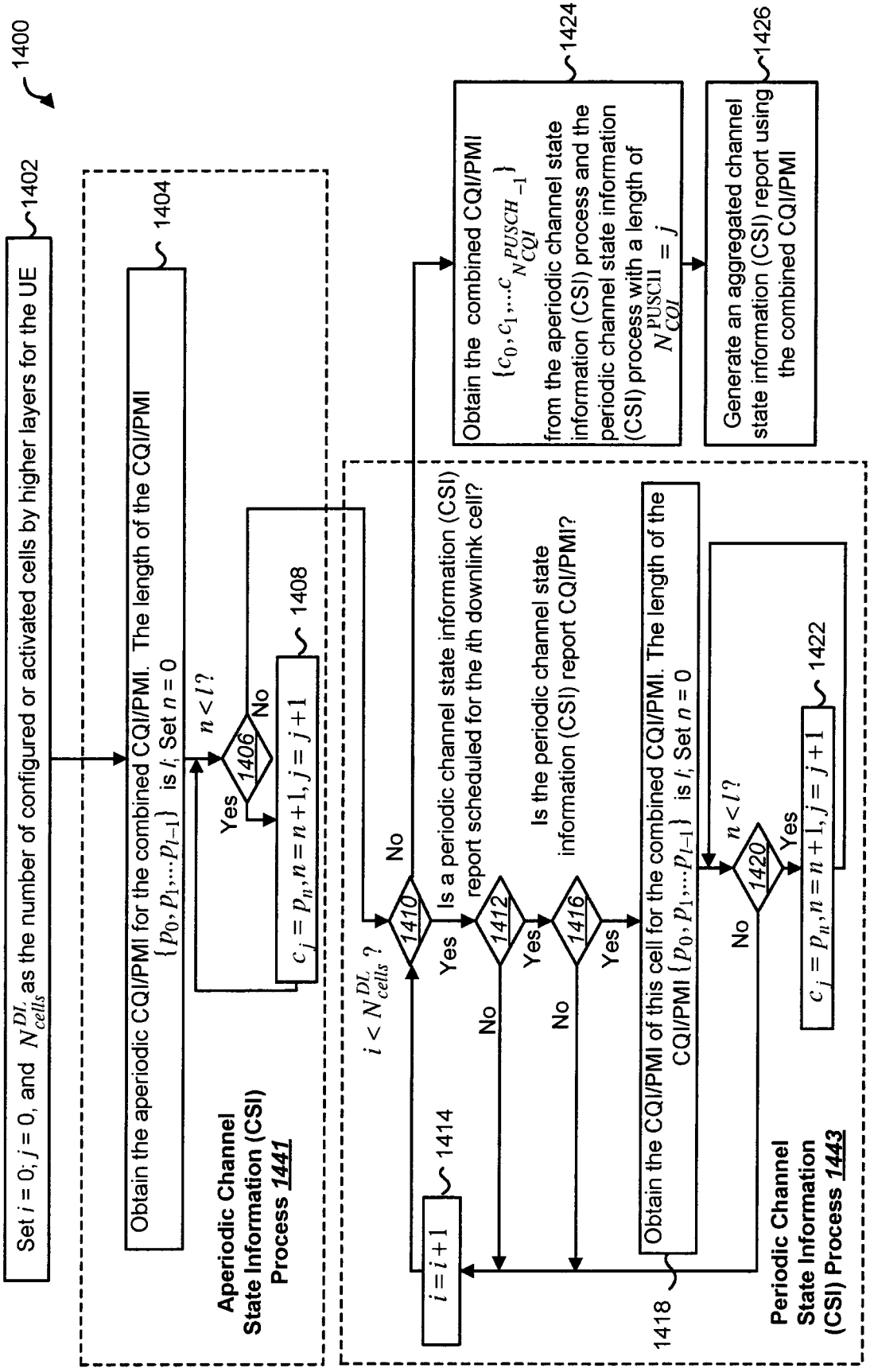

1400
1402
Set $i = 0$; $j = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
1404
Obtain the aperiodic CQI/PMI for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l; Set $n = 0$
1406
$n < l$?
Yes
No
1408
$c_j = p_n, n = n+1, j = j+1$
Aperiodic Channel State Information (CSI) Process 1441
1410
$i < N_{cells}^{DL}$?
Yes
No
1412
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
Yes
No
1414
$i = i+1$
1416
Is the periodic channel state information (CSI) report CQI/PMI?
Yes
No
1418
Obtain the CQI/PMI of this cell for the combined CQI/PMI. The length of the CQI/PMI $\{p_0, p_1, \ldots p_{l-1}\}$ is l; Set $n = 0$
1420
$n < l$?
Yes
No
1422
$c_j = p_n, n = n+1, j = j+1$
Periodic Channel State Information (CSI) Process 1443
1424
Obtain the combined CQI/PMI $\{c_0, c_1, \ldots c_{N_{CQI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process and the periodic channel state information (CSI) process with a length of $N_{CQI}^{PUSCH} = j$
1426
Generate an aggregated channel state information (CSI) report using the combined CQI/PMI

FIG. 15

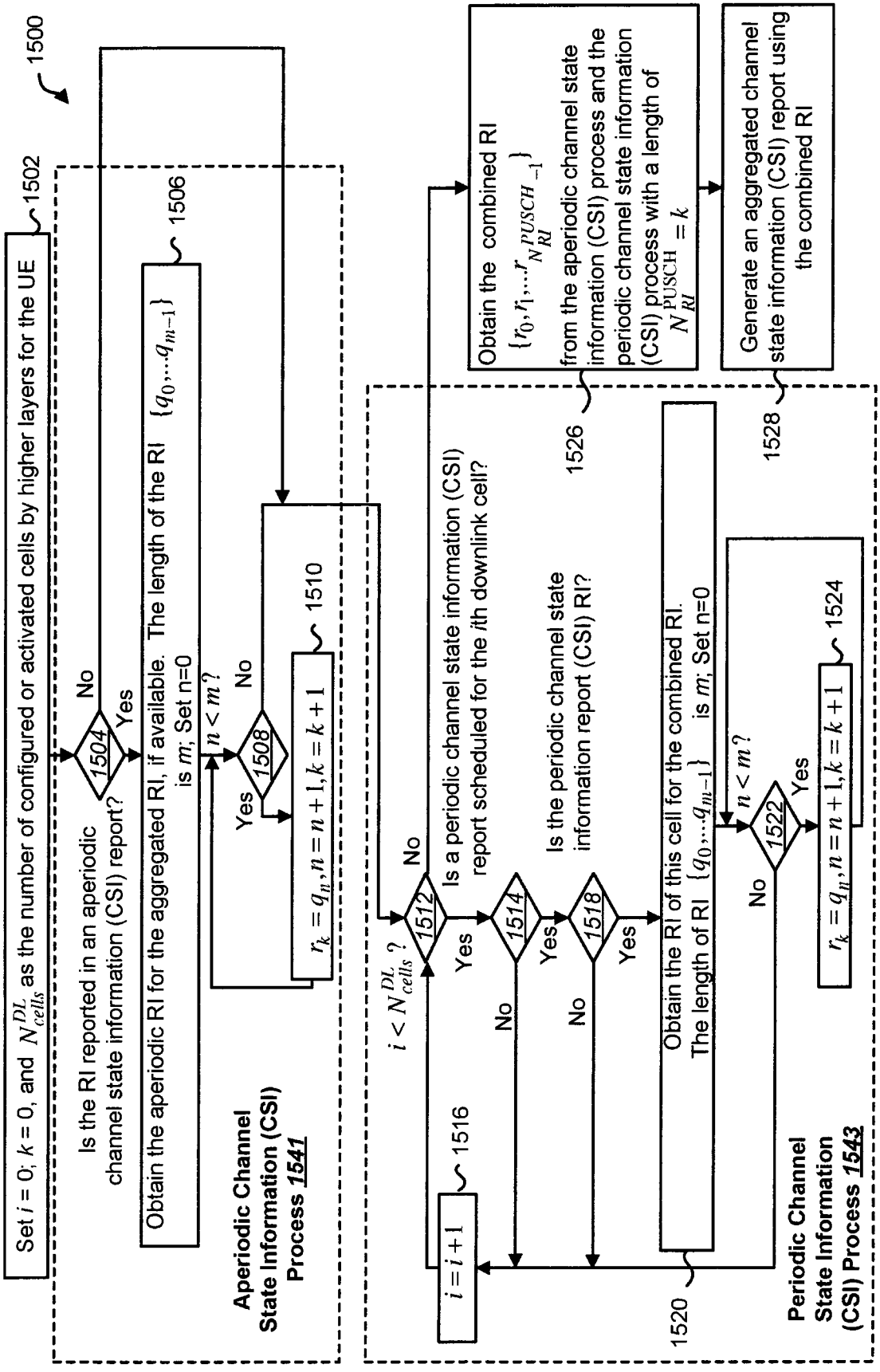

1500
Set $i = 0$; $k = 0$, and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
1502
Is the RI reported in an aperiodic channel state information (CSI) report?
1504
No
Yes
Obtain the aperiodic RI for the aggregated RI, if available. The length of the RI $\{q_0,...q_{m-1}\}$ is m; Set n=0
1506
$n < m$?
1508
No
Yes
$r_k = q_n, n = n+1, k = k+1$
1510
Aperiodic Channel State Information (CSI) Process 1541
$i < N_{cells}^{DL}$?
1512
No
Yes
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
1514
No
Yes
Is the periodic channel state information report (CSI) RI?
1518
No
Yes
$i = i+1$
1516
Obtain the RI of this cell for the combined RI. The length of RI $\{q_0,...q_{m-1}\}$ is m; Set n=0
1520
$n < m$?
1522
No
Yes
$r_k = q_n, n = n+1, k = k+1$
1524
Obtain the combined RI $\{r_0, r_1,...r_{N_{RI}^{PUSCH}-1}\}$ from the aperiodic channel state information (CSI) process and the periodic channel state information (CSI) process with a length of $N_{RI}^{PUSCH} = k$
1526
Generate an aggregated channel state information (CSI) report using the combined RI
1528
Periodic Channel State Information (CSI) Process 1543

FIG. 16

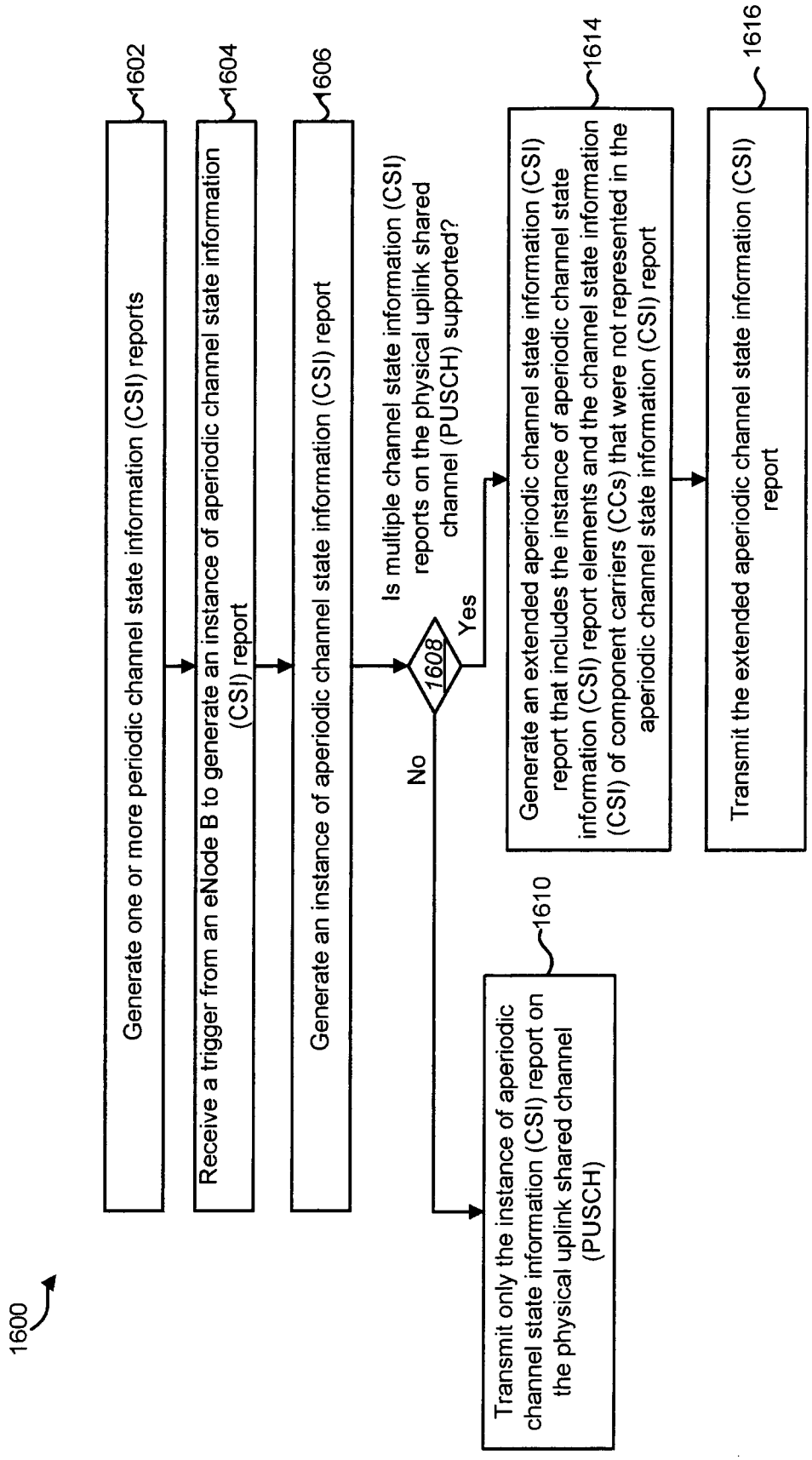

1600
Generate one or more periodic channel state information (CSI) reports
1602
Receive a trigger from an eNode B to generate an instance of aperiodic channel state information (CSI) report
1604
Generate an instance of aperiodic channel state information (CSI) report
1606
Is multiple channel state information (CSI) reports on the physical uplink shared channel (PUSCH) supported?
1608
Yes
No
Generate an extended aperiodic channel state information (CSI) report that includes the instance of aperiodic channel state information (CSI) report elements and the channel state information (CSI) of component carriers (CCs) that were not represented in the aperiodic channel state information (CSI) report
1614
Transmit the extended aperiodic channel state information (CSI) report
1616
Transmit only the instance of aperiodic channel state information (CSI) report on the physical uplink shared channel (PUSCH)
1610

FIG. 17

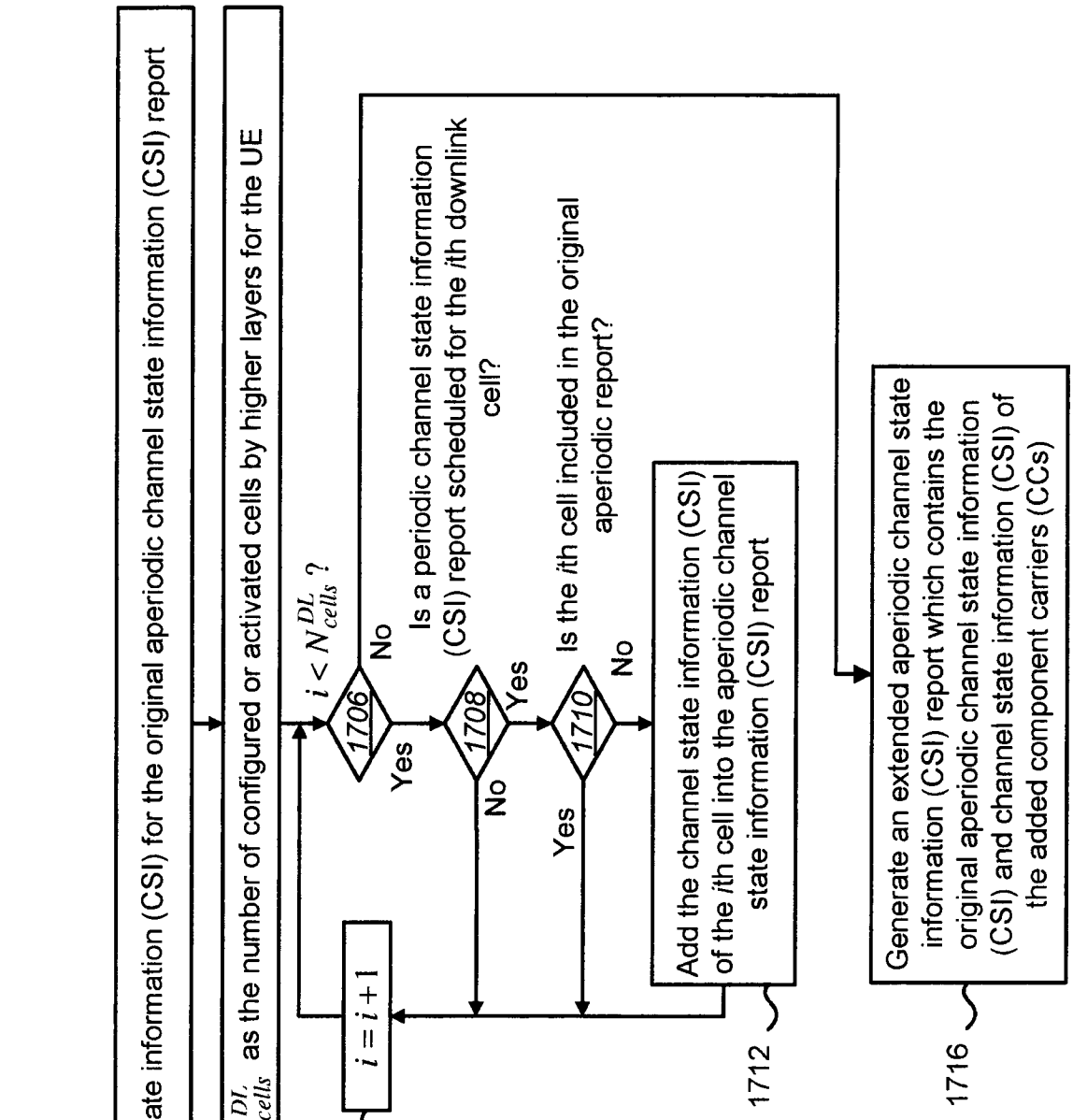

1700
1702
Obtain the channel state information (CSI) for the original aperiodic channel state information (CSI) report
1704
Set $i = 0$; and N_{cells}^{DL} as the number of configured or activated cells by higher layers for the UE
1706
$i < N_{cells}^{DL}$?
No
Yes
1708
Is a periodic channel state information (CSI) report scheduled for the ith downlink cell?
Yes
No
1710
Is the ith cell included in the original aperiodic report?
Yes
No
1712
Add the channel state information (CSI) of the ith cell into the aperiodic channel state information (CSI) report
1714
$i = i + 1$
1716
Generate an extended aperiodic channel state information (CSI) report which contains the original aperiodic channel state information (CSI) and channel state information (CSI) of the added component carriers (CCs)

FIG. 18

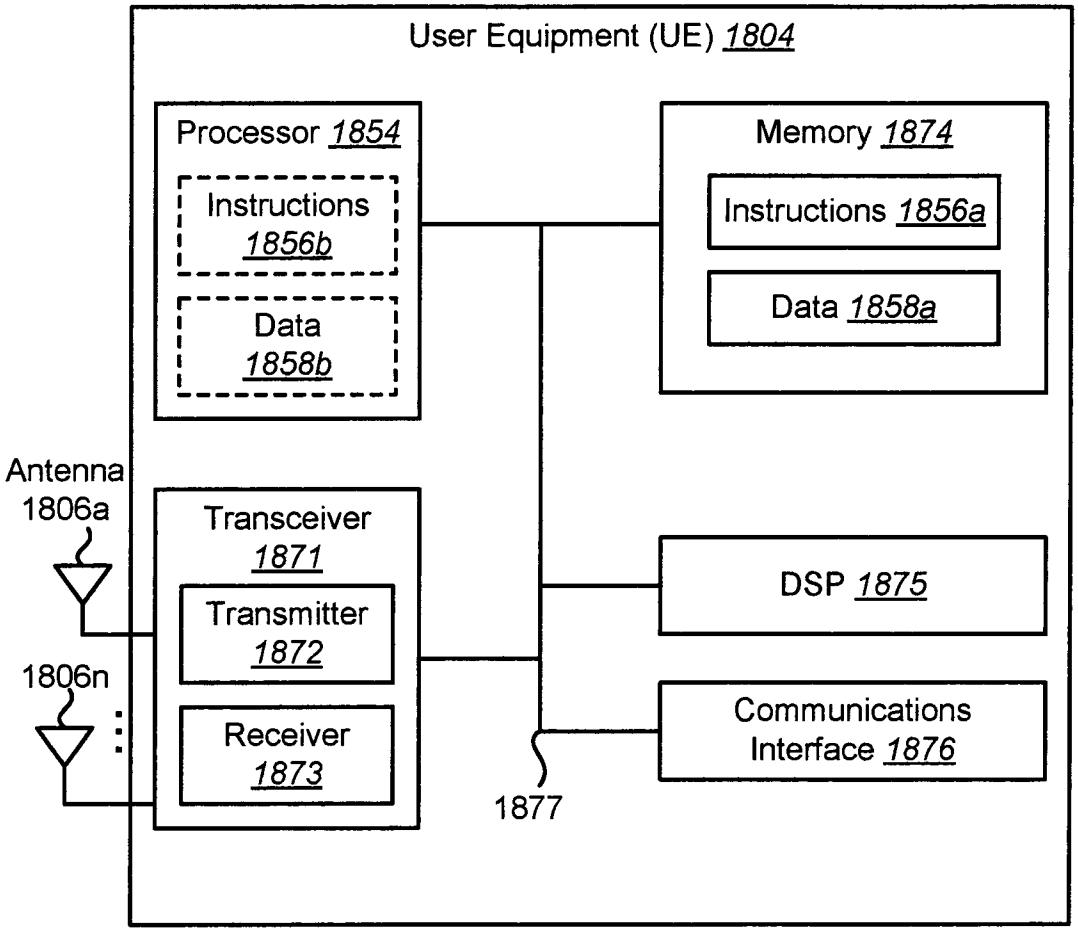
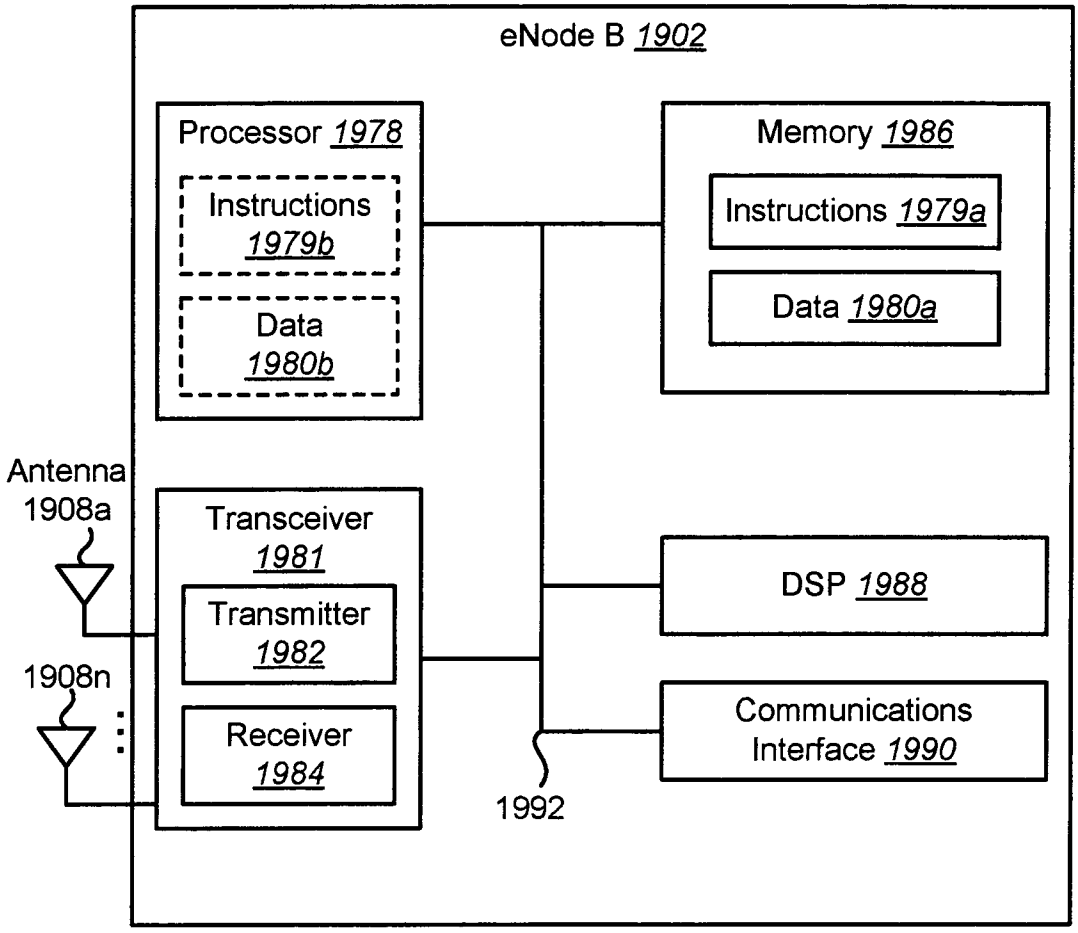

User Equipment (UE) 1804
Processor 1854
Instructions 1856b
Data 1858b
Memory 1874
Instructions 1856a
Data 1858a
Antenna 1806a
Transceiver 1871
Transmitter 1872
Receiver 1873
1806n
DSP 1875
Communications Interface 1876
1877

FIG. 19


eNode B 1902
Processor 1978
Instructions 1979b
Data 1980b
Memory 1986
Instructions 1979a
Data 1980a
Antenna 1908a
1908n
Transceiver 1981
Transmitter 1982
Receiver 1984
DSP 1988
Communications Interface 1990
1992

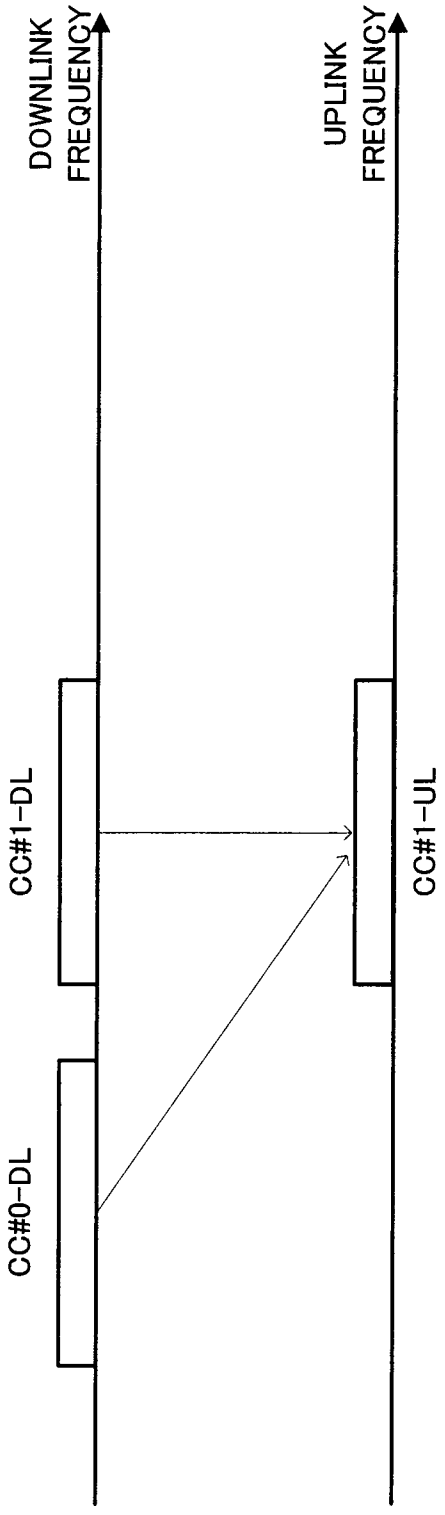
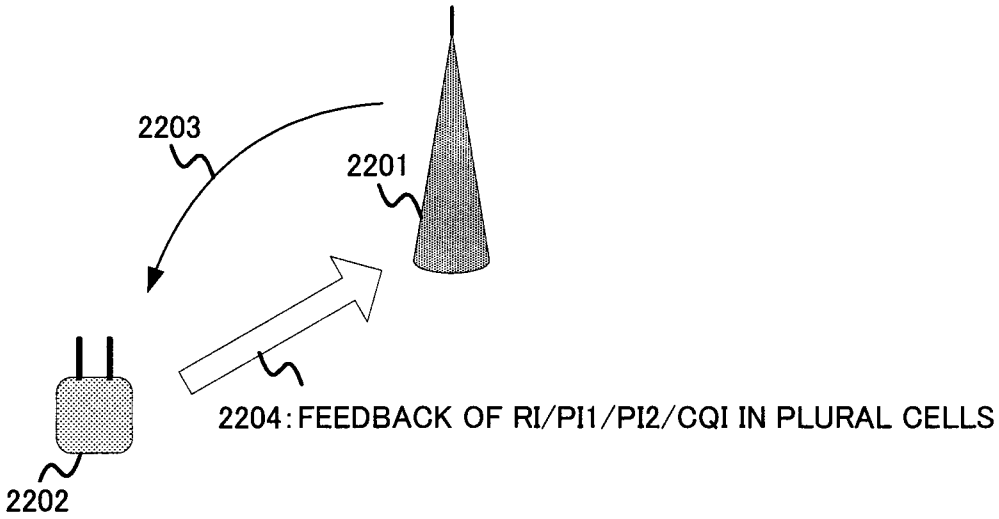


FIG. 20

FIG. 21


2203
2201
2204: FEEDBACK OF RI/PI1/PI2/CQI IN PLURAL CELLS
2202

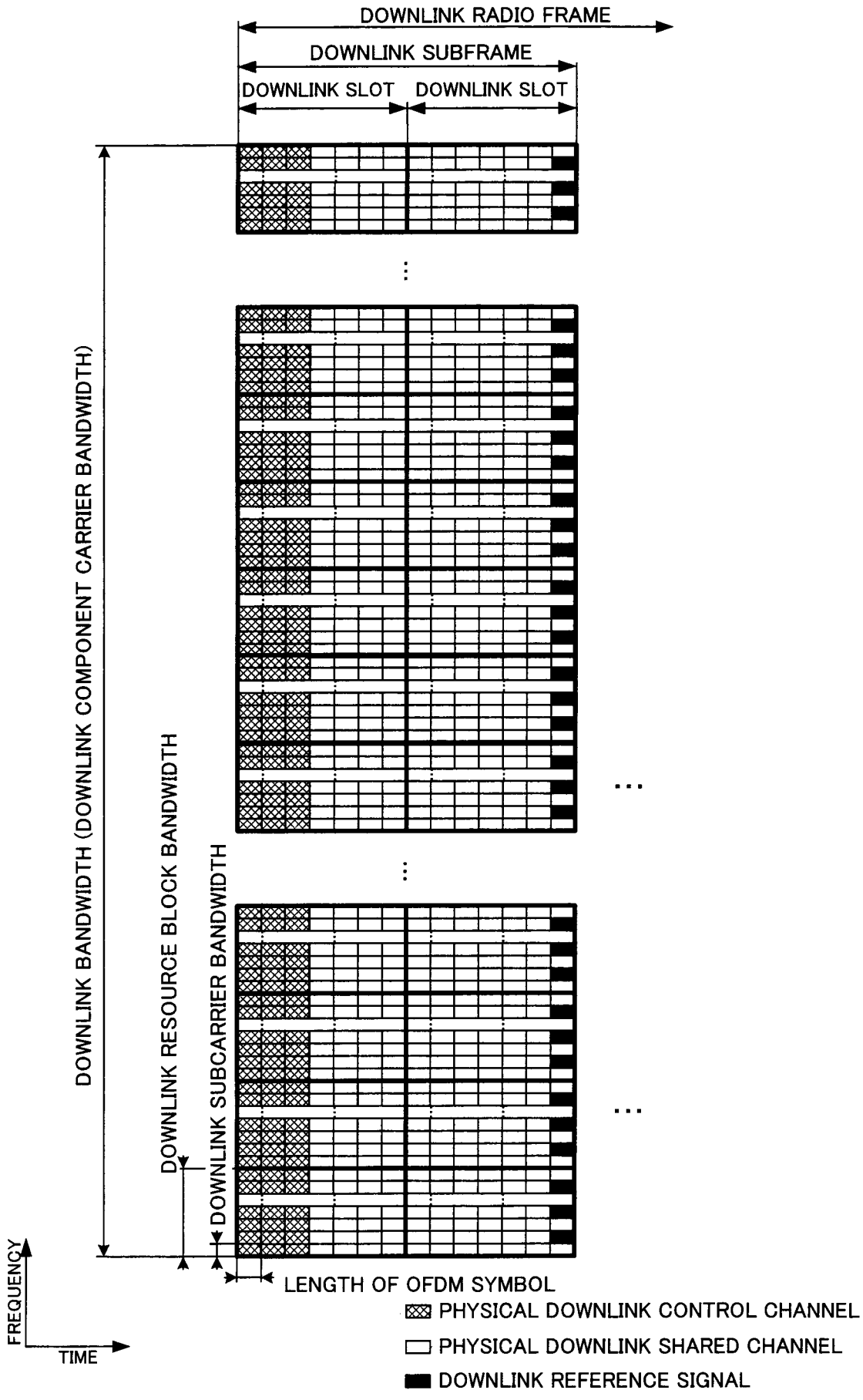

DOWNLINK RADIO FRAME
DOWNLINK SUBFRAME
DOWNLINK SLOT
DOWNLINK SLOT
DOWNLINK BANDWIDTH (DOWNLINK COMPONENT CARRIER BANDWIDTH)
DOWNLINK RESOURCE BLOCK BANDWIDTH
DOWNLINK SUBCARRIER BANDWIDTH
LENGTH OF OFDM SYMBOL
FREQUENCY
TIME
PHYSICAL DOWNLINK CONTROL CHANNEL
PHYSICAL DOWNLINK SHARED CHANNEL
DOWNLINK REFERENCE SIGNAL

FIG. 22

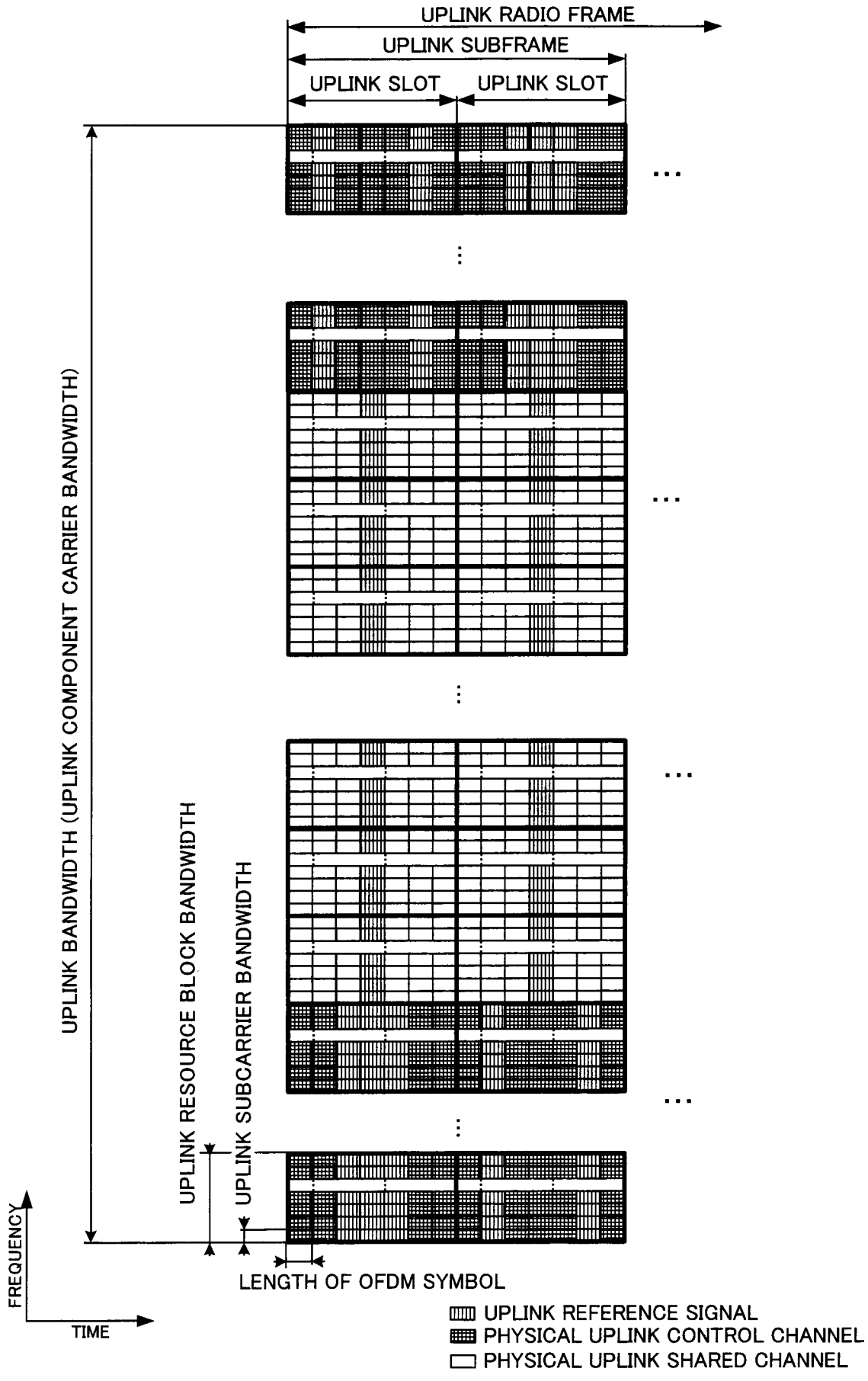

UPLINK RADIO FRAME
UPLINK SUBFRAME
UPLINK SLOT
UPLINK SLOT
UPLINK BANDWIDTH (UPLINK COMPONENT CARRIER BANDWIDTH)
UPLINK RESOURCE BLOCK BANDWIDTH
UPLINK SUBCARRIER BANDWIDTH
LENGTH OF OFDM SYMBOL
FREQUENCY
TIME
UPLINK REFERENCE SIGNAL
PHYSICAL UPLINK CONTROL CHANNEL
PHYSICAL UPLINK SHARED CHANNEL

FIG. 23

FIG. 24

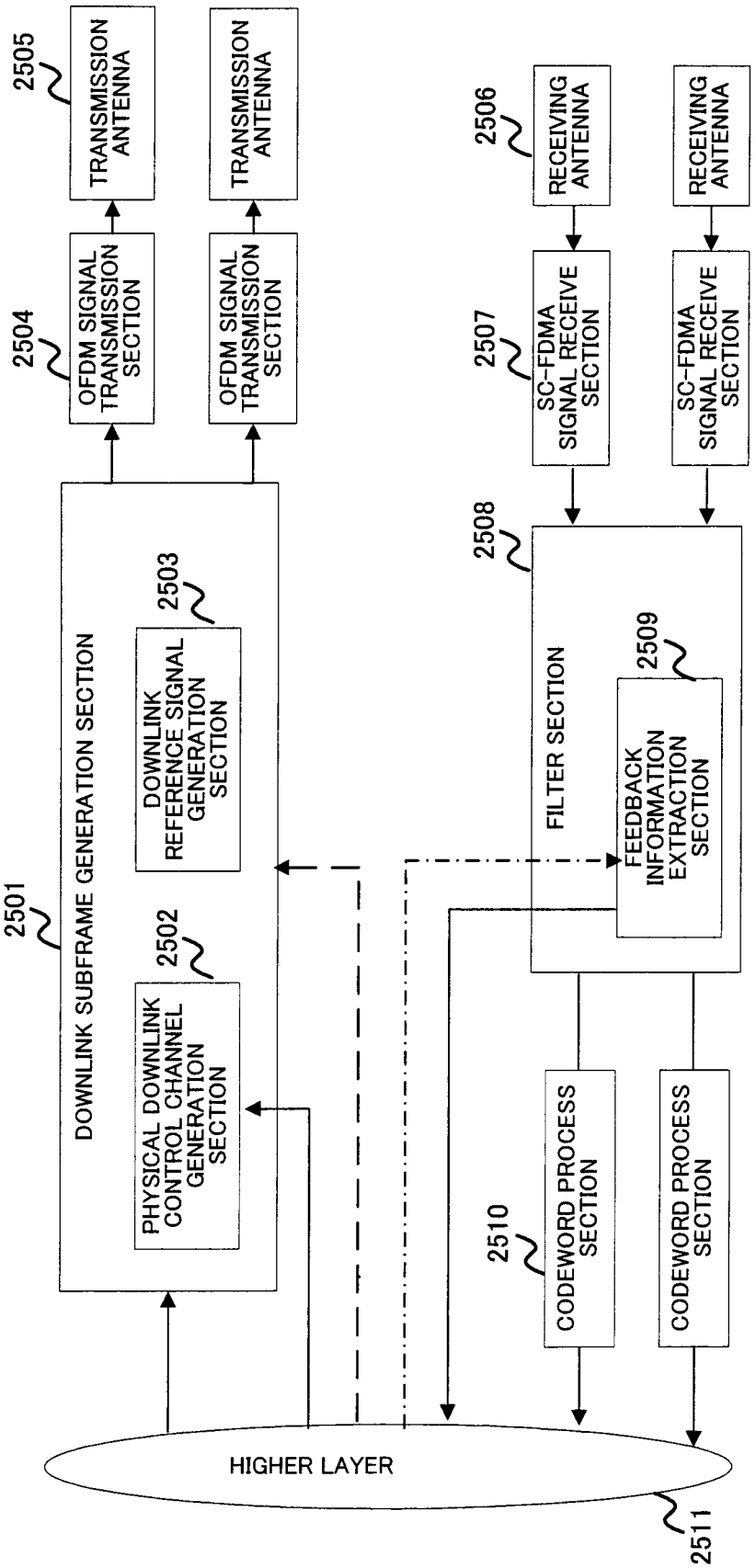

2505
TRANSMISSION ANTENNA
TRANSMISSION ANTENNA
2504
OFDM SIGNAL TRANSMISSION SECTION
OFDM SIGNAL TRANSMISSION SECTION
2506
RECEIVING ANTENNA
RECEIVING ANTENNA
2507
SC-FDMA SIGNAL RECEIVE SECTION
SC-FDMA SIGNAL RECEIVE SECTION
2508
FILTER SECTION
2509
FEEDBACK INFORMATION EXTRACTION SECTION
2501
DOWNLINK SUBFRAME GENERATION SECTION
2503
DOWNLINK REFERENCE SIGNAL GENERATION SECTION
2502
PHYSICAL DOWNLINK CONTROL CHANNEL GENERATION SECTION
2510
CODEWORD PROCESS SECTION
CODEWORD PROCESS SECTION
HIGHER LAYER
2511

FIG. 25

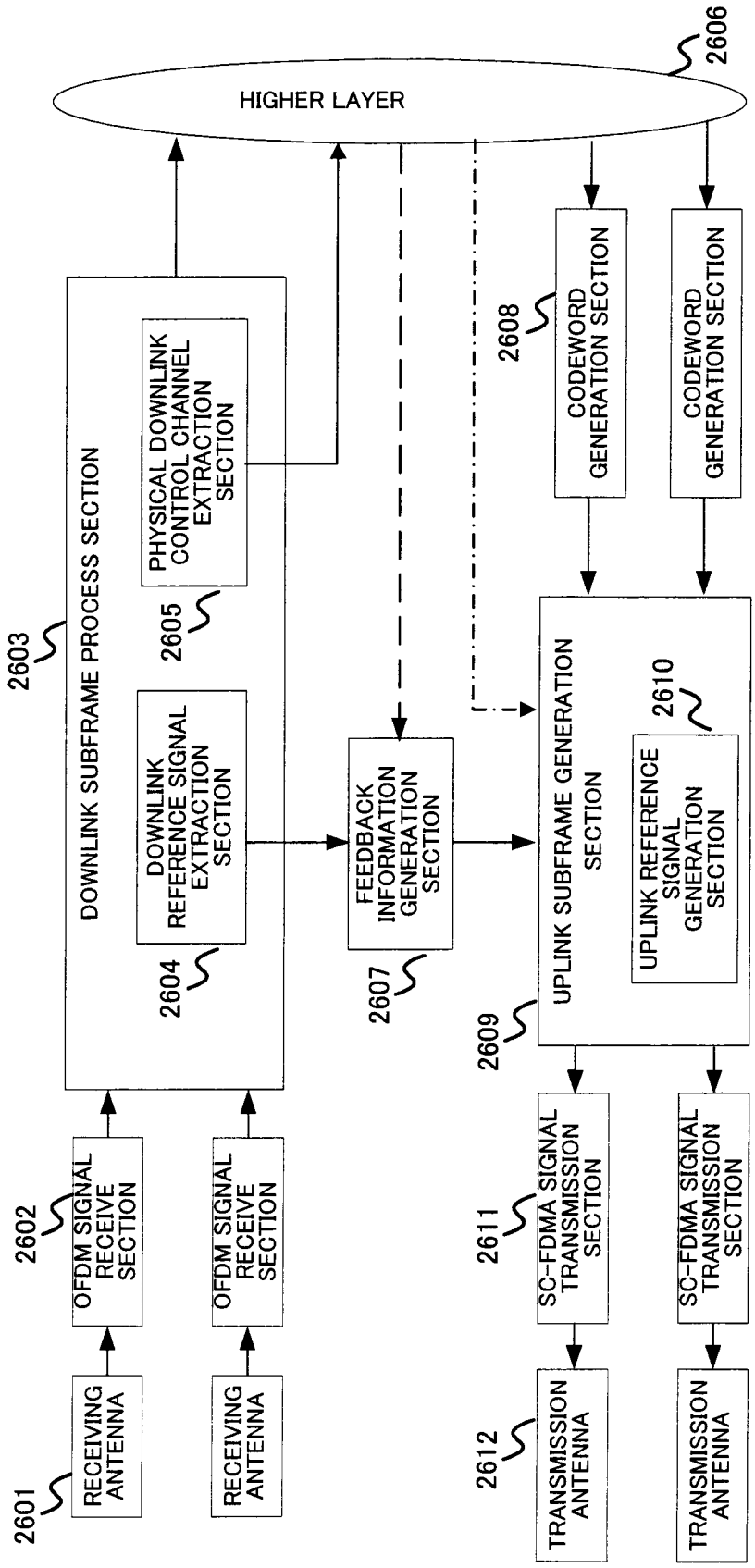

HIGHER LAYER
2606
DOWNLINK SUBFRAME PROCESS SECTION
2603
PHYSICAL DOWNLINK CONTROL CHANNEL EXTRACTION SECTION
2605
DOWNLINK REFERENCE SIGNAL EXTRACTION SECTION
2604
FEEDBACK INFORMATION GENERATION SECTION
2607
CODEWORD GENERATION SECTION
2608
CODEWORD GENERATION SECTION
UPLINK SUBFRAME GENERATION SECTION
2609
UPLINK REFERENCE SIGNAL GENERATION SECTION
2610
OFDM SIGNAL RECEIVE SECTION
2602
OFDM SIGNAL RECEIVE SECTION
SC-FDMA SIGNAL TRANSMISSION SECTION
2611
SC-FDMA SIGNAL TRANSMISSION SECTION
RECEIVING ANTENNA
2601
RECEIVING ANTENNA
TRANSMISSION ANTENNA
2612
TRANSMISSION ANTENNA

FIG. 26

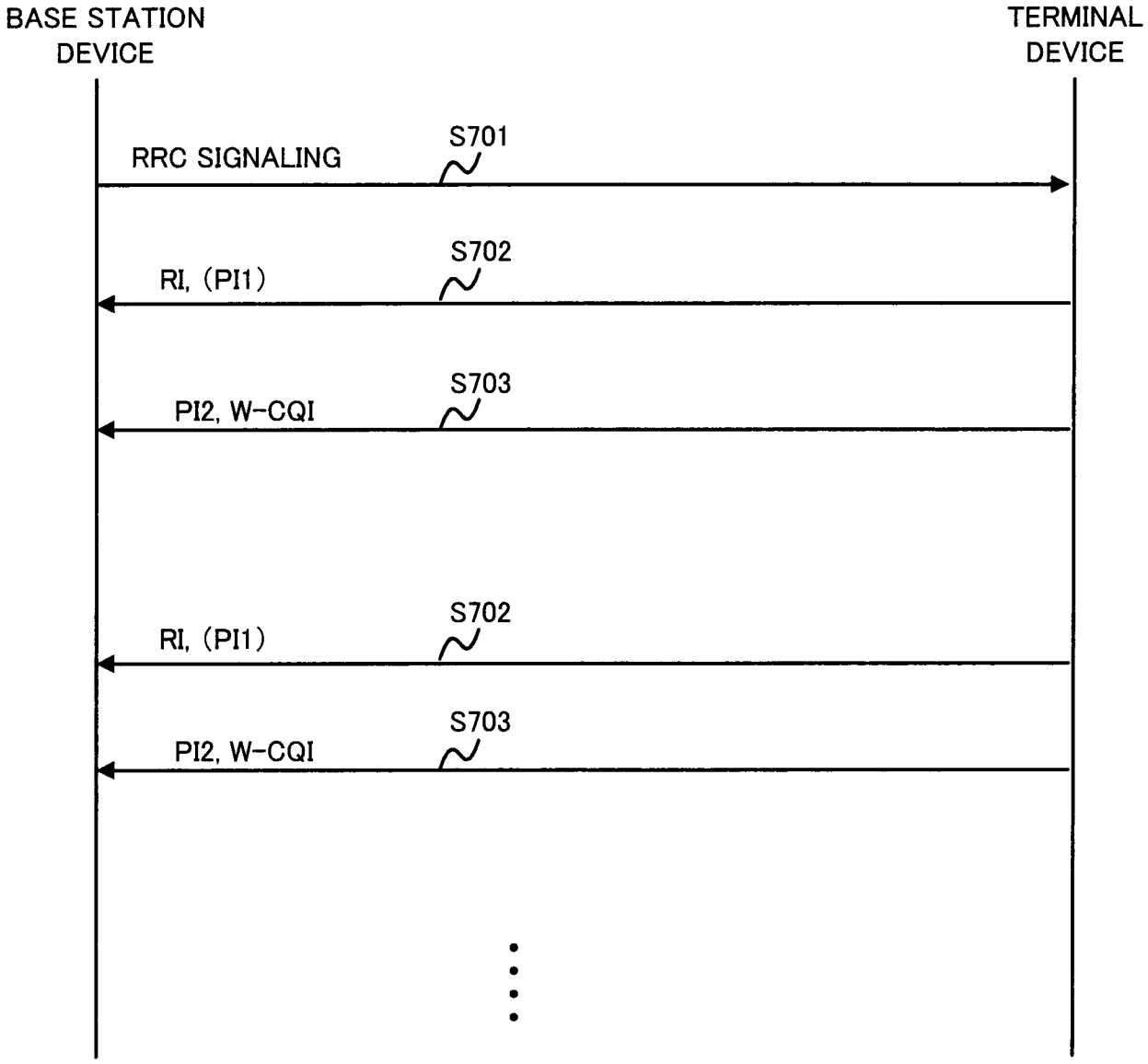

BASE STATION DEVICE
TERMINAL DEVICE
S701
RRC SIGNALING
S702
RI, (PI1)
S703
PI2, W-CQI
S702
RI, (PI1)
S703
PI2, W-CQI

FIG. 27

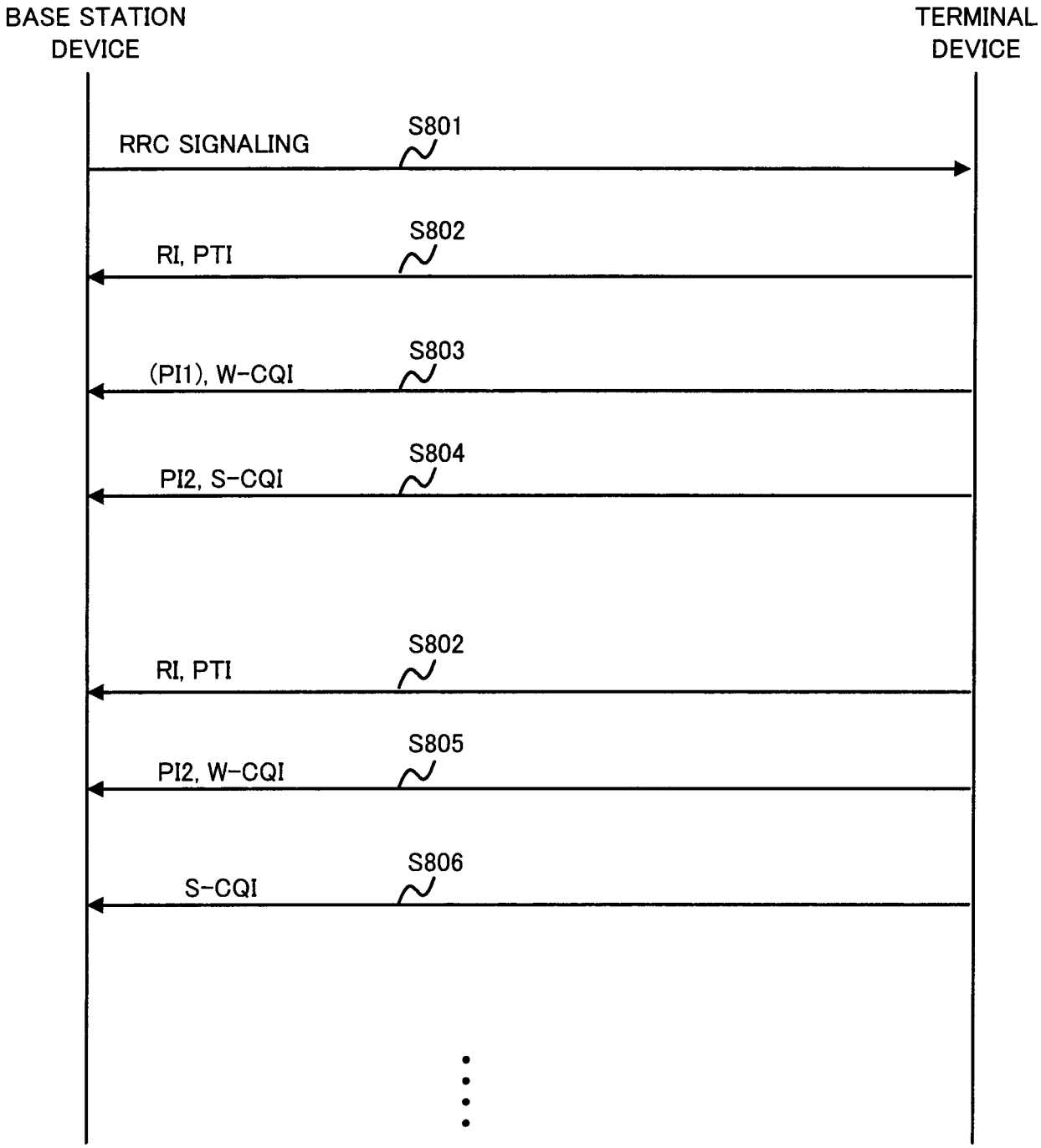

BASE STATION DEVICE
TERMINAL DEVICE
S801
RRC SIGNALING
S802
RI, PTI
S803
(PI1), W-CQI
S804
PI2, S-CQI
S802
RI, PTI
S805
PI2, W-CQI
S806
S-CQI

FIG. 28

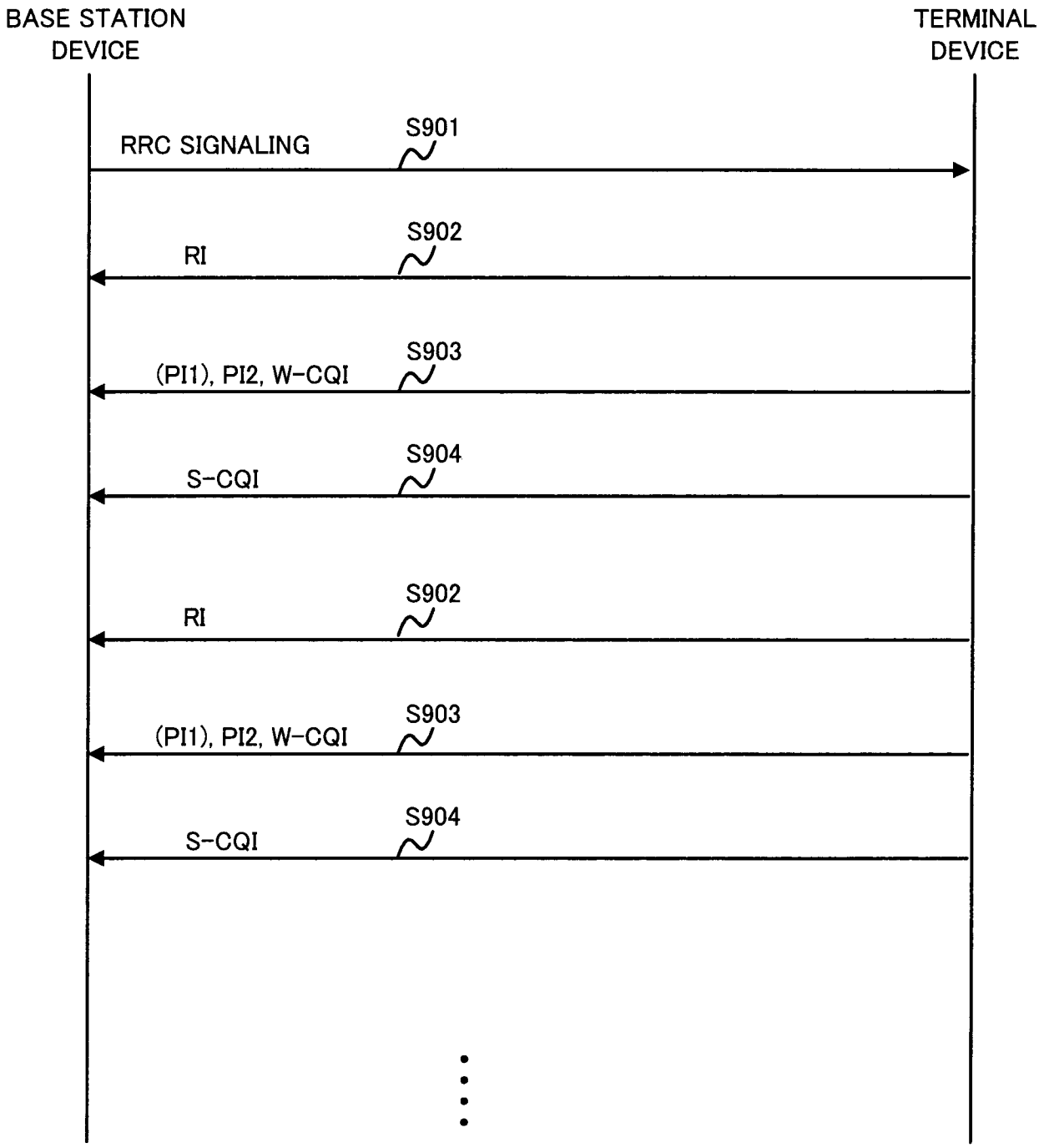

BASE STATION DEVICE
TERMINAL DEVICE
RRC SIGNALING
S901
RI
S902
(PI1), PI2, W-CQI
S903
S-CQI
S904
RI
S902
(PI1), PI2, W-CQI
S903
S-CQI
S904

FIG. 29

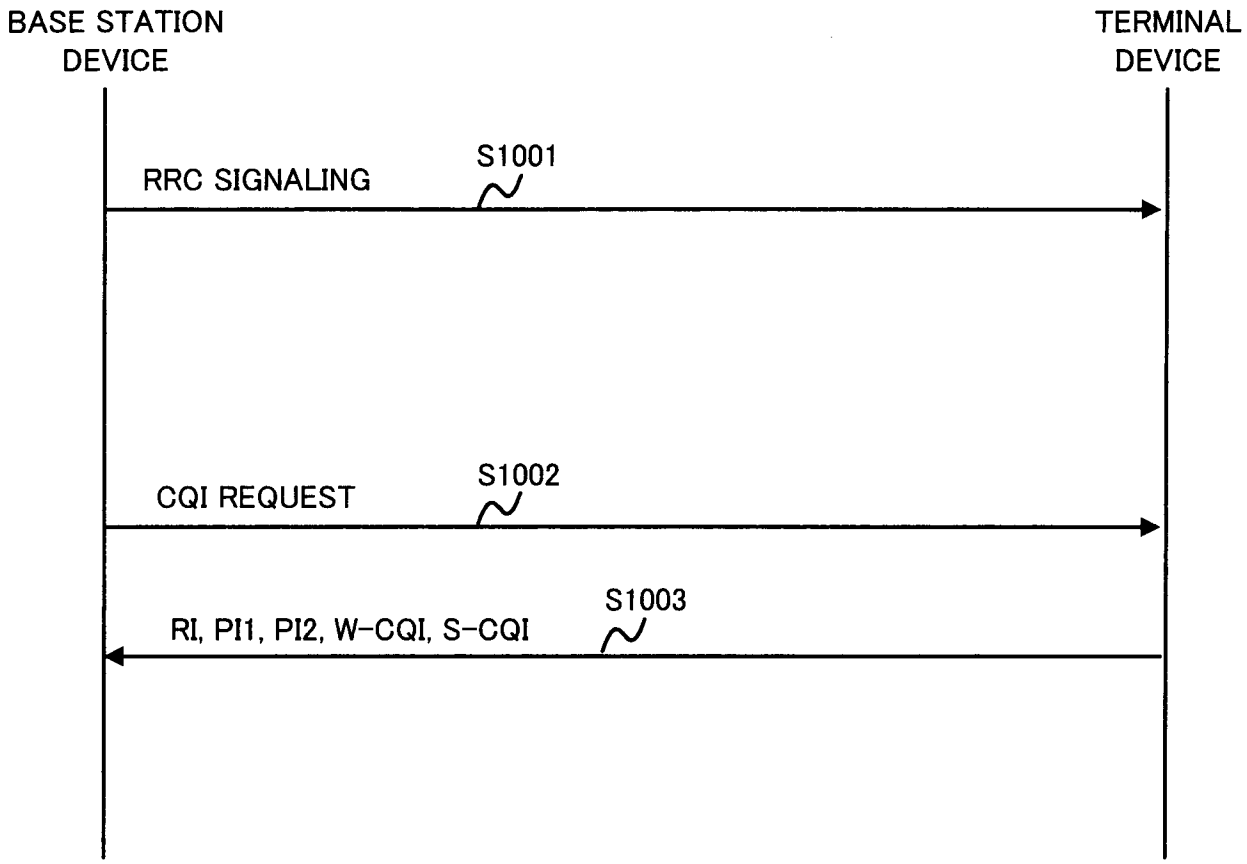

BASE STATION DEVICE
TERMINAL DEVICE
RRC SIGNALING
S1001
CQI REQUEST
S1002
RI, PI1, PI2, W-CQI, S-CQI
S1003

FIG. 30

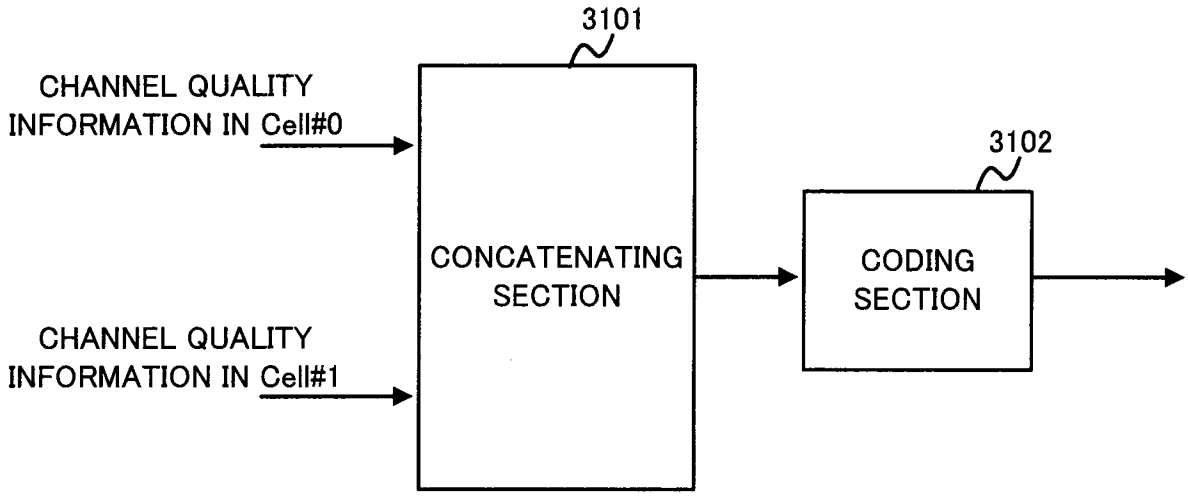

3101
CHANNEL QUALITY INFORMATION IN Cell#0
CHANNEL QUALITY INFORMATION IN Cell#1
CONCATENATING SECTION
3102
CODING SECTION

FIG. 31

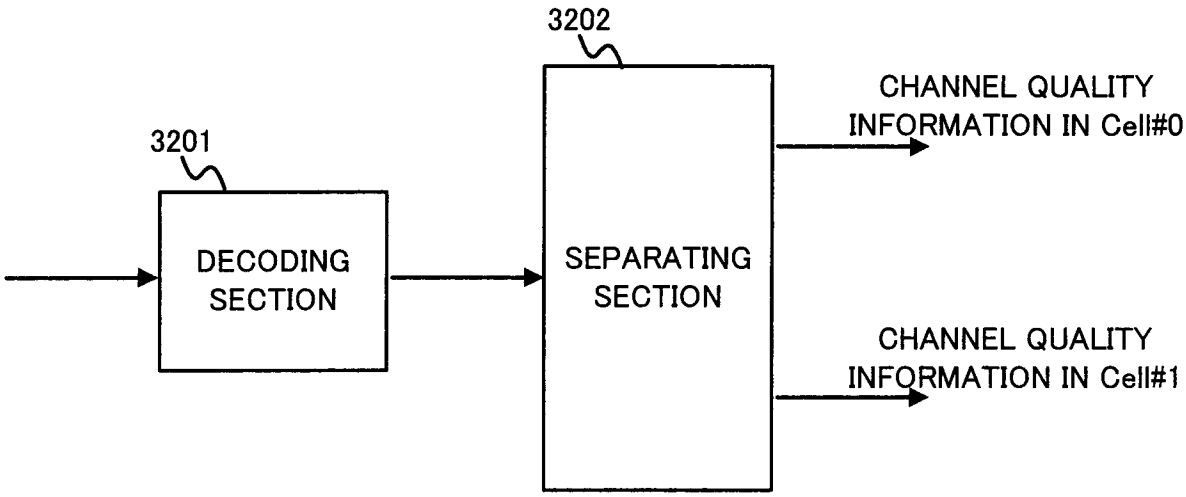

3202
3201
DECODING SECTION
SEPARATING SECTION
CHANNEL QUALITY INFORMATION IN Cell#0
CHANNEL QUALITY INFORMATION IN Cell#1

FIG. 32

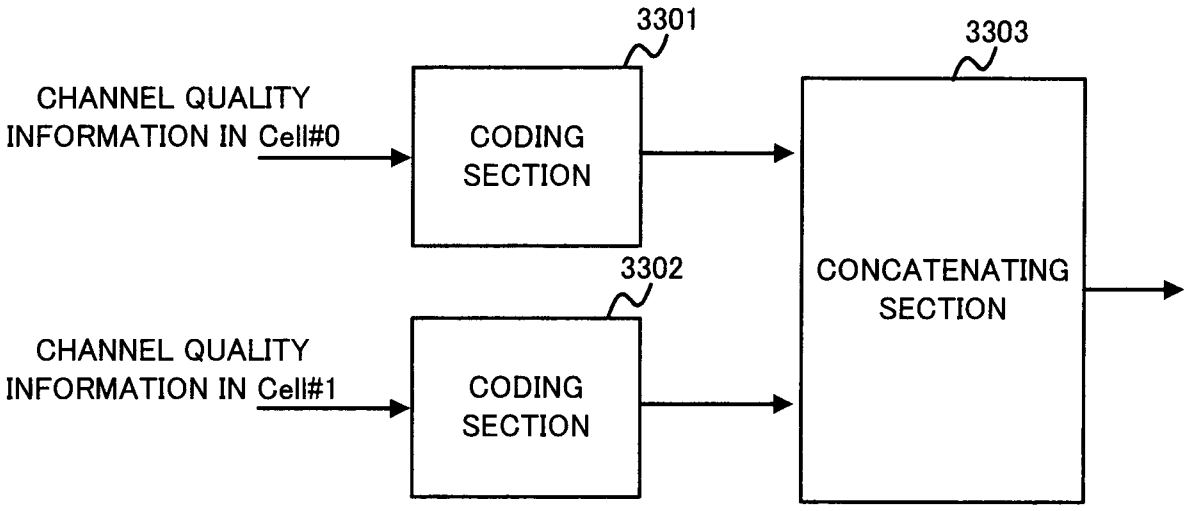
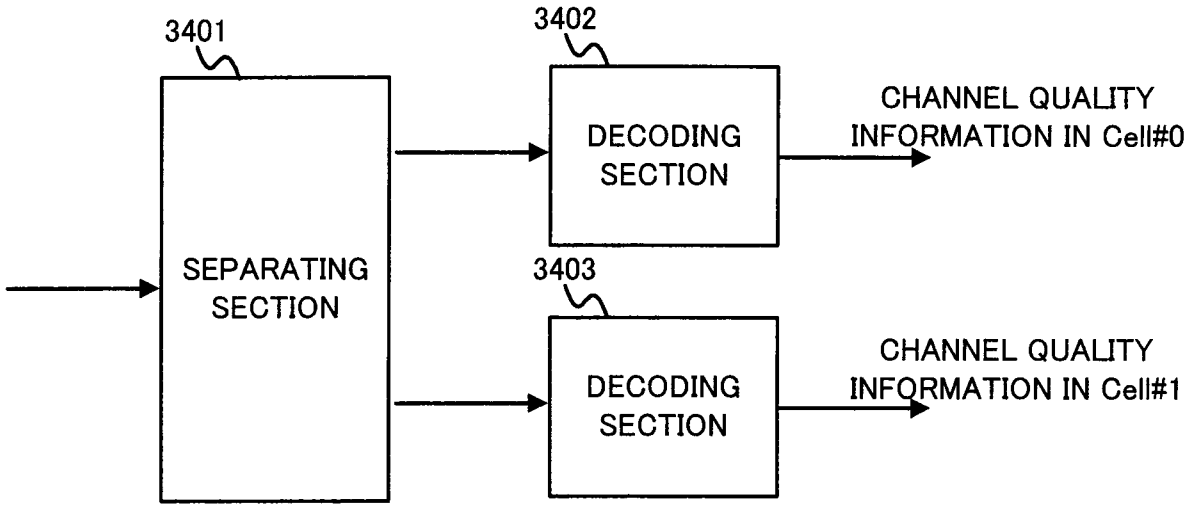

3301
3303
CHANNEL QUALITY INFORMATION IN Cell#0
CODING SECTION
3302
CONCATENATING SECTION
CHANNEL QUALITY INFORMATION IN Cell#1
CODING SECTION

FIG. 33


3401
3402
SEPARATING SECTION
DECODING SECTION
CHANNEL QUALITY INFORMATION IN Cell#0
3403
DECODING SECTION
CHANNEL QUALITY INFORMATION IN Cell#1

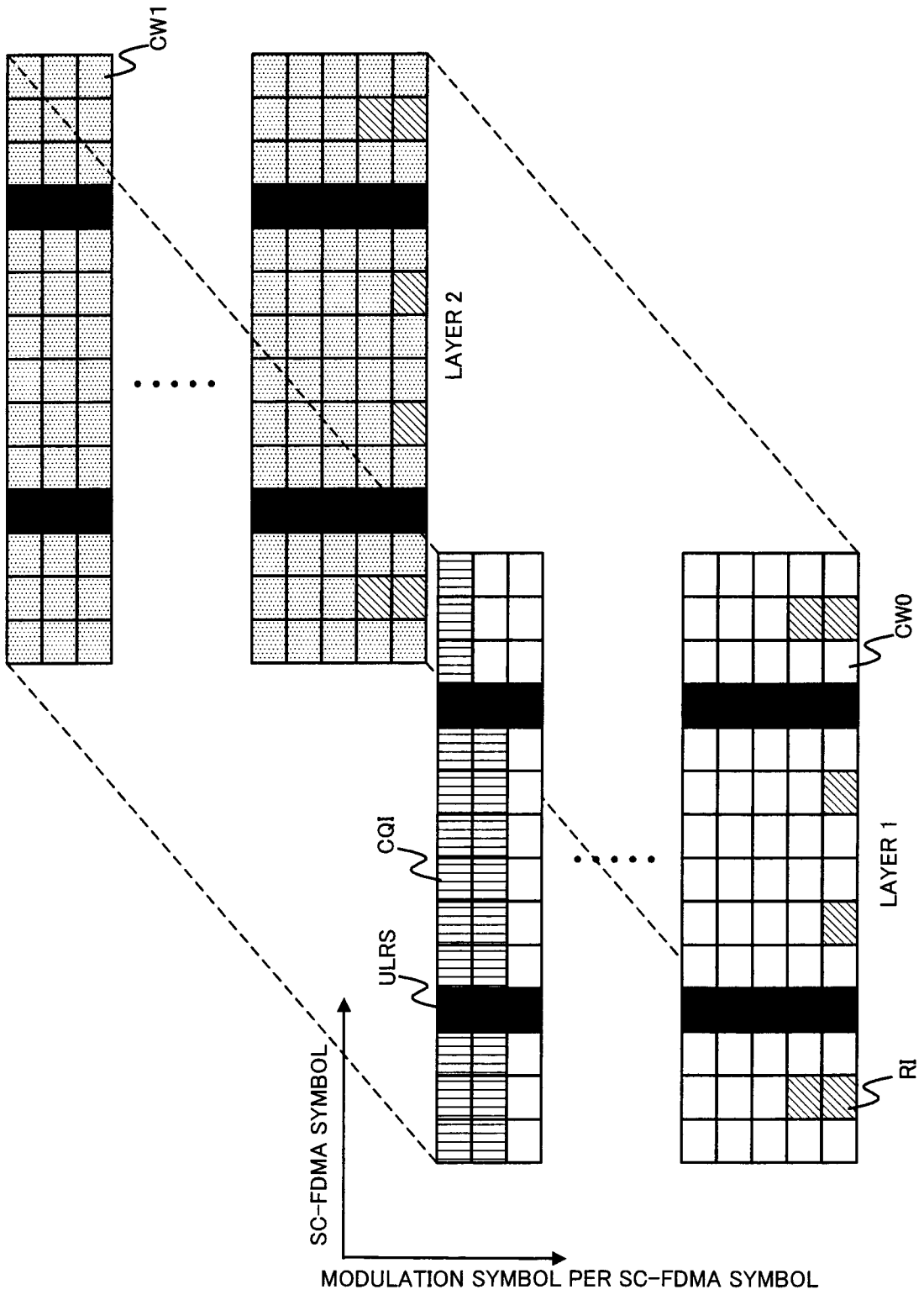
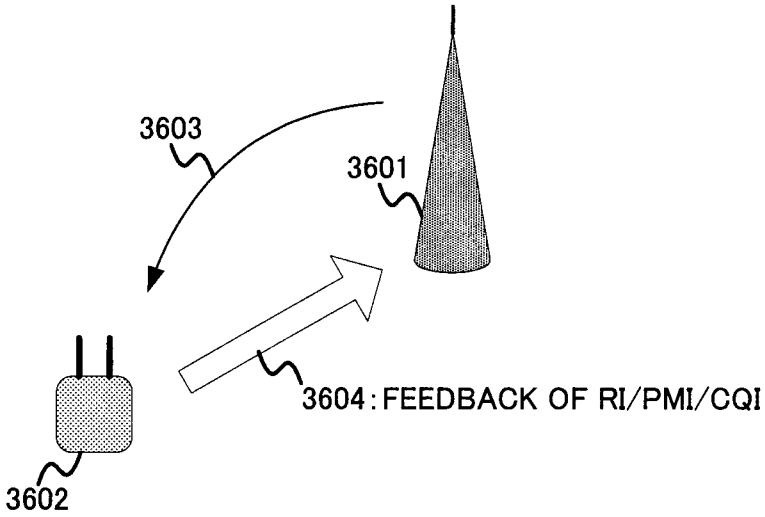

CW1
LAYER 2
CW0
LAYER 1
CQI
ULRS
RI
SC-FDMA SYMBOL
MODULATION SYMBOL PER SC-FDMA SYMBOL

FIG. 34

FIG. 35



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/077287

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H04W24/10(2009.01)i, H04J1/00(2006.01)i, H04J11/00(2006.01)i, H04J99/00(2009.01)i, H04W72/12(2009.01)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)

Int.Cl. H04W24/10, H04J1/00, H04J11/00, H04J99/00, H04W72/12

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2012
Registered utility model specifications of Japan 1996-2012
Published registered utility model applications of Japan 1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/105653 A2 (PANASONIC CORPORATION) 2010.09.23, page 22 line 7 - page 23 line 3, page 35 line 23 - page 37 line 19, fig.9, fig.13 & EP 2230786 A1	1-37
A	ZTE, Issues on UCI transmission on PUSCH in LTE-A, [online]. 3GPP TSG RAN WG1 Meeting #62, 2010.08.27, R1-104673, [retrieved on 2012-02-08]. Retrieved from the Internet: <URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_62/Docs/R1-104673.zip>	1-37
A	WO 2010/126339 A1 (SAMSUNG ELECTRONICS CO., LTD.) 2010.11.04, whole document & US 2010/0278109 A1	1-37

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08.02.2012	21.02.2012

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/077287

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Sharp, Periodic CQI Reporting for Multiple Component Carriers, [online]. 3GPP TSG-RAN WG1#61bis, 2010.07.02, R1-103718, [retrieved on 2012-02-08]. Retrieved from the Internet: <URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_61b/Docs/R1-103718.zip>	1-37