US009271279B2

(12) **United States Patent**
Khoshnevis et al.

(10) **Patent No.: US 9,271,279 B2**
(45) **Date of Patent: Feb. 23, 2016**

(54) **CHANNEL STATE MEASUREMENT AND REPORTING**

(71) Applicant: **Sharp Laboratories of America, Inc.**, Camas, WA (US)

(72) Inventors: **Ahmad Khoshnevis**, Portland, OR (US); **Shohei Yamada**, Camas, WA (US); **Zhanping Yin**, Vancouver, WA (US)

(73) Assignee: **Sharp Laboratories of America, Inc.**, Camas, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 77 days.

(21) Appl. No.: **13/891,162**

(22) Filed: **May 9, 2013**

(65) **Prior Publication Data**

US 2014/0334391 A1 Nov. 13, 2014

(51) **Int. Cl.**

H04W 4/00	(2009.01)
H04W 72/04	(2009.01)
H04L 5/00	(2006.01)
H04L 1/00	(2006.01)
H04L 5/14	(2006.01)

(52) **U.S. Cl.**

CPC ***H04W 72/0413*** (2013.01); ***H04L 1/00*** (2013.01); ***H04L 5/0048*** (2013.01); ***H04L 5/0057*** (2013.01); ***H04L 5/0078*** (2013.01); *H04L 5/001* (2013.01); *H04L 5/0023* (2013.01); *H04L 5/14* (2013.01)

(58) **Field of Classification Search**

USPC 370/252–311, 328–480; 375/224–260; 455/452–562

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,305,987	B2 *	11/2012	Fong et al.	370/329
8,537,911	B2 *	9/2013	Sayana et al.	375/260
8,559,879	B2 *	10/2013	Bhushan et al.	455/63.1
8,588,252	B2 *	11/2013	Montojo et al.	370/471
8,675,528	B2 *	3/2014	Khoshnevis et al.	370/310
8,681,627	B2 *	3/2014	Choudhury et al.	370/235
8,767,581	B2 *	7/2014	Yamada	370/252
8,825,069	B2 *	9/2014	Koivisto et al.	455/452.1
8,885,496	B2 *	11/2014	Yin et al.	370/252
2012/0076106	A1 *	3/2012	Bhattad et al.	370/330
2012/0287875	A1 *	11/2012	Kim et al.	370/329
2013/0077518	A1 *	3/2013	Abe et al.	370/252
2013/0094384	A1 *	4/2013	Park et al.	370/252
2013/0242778	A1 *	9/2013	Geirhofer et al.	370/252
2013/0315197	A1 *	11/2013	Park et al.	370/329

(Continued)

FOREIGN PATENT DOCUMENTS

WO 2011/115421 9/2011

OTHER PUBLICATIONS

"Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 11)", 3GPP TS 36.213 V11.2.0, 2013.02, pp. 52-86.

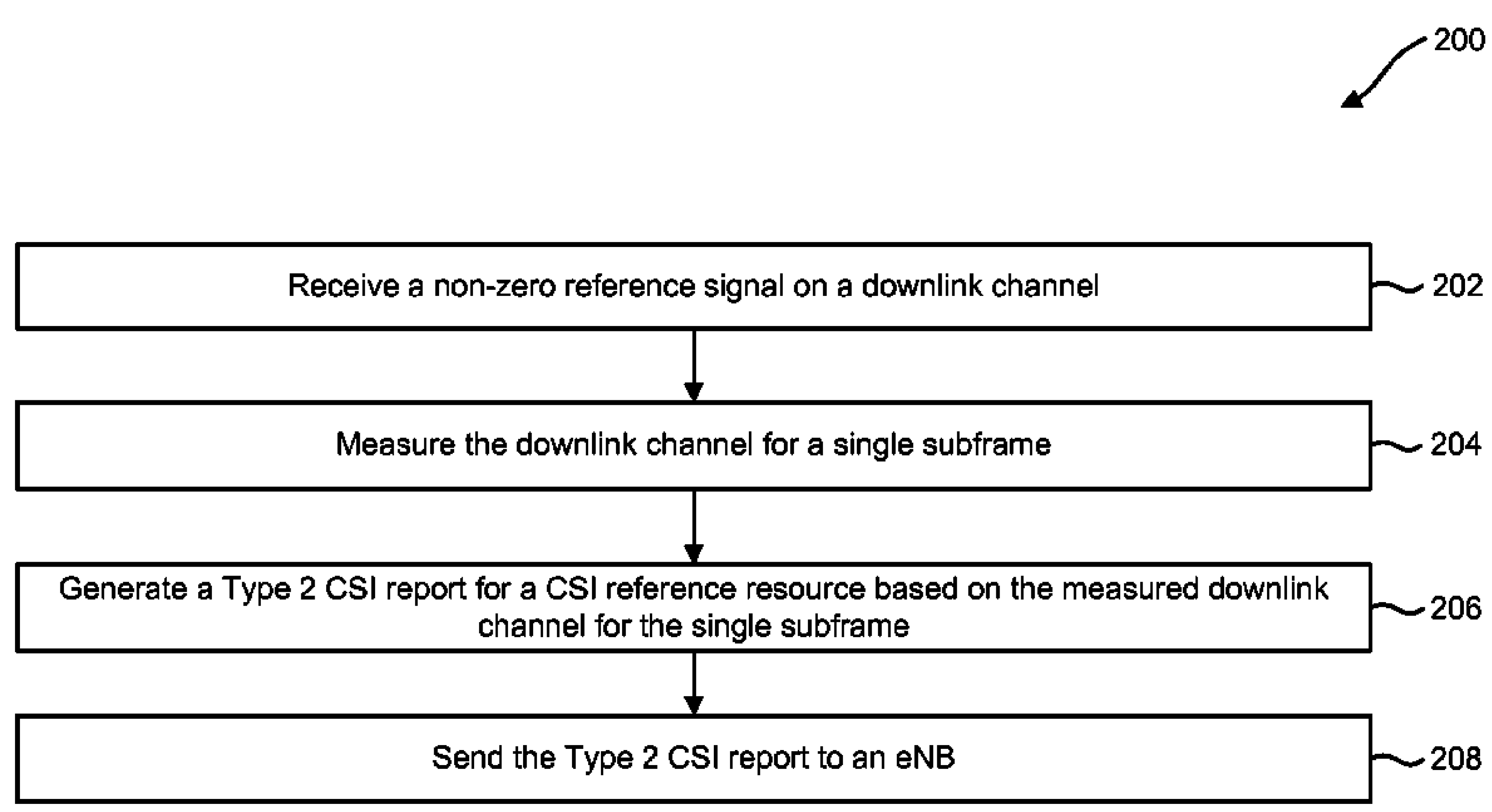
(Continued)

Primary Examiner — Man Phan
(74) *Attorney, Agent, or Firm* — Austin Rapp & Hardman

(57) **ABSTRACT**

A method for reporting uplink control information (UCI) on a user equipment (UE) is described. A Type 2 channel state information (CSI) report is generated for a CSI reference resource. The Type 2 CSI report is sent to a base station. The Type 2 CSI report is computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process.

37 Claims, 9 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0038623	A1 *	2/2014	Davydov et al.	455/450
2014/0044040	A1 *	2/2014	Chen et al.	370/328

OTHER PUBLICATIONS

Samsung, "CQI Reference Resource Timing for LTE-A", 3GPP TSG RAN WG1 #63bis, R1-110089, Jan. 2011, pp. 1-5.

International Search Report issued for International Patent Application No. PCT/JP2014-002461 on May 9, 2014.

3GPP TS 36.213 V9.1.0, Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Layer Procedures, (Release 9), Mar. 2010.

3GPP TS 36.212 V9.2.0, Evolved Universal Terrestrial Radio Access (E-UTRA) Multiplexing and Channel Coding, (Release 9), Jun. 2010.

3GPP TS 36.211 V9.0.0, Evolved Universal Terrestrial Radio Access (E-UTRA) Physical Channels and Modulation, (Release 9), Dec. 2012.

3GPP TS 36.300 V8.5.0, Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN), (Release 8), May 2008.

3GPP TS 36.331 V9.1.0, Evolved Universal Terrestrial Radio Access (E-UTRA) Radio Resource Control (RRC), Protocol Specification, (Release 9), Dec. 2009.

* cited by examiner

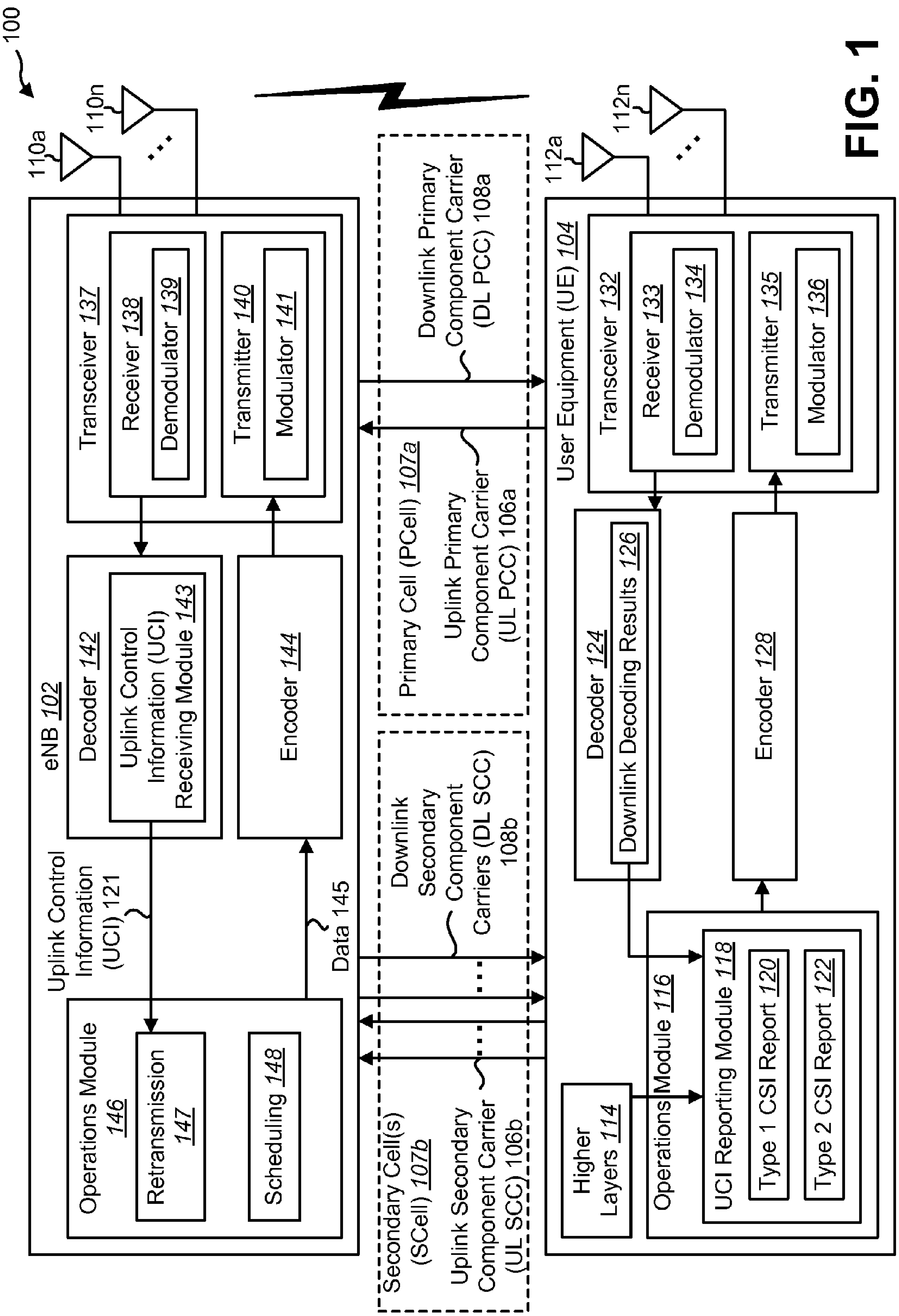

100
110a
110n
eNB 102
Transceiver 137
Receiver 138
Demodulator 139
Transmitter 140
Modulator 141
Decoder 142
Uplink Control Information (UCI) Receiving Module 143
Encoder 144
Uplink Control Information (UCI) 121
Data 145
Operations Module 146
Retransmission 147
Scheduling 148
Downlink Primary Component Carrier (DL PCC) 108a
Primary Cell (PCell) 107a
Uplink Primary Component Carrier (UL PCC) 106a
Downlink Secondary Component Carriers (DL SCC) 108b
Secondary Cell(s) (SCell) 107b
Uplink Secondary Component Carrier (UL SCC) 106b
112a
112n
User Equipment (UE) 104
Transceiver 132
Receiver 133
Demodulator 134
Transmitter 135
Modulator 136
Decoder 124
Downlink Decoding Results 126
Encoder 128
Higher Layers 114
Operations Module 116
UCI Reporting Module 118
Type 1 CSI Report 120
Type 2 CSI Report 122

FIG. 1

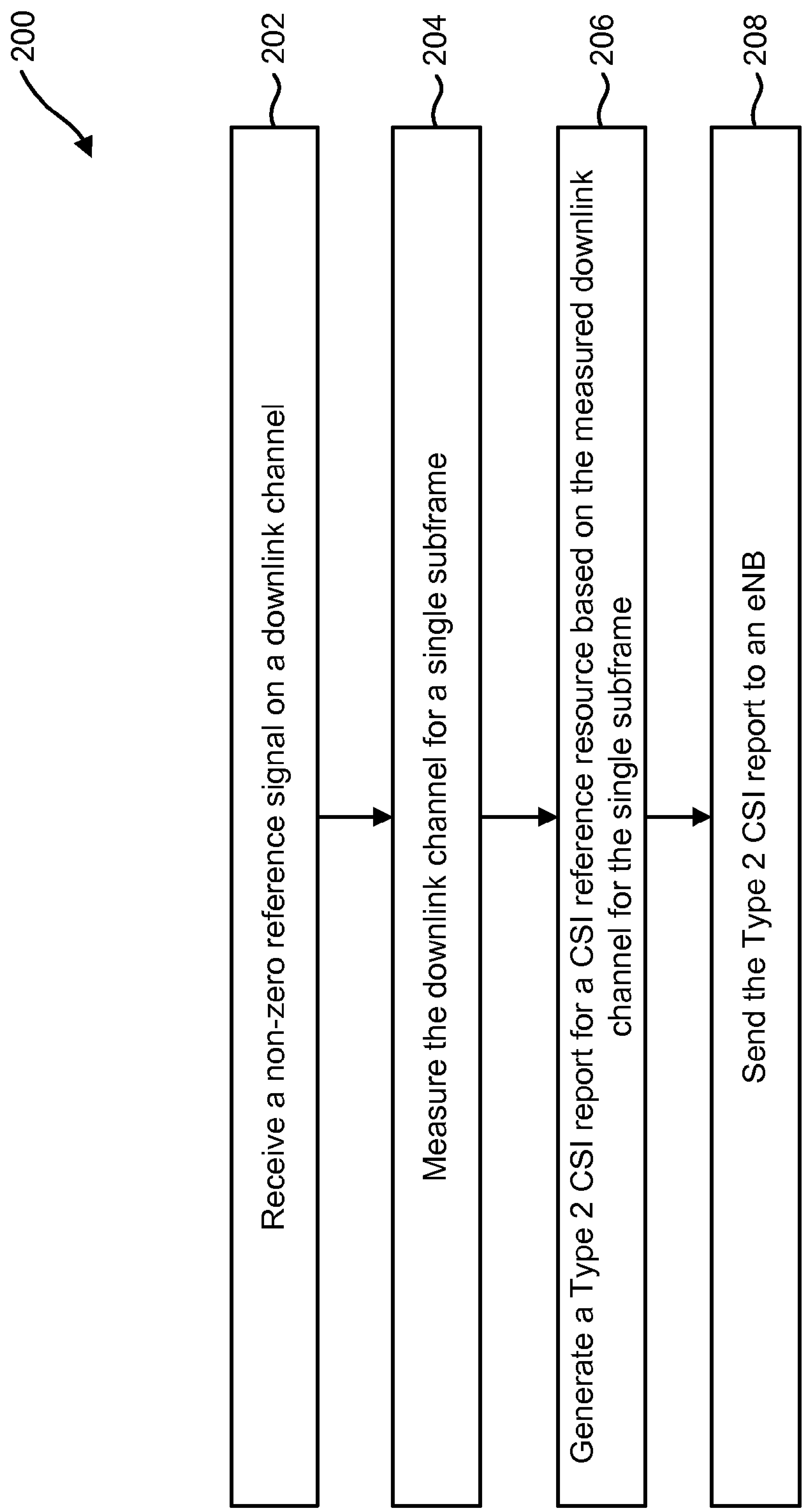

200
202
Receive a non-zero reference signal on a downlink channel
204
Measure the downlink channel for a single subframe
206
Generate a Type 2 CSI report for a CSI reference resource based on the measured downlink channel for the single subframe
208
Send the Type 2 CSI report to an eNB

FIG. 2

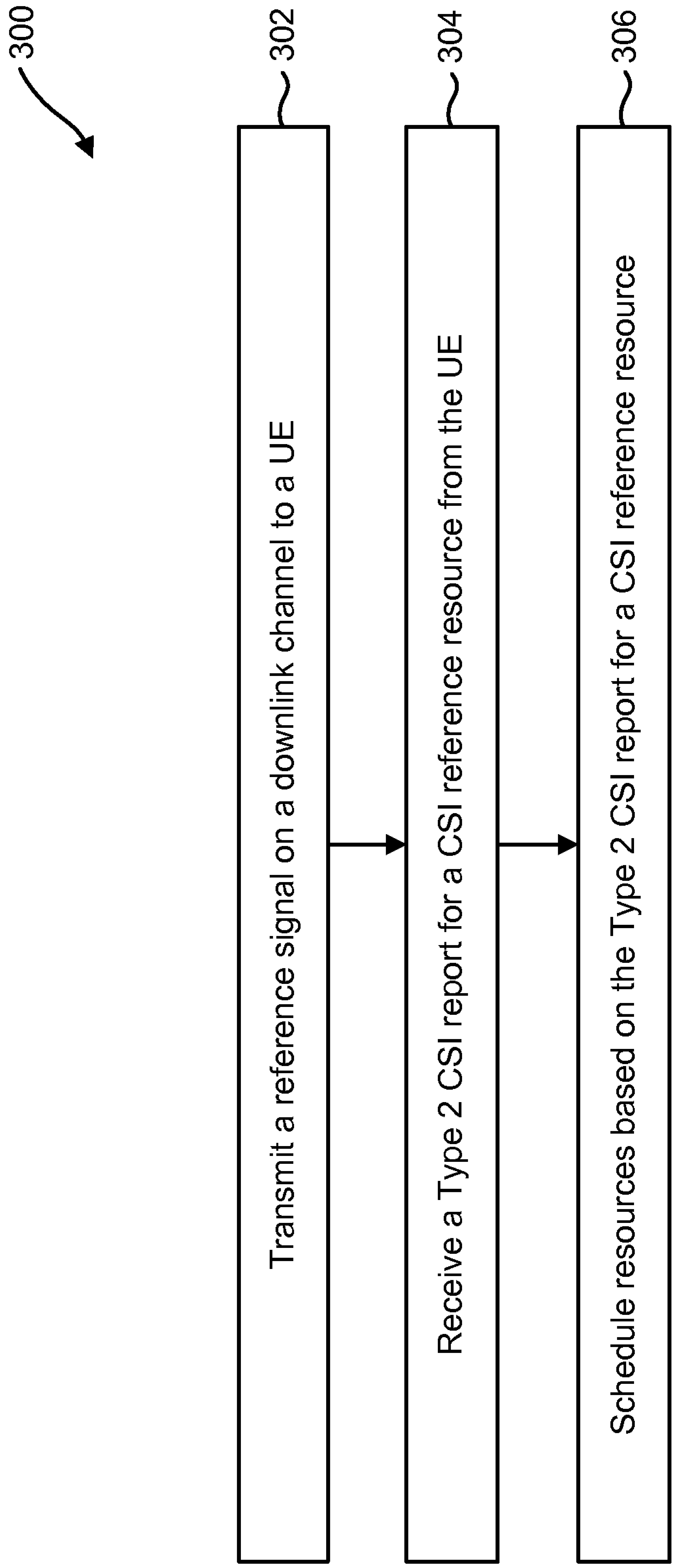

300
302
Transmit a reference signal on a downlink channel to a UE
304
Receive a Type 2 CSI report for a CSI reference resource from the UE
306
Schedule resources based on the Type 2 CSI report for a CSI reference resource

FIG. 3

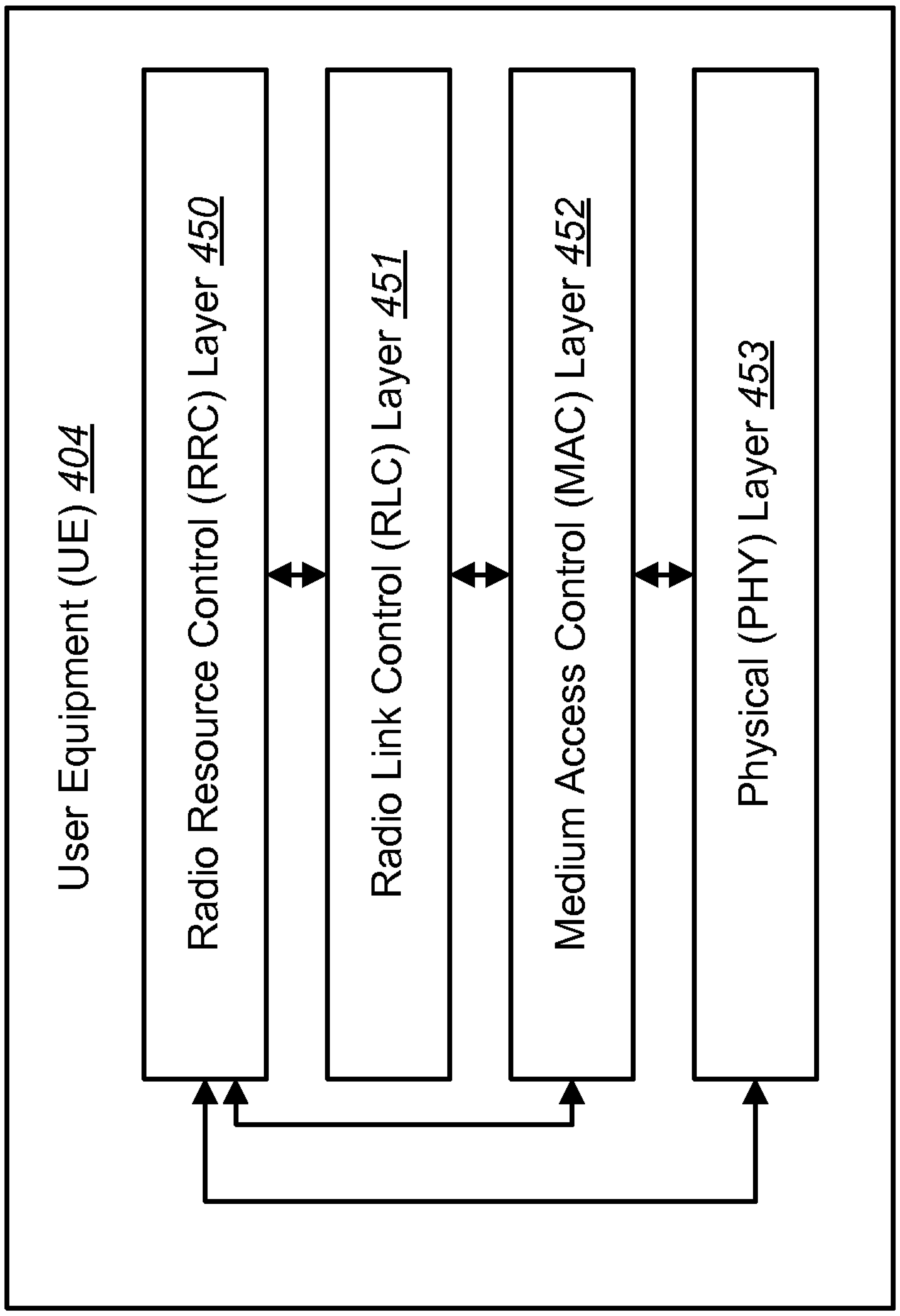

User Equipment (UE) 404
Radio Resource Control (RRC) Layer 450
Radio Link Control (RLC) Layer 451
Medium Access Control (MAC) Layer 452
Physical (PHY) Layer 453

FIG. 4

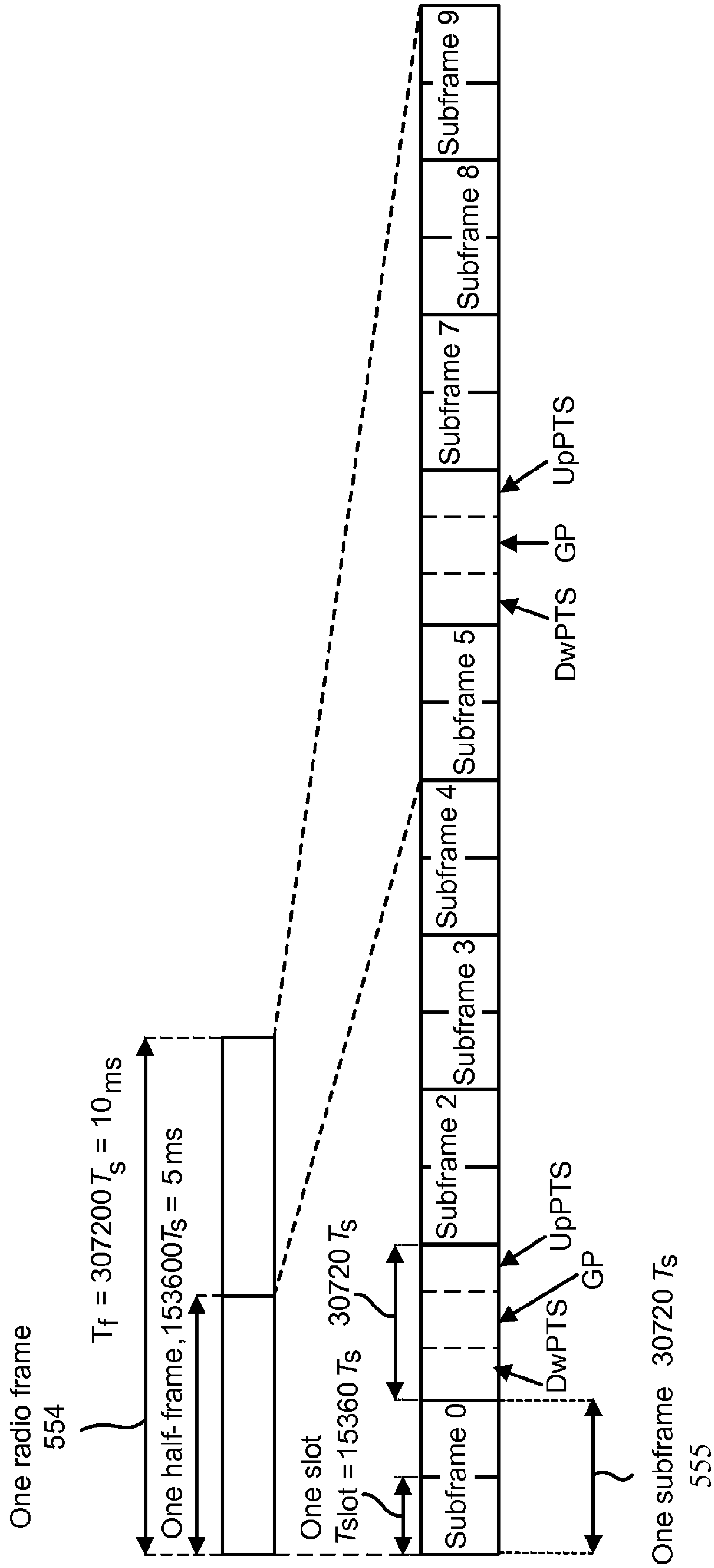

One radio frame
554
$T_f = 307200\,T_s = 10$ ms
One half-frame, $153600\,T_s = 5$ ms
One slot
$T_{slot} = 15360\,T_s$
$30720\,T_s$
Subframe 0
Subframe 2
Subframe 3
Subframe 4
Subframe 5
Subframe 7
Subframe 8
Subframe 9
DwPTS
GP
UpPTS
One subframe $30720\,T_s$
555

FIG. 5

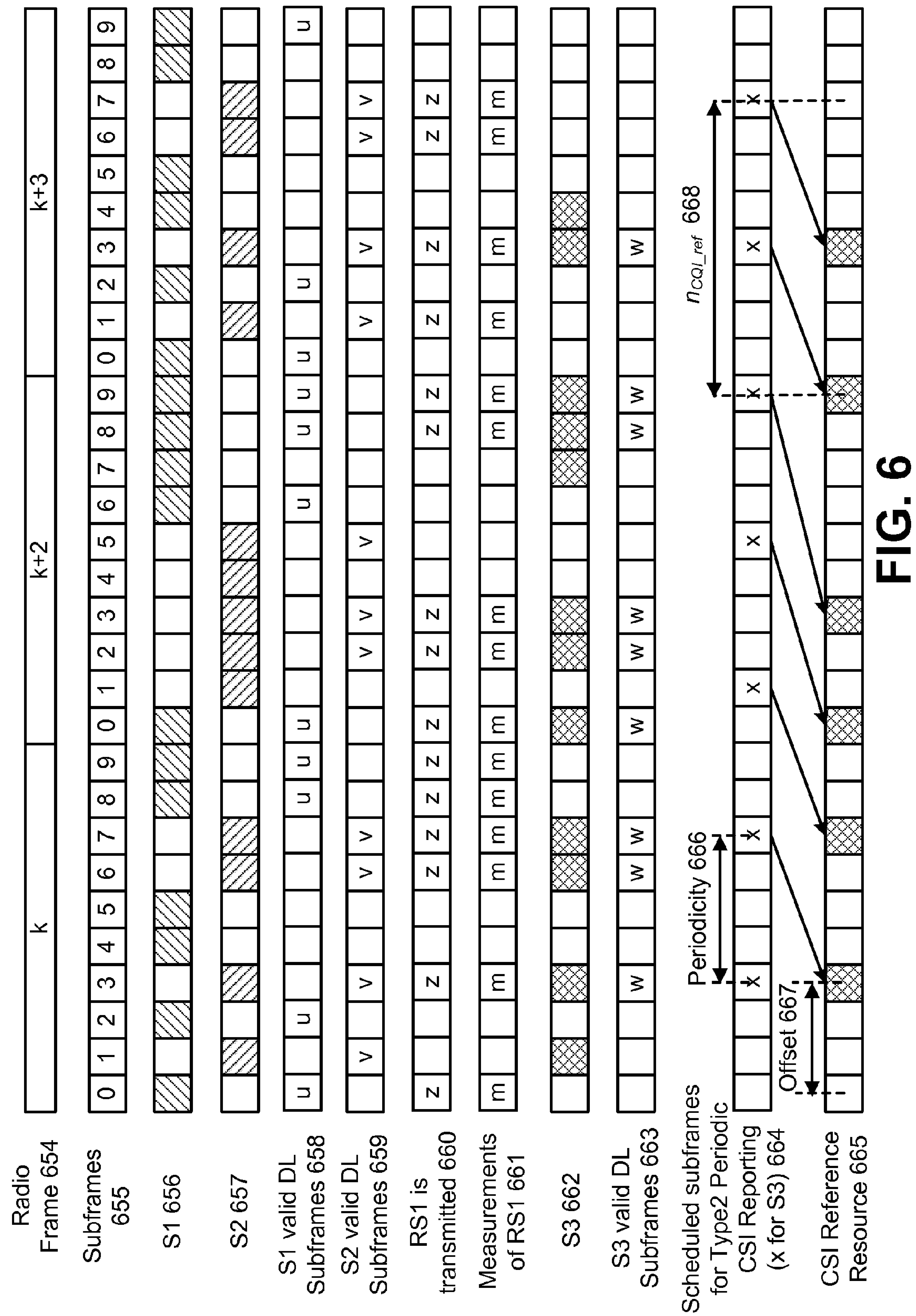

Radio Frame 654
k
k+2
k+3
Subframes 655
S1 656
S2 657
S1 valid DL Subframes 658
S2 valid DL Subframes 659
RS1 is transmitted 660
Measurements of RS1 661
S3 662
S3 valid DL Subframes 663
Scheduled subframes for Type2 Periodic CSI Reporting (x for S3) 664
CSI Reference Resource 665
Periodicity 666
Offset 667
n_{CQI_ref} 668

FIG. 6

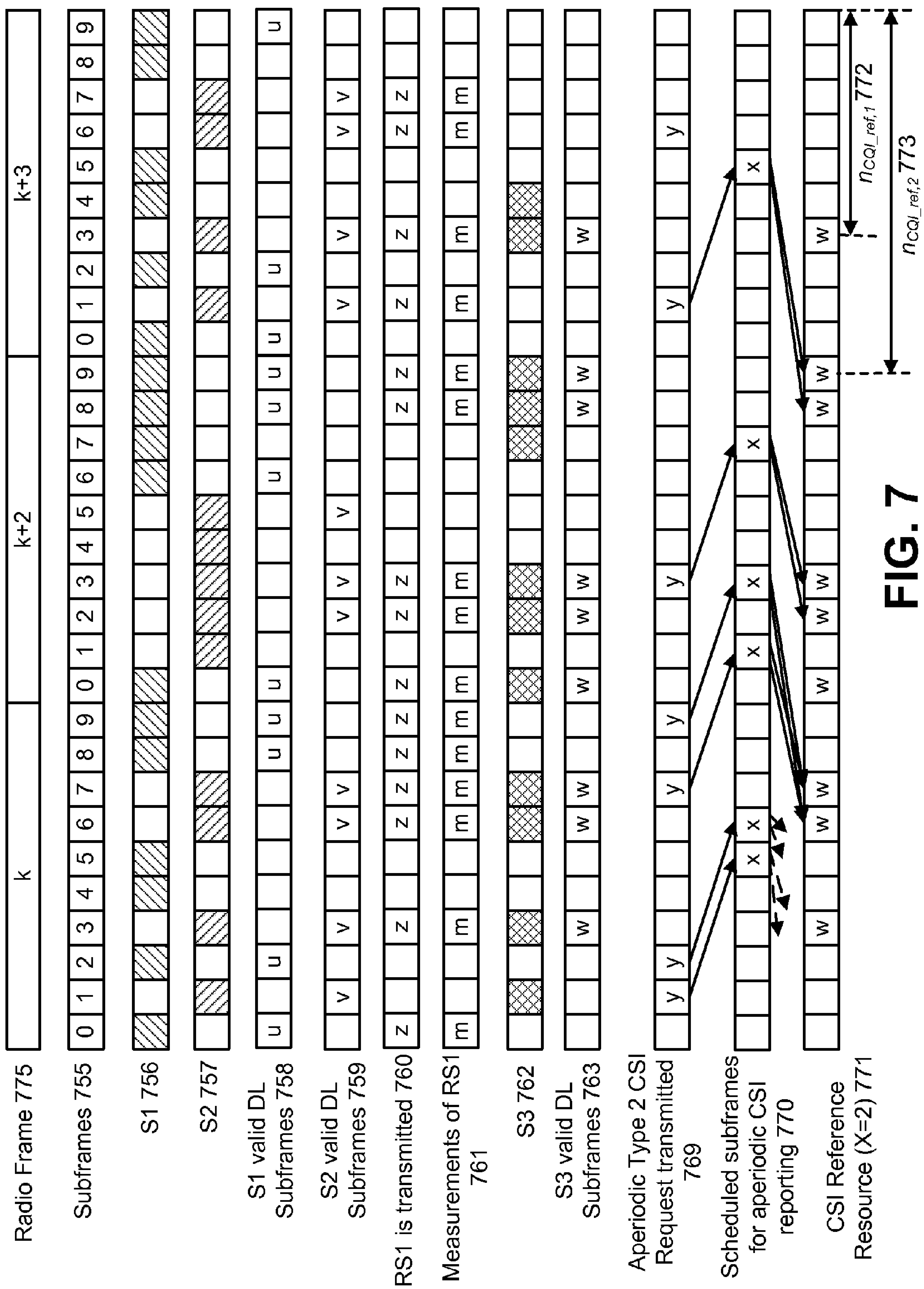

Radio Frame 775
k
k+2
k+3
Subframes 755
S1 756
S2 757
S1 valid DL Subframes 758
S2 valid DL Subframes 759
RS1 is transmitted 760
Measurements of RS1 761
S3 762
S3 valid DL Subframes 763
Aperiodic Type 2 CSI Request transmitted 769
Scheduled subframes for aperiodic CSI reporting 770
CSI Reference Resource (X=2) 771
$n_{CQI\_ref,1}$ 772
$n_{CQI\_ref,2}$ 773

FIG. 7

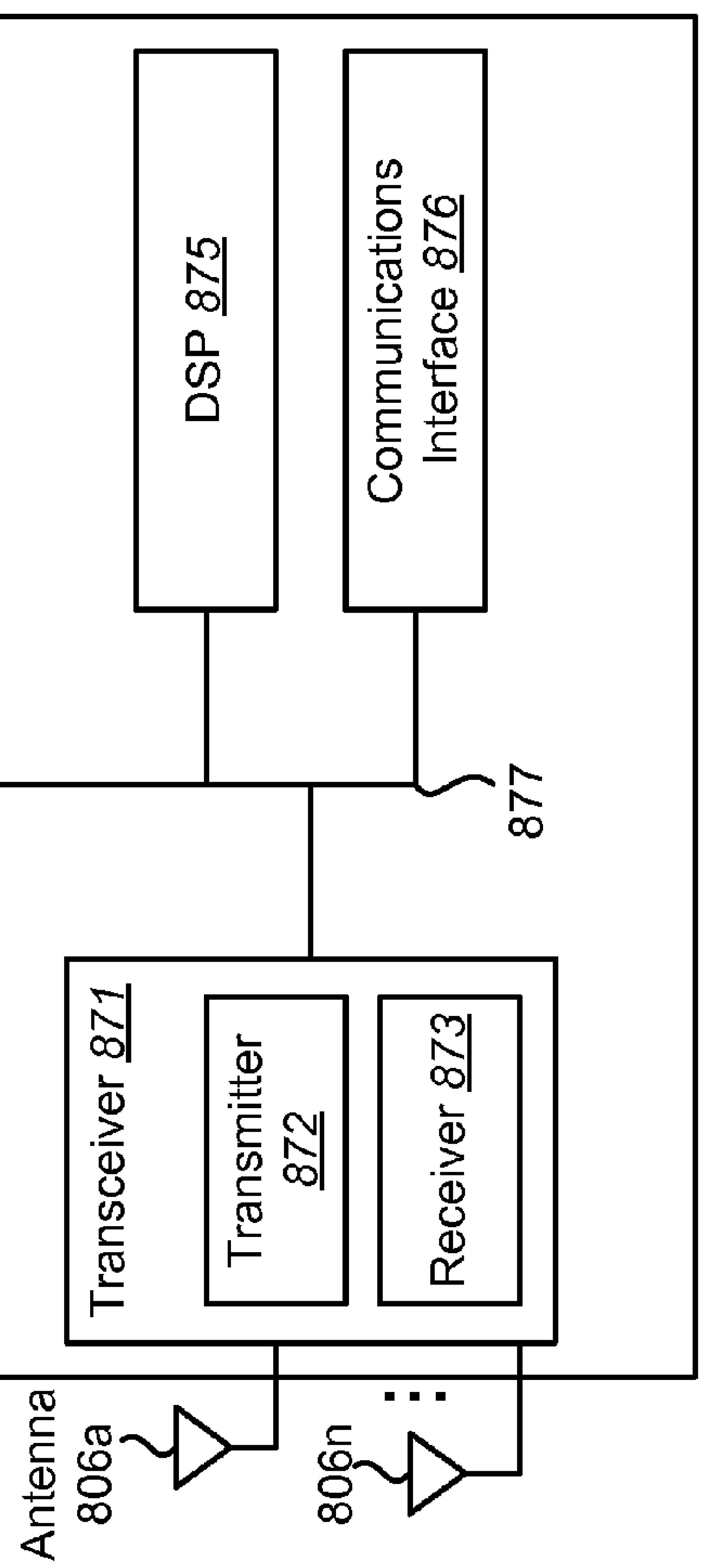

User Equipment (UE) 804
Memory 874
Instructions 856a
Data 858a
DSP 875
Communications Interface 876
Processor 854
Instructions 856b
Data 858b
Transceiver 871
Transmitter 872
Receiver 873
877
Antenna 806a
806n

FIG. 8

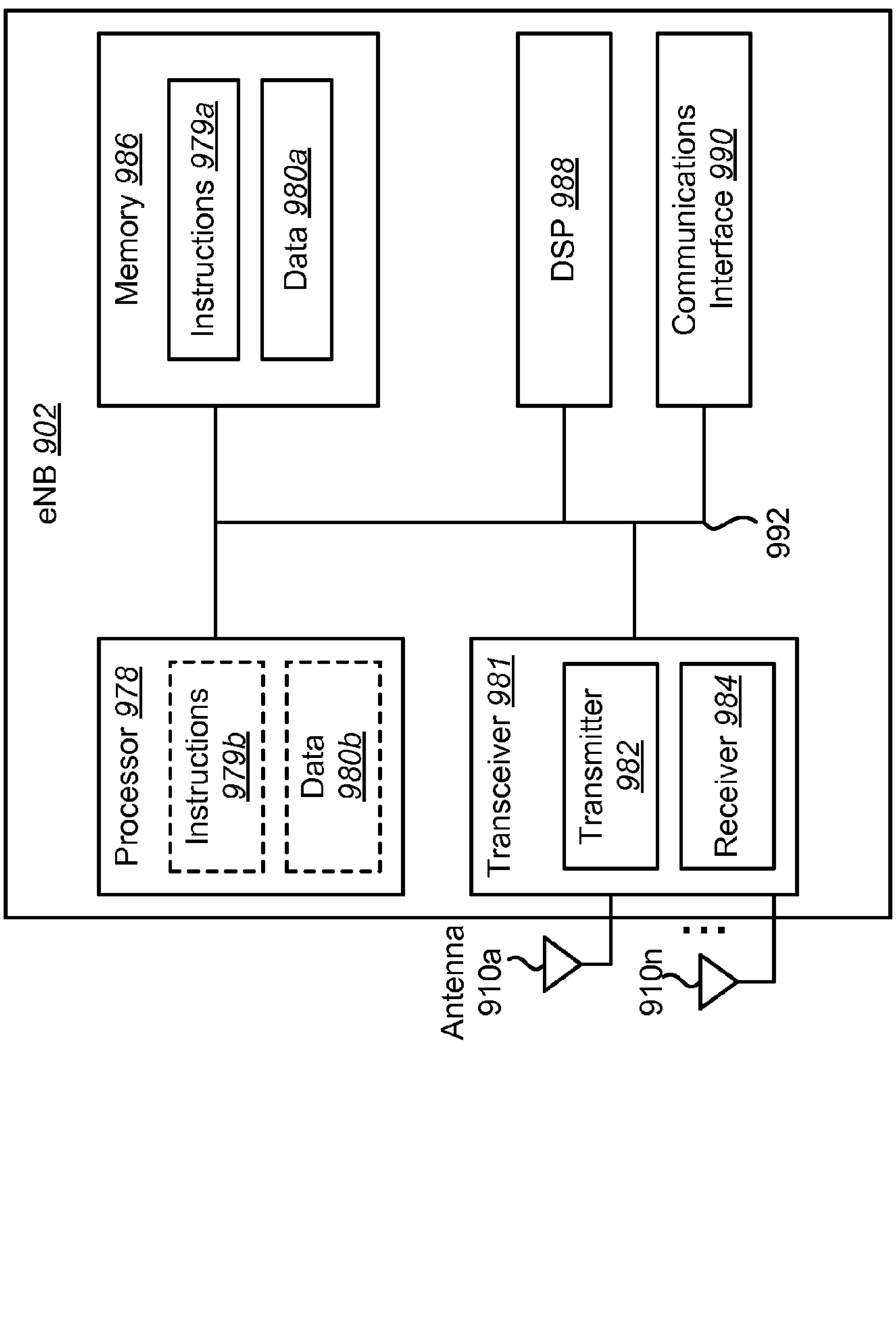

eNB 902
Memory 986
Instructions 979a
Data 980a
DSP 988
Communications Interface 990
992
Processor 978
Instructions 979b
Data 980b
Transceiver 981
Transmitter 982
Receiver 984
Antenna 910a
910n

FIG. 9

CHANNEL STATE MEASUREMENT AND REPORTING

TECHNICAL FIELD

The present invention relates generally to wireless communications and wireless communications-related technology. More specifically, the present invention relates to systems and methods for channel state measurement and reporting.

BACKGROUND

Wireless 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 wireless communication devices and have come to expect reliable service, expanded areas of coverage and increased functionality. A wireless 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.

Various signal processing techniques may be used in wireless communication systems to improve efficiency and quality of wireless communication. Benefits may be realized by improved methods for reporting uplink control information (UCI) by a wireless communication device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustrating a wireless communication system that utilizes Type 2 CSI reporting;

FIG. **2** is a flow diagram of a method for Type 2 measurement/reporting;

FIG. **3** is a flow diagram of another method for Type 2 measurement/reporting;

FIG. **4** is a block diagram illustrating the layers used by a user equipment (UE);

FIG. **5** illustrates the slot and subframe structure for Frame Structure Type 2;

FIG. **6** illustrates the procedures for determining the CSI reference resources for periodic Type 2 CSI measurement/reporting;

FIG. **7** illustrates the procedures for determining the CSI reference resources for aperiodic Type 2 CSI measurement/reporting;

FIG. **8** illustrates various components that may be utilized in a user equipment (UE); and

FIG. **9** illustrates various components that may be utilized in an eNB.

DETAILED DESCRIPTION

A method for receiving uplink control information (UCI) is described. A Type 2 channel state information (CSI) report for a CSI reference resource is received from a user equipment (UE). The Type 2 CSI report is computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process.

The single subframe may be a subframe of the CSI reference resource. The CSI reference resource for the Type 2 CSI report reported in uplink subframe n may be defined by a valid downlink subframe n-nCQI_ref. The valid downlink subframe may be in a set of subframes for a channel measurement for the Type 2 CSI report. The valid downlink subframe may be in a set of subframes in which the non-zero power reference signal is configured.

The valid downlink subframe may be in a set of subframes for Type 2 channel measurement if the set of subframes for Type 2 channel measurement is configured. The valid downlink subframe may be in a set of subframes in which the non-zero power reference signal is configured if the set of subframes for Type 2 channel measurement is not configured. The Type 2 CSI report may be a periodic CSI report. Type 2 CSI reporting may be configured in a CSI process configuration. The Type 2 CSI report may also be an aperiodic CSI report. A field in a downlink control information (DCI) may specify whether Type 2 aperiodic CSI reporting is triggered. The Type 2 CSI report may correspond to a configured CSI process.

A method for reporting uplink control information (UCI) is also described. A Type 2 channel state information (CSI) report for a CSI reference resource is generated. The Type 2 CSI report is sent to a base station. The Type 2 CSI report is computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process.

A base station configured for receiving uplink control information (UCI) is described. The base station includes a processor, memory in electronic communication with the processor and instructions stored in the memory. The instructions are executable to receive a Type 2 channel state information (CSI) report for a CSI reference resource from a user equipment (UE). The Type 2 CSI report is computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process.

A user equipment (UE) configured for reporting uplink control information (UCI) is also described. The UE includes a processor, memory in electronic communication with the processor and instructions stored in the memory. The instructions are executable to generate a Type 2 channel state information (CSI) report for a CSI reference resource. The instructions are also executable to send the Type 2 CSI report to a base station. The Type 2 CSI report is computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process.

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 wireless 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, Release-10 and Release-11). 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 wireless 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.

FIG. **1** is a block diagram illustrating a wireless communication system **100** that utilizes Type 2 CSI reporting. Downlink and uplink transmissions are organized into radio frames. Two radio frame structures are supported: Type 1 (applicable to frequency division duplex (FDD)) and Type 2 (applicable to time division duplex (TDD)). Type 2 CSI reporting is defined as channel measurements for a CSI report that are based on only either or both of a channel measurement in a single subframe and an interference measurement in a single subframe. The details describing Type 2 CSI reporting are given below. In contrast, Type 1 CSI reporting is defined as channel measurements for a CSI report that are based on unrestricted observations or measurements in time and/or frequency. Thus, Type 1 CSI reporting may provide a CSI report that includes channel measurements for the reference signal over multiple contiguous or non-contiguous subframes.

It is possible that some of the subframes measured for Type 1 CSI reporting may not carry a reference signal. If a UE **104** measures the channel in multiple subframes, some of which do not carry a reference signal, and then includes both measurements in generating a report (such as a weighted average of measurements), the generated report may include erroneous measurements. Thus, there is a need for Type 2 CSI reporting to provide more accurate and reliable CSI reports to an eNB **102**. Even though a UE may not know whether a subframe is an uplink, downlink or special subframe, the resulting report may be useful to the eNB, because the eNB is aware of whether a CSI report is generated based on a measurement on a downlink subframe, an uplink subframe or a special subframe.

An eNB **102** may be in wireless communication with one or more user equipments (UEs) **104**. An eNB **102** may also be referred to as an access point, a Node B, an evolved Node B, a base station or some other terminology. Likewise, a user equipment (UE) **104** may also 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 wireless communication device, or some other terminology.

Communication between a user equipment (UE) **104** and an eNB **102** may be accomplished using transmissions over a wireless link, including an uplink and a downlink. The uplink refers to communications sent from a user equipment (UE) **104** to an eNB **102**. The downlink refers to communications sent from an eNB **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 eNB **102** may have multiple antennas **110***a-n* and a user equipment (UE) **104** may have multiple antennas **112***a-n*. In this way, the eNB **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 eNB **102** using one or more antenna ports, which may be realized by one or more physical antennas **112***a-n*. The user equipment (UE) **104** may include a transceiver **132**, a decoder **124**, an encoder **128** and an operations module **116**. The transceiver **132** may include a receiver **133** and a transmitter **135**. The receiver **133** may receive signals from the eNB **102** using one or more antennas **112***a-n*. For example, the receiver **133** may receive and demodulate received signals using a demodulator **134**. The transmitter **135** may transmit signals to the eNB **102** using one or more antenna ports, which may be realized by one or more physical antennas **112***a-n*. For example, the transmitter **135** may modulate signals using a modulator **136** and transmit the modulated signals.

The receiver **133** may provide a demodulated signal to the decoder **124**. The user equipment (UE) **104** may use the decoder **124** to decode signals and make downlink decoding results **126**. The downlink decoding results **126** may indicate whether data was received correctly. For example, the downlink decoding results **126** may indicate whether a packet was correctly or erroneously received (i.e., positive acknowledgement, negative acknowledgement or discontinuous transmission (no signal)).

The operations module **116** may be a software and/or hardware module used to control user equipment (UE) **104** communications. For example, the operations module **116** may determine when the user equipment (UE) **104** requires resources to communicate with an eNB **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 (CCs) (or cells) that are contiguously or separately located. In carrier aggregation (CA), only one uplink component carrier (CC) (or cell) (i.e., PCC or PCell) may be utilized for transmission using the physical uplink control channel (PUCCH). A component carrier (CC) is a carrier frequency to which cells belong.

To select a suitable modulation scheme and channel coding rate, the transmitter needs information about the radio-link between the transmitter and the receiver (i.e., channel state information (CSI)). The CSI may also be used for channel-dependent scheduling. In an FDD system, only the receiver can accurately and reliably estimate the radio-link channel condition. For downlink transmissions, the base station (e.g., an eNode B, eNB **102**, transmission point) sends a signal to the UE **104** that includes time and frequency resources as well as sequence information, antenna port information and transmit power. In release 11 of the 3GPP specification, one reference signal that is used for channel measurement is the CSI-RS.

The user equipment (UE) **104** may transmit uplink control information (UCI) to an eNB **102** on the uplink. The uplink control information (UCI) may include one or more channel state information (CSI) reports. A CSI report may be a Type 1 CSI report **120** or a Type 2 CSI report **122**. A channel state information (CSI) report may include a channel quality indicator (CQI), a precoder matrix indicator (PMI), and/or a rank indicator (RI). The rank indicator (RI) provides a recommendation on the number of spatial layers that should preferably be used for downlink transmission. The precoder matrix indicator (PMI) indicates the precoder matrix that should be used for downlink transmission. The precoder matrix may be determined by considering the number of supported layers indicated in the rank indicator (RI). The CQI indicates the highest modulation and coding scheme (MCS) that can be used for transmission of the PDSCH with a block error rate no larger than 10%.

A CSI report may be transmitted to an eNB **102** using aperiodic reporting and/or periodic reporting. Aperiodic CSI reports are sent by a UE **104** when explicitly requested (by a field in an uplink DCI (downlink control information)). Periodic CSI reports are configured by the eNB **102** (which may also be referred to as the network) to be sent by the UE **104** periodically.

The CQI indices and their interpretations are given in Table 1 below.

TABLE 1

CQI index	Modulation	Code rate × 1024	Efficiency
0		out of range	
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16 QAM	378	1.4766
8	16 QAM	490	1.9141
9	16 QAM	616	2.4063
10	64 QAM	466	2.7305
11	64 QAM	567	3.3223
12	64 QAM	666	3.9023
13	64 QAM	772	4.5234
14	64 QAM	873	5.1152
15	64 QAM	948	5.5547

Based on an unrestricted observation interval in time and frequency, the UE **104** may be required to derive, for each CQI value reported in uplink subframe n, the highest CQI index between 1 and 15 which satisfies the condition that a single physical downlink shared channel (PDSCH) transport block with a combination of modulation scheme and transport block size corresponding to the CQI index and occupying a group of downlink physical resource blocks (termed the CSI reference resource) could be received with a transport block error probability not exceeding 0.1. If CQI index 1 does not satisfy this condition, the UE **104** may instead use CQI index 0.

A UE **104** in transmission mode 10 can be configured with one or more CSI processes per serving cell by higher layers **114**. Each CSI process may be associated with a CSI-RS resource and a CSI interference measurement (CSI-IM) resource. A CSI reported by the UE **104** corresponds to a CSI process configured by higher layers **114**.

In the frequency domain, the CSI reference resource is defined by the group of downlink physical resource blocks corresponding to the band to which the CQI value relates. In the time domain, for a UE **104** configured in transmission mode 1-9 or in transmission mode 10 with a single configured CSI process for the serving cell, the CSI reference resource is defined by a single downlink subframe $n-n_{CQI\_ref}$. For periodic CSI reporting, n_{CQI_ref} is the smallest value greater than or equal to 4 such that subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe. For aperiodic CSI reporting, n_{CQI_ref} is such that the reference resource is in the same valid downlink subframe as the corresponding CSI request in an uplink DCI format. For aperiodic CSI reporting, n_{CQI_ref} is equal to 4 and the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe, where the downlink subframe $n-n_{CQI\_ref}$ is received after the subframe with the corresponding CSI request in a random access response grant.

For a UE **104** configured in transmission mode 10 with multiple configured CSI processes for the serving cell, the CSI reference resource for a given CSI process may be defined by a single downlink subframe $n-n_{CQI\_ref}$. For FDD and periodic or aperiodic CSI reporting, n_{CQI_ref} is the smallest value greater than or equal to 5 such that the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe. For FDD and aperiodic CSI reporting, n_{CQI_ref} is equal to 5 and the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe, where the downlink subframe $n-n_{CQI\_ref}$ is received after the subframe with the corresponding CSI request in a random access response grant.

For TDD with two or three configured CSI processes and aperiodic or periodic CSI reporting, n_{CQI_ref} is the smallest value greater than or equal to 4 such that the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe. For TDD with two or three configured CSI processes and aperiodic reporting, n_{CQI_ref} is equal to 4 and the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe, where the downlink subframe $n-n_{CQI\_ref}$ is received after the subframe with the corresponding CSI request in a random access response grant.

For TDD with four configured CSI processes and periodic or aperiodic CSI reporting, n_{CQI_ref} is the smallest value greater than or equal to 4 such that the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe. For TDD with four configured CSI processes and aperiodic CSI reporting, n_{CQI_ref} is equal to 5 and the downlink subframe $n-n_{CQI\_ref}$ corresponds to a valid downlink subframe, where the downlink subframe $n-n_{CQI\_ref}$ is received after the subframe with the corresponding CSI request in a random access response grant.

Upon decoding in subframe n either an uplink DCI (downlink control information) or a random access response grant, the UE **104** may perform aperiodic CSI reporting using the physical uplink shared channel (PUSCH) in subframe n+k on a serving cell, if the respective CSI request field is set to trigger a report and is not reserved. If the CSI request field is 1 bit, the CSI request field is set to 1 and the UE **104** is configured in transmission mode 1-9, a report is triggered for the serving cell. If the CSI request field is 1 bit and the UE **104** is configured in transmission mode 10, a report is triggered for a set of CSI process(es) for the serving cell corresponding to the higher layer **114** configured set of CSI process(es) associated with the value of the CSI request field in Table 1 below.

TABLE 2

Value of CSI request field	Description
'00'	No aperiodic CSI report is triggered
'01'	Aperiodic CSI report is triggered for serving cell
'10'	Aperiodic CSI report is triggered for a 1^{st} set of serving cells configured by higher layers
'11'	Aperiodic CSI report is triggered for a 2^{nd} set of serving cells configured by higher layers

If the CSI request field size is 2 bits and the UE **104** is configured in transmission mode 1-9 for all serving cells, a report is triggered according to the value in Table 2 above corresponding to aperiodic CSI reporting. If the CSI request field size is 2 bits and the UE **104** is configured in transmission mode 10 for at least one serving cell, a report is triggered according to the value in Table 3 below corresponding to aperiodic CSI reporting. For a given serving cell, if the UE **104** is configured in transmission modes 1-9, the "CSI process" in Table 3 refers to the aperiodic CSI configured for the UE **104** on the given serving cell. A UE **104** is not expected to be configured by higher layers **114** with more than 5 CSI processes in each of the 1^{st} and 2^{nd} set of CSI process(es) in Table 3.

TABLE 3

Value of CSI request field	Description
'00'	No aperiodic CSI report is triggered
'01'	Aperiodic CSI report is triggered for a set of CSI process(es) configured by higher layers for serving cell
'10'	Aperiodic CSI report is triggered for a 1^{st} set of CSI process(es) configured by higher layers
'11'	Aperiodic CSI report is triggered for a 2^{nd} set of CSI process(es) configured by higher layers

When the CSI request field from an uplink DCI format is set to trigger a report, for FDD k=4, and for TDD UL/DL configuration 1-6, k is given from Table 4 below. TDD UL/DL configuration is a configuration that indicates whether a subframe is uplink, downlink or a special subframe. For TDD UL/DL configuration 0, if the most significant bit (MSB) of the uplink index is set to 1 and the least significant bit (LSB) of the uplink index is set to 0, k is given in Table 5 below.

TABLE 4

TDD UL/DL	subframe number n									
Configuration	0	1	2	3	4	5	6	7	8	9
0	4	6				4	6			
1		6			4		6			4
2				4					4	
3	4								4	4
4									4	4
5									4	
6	7	7				7	7			5

TABLE 5

TDD UL/DL	subframe number n									
Configuration	0	1	2	3	4	5	6	7	8	9
0	9	6				9	6			
1		2			3		2			3
6	5	5				6	6			8

If the most significant bit (MSB) of the uplink index is set to 0 and the least significant bit (LSB) of the uplink index is set to 1, k is equal to 7. If both the most significant bit (MSB) and the least significant bit (LSB) of the uplink index are set to 1, k is given in Table 4. For TDD, if a UE **104** is configured with more than one serving cell and if the UL/DL configurations of at least two serving cells are different, the TDD UL/DL Configuration given in Table 4 refers to the UL-reference UL/DL configuration.

When the CSI request field from a Random Access Response Grant is set to trigger a report and is not reserved, k is equal to k_1 if the uplink delay field is set to zero. The UE **104** may postpone aperiodic CSI reporting to the next available uplink subframe if the UL delay field is set to 1.

A UE **104** may be semi-statically configured by higher layers **114** to periodically feedback different CSI components (CQI, PMI, PTI, and/or RI) on the physical uplink control channel (PUCCH). A UE **104** in transmission mode 10 can be configured by higher layers **114** for multiple periodic CSI reports corresponding to one or more CSI processes per serving cell on the PUCCH.

The information element CQI-ReportConfig given below is used to specify the CQI reporting configuration.

CQI-ReportConfig Information Element

```
CQI-ReportConfig-r10 ::=SEQUENCE {
    cqi-ReportAperiodic-r10          CQI-ReportAperiodic-r10     OPTIONAL, -
- Need ON
    nomPDSCH-RS-EPRE-Offset             INTEGER (−1..6),
    cqi-ReportPeriodic-r10           CQI-ReportPeriodic-r10      OPTIONAL, -
- Need ON
    pmi-RI-Report-r9               ENUMERATED {setup}            OPTIONAL, -
- Cond PMIRIPCell
    csi-SubframePatternConfig-r10    CHOICE {
        release                      NULL,
        setup                      SEQUENCE {
            csi-MeasSubframeSet1-r10        MeasSubframePattern-r10,
            csi-MeasSubframeSet2-r10        MeasSubframePattern-r10
        }
    }                                                        OPTIONAL -- Need
ON
}
```

The "MeasSubframePattern-r10" is a bit map of size 20, 40, 60, or 70 bits. Each bit in the bit map represents a subframe. The value of each bit determines whether that subframe belongs to the measurement set or not. For example, 1 may indicate inclusion and 0 may indicate exclusion.

The uplink control information (UCI) (such as a CSI report) may be generated by an uplink control information (UCI) reporting module **118** and transferred to an encoder **128**. The encoder **128** may then provide the uplink control information (UCI) to the transmitter **135**.

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), with 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).

In LTE Release-8, only one uplink component carrier (CC) **106** or serving cell **107** and one downlink component carrier (CC) **108** or serving cell **107** can be used for transmission to and reception from each user equipment (UE) **104**.

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) **106**, **108**. Each component carrier (CC) **106**, **108** or cell **107** may have a transmission bandwidth of up to 110 resource blocks (i.e., up to 20 megahertz (MHz)). In carrier aggregation, two or more component carriers (CCs) **106**, **108** are aggregated to support wider transmission bandwidths up to one hundred megahertz (MHz). A user equipment (UE) **104** may simultaneously receive and/or transmit on one or multiple component carriers (CCs) **106**, **108**, depending on the capabilities of the user equipment (UE) **104**.

A user equipment (UE) **104** may communicate with an eNB **102** using multiple component carriers (CCs) **108** at the same time. For example, a user equipment (UE) **104** may communicate with an eNB **102** using a primary cell (PCell) **107***a* while simultaneously communicating with the eNB **102** using secondary cell(s) (SCell) **107***b*. Similarly, an eNB **102** may communicate with a user equipment (UE) **104** using multiple component carriers (CCs) **108** at the same time. For example, an eNB **102** may communicate with a user equipment (UE) **104** using a primary cell (PCell) **107***a* while simultaneously communicating with the user equipment (UE) **104** using secondary cell(s) (SCell) **107***b*.

An eNB **102** may include a transceiver **137** that includes a receiver **138** and a transmitter **140**. An eNB **102** may additionally include a decoder **142**, an encoder **144** and an operations module **146**. An eNB **102** may receive uplink control information (UCI) **121** using its one or more antenna ports, which may be realized by one or more physical antennas **110***a-n*, and its receiver **138**. The receiver **138** may use the demodulator **139** to demodulate the uplink control information (UCI) **121**.

The decoder **142** may include an uplink control information (UCI) receiving module **143**. An eNB **102** may use the uplink control information (UCI) receiving module **143** to decode and interpret the uplink control information (UCI) **121** received by the eNB **102**. The eNB **102** may use the decoded uplink control information (UCI) **121** to perform certain operations, such as retransmit one or more packets based on scheduled communication resources for the user equipment (UE) **104**.

The operations module **146** may include a retransmission module **147** and a scheduling module **148**. The retransmission module **147** may determine which packets to retransmit (if any) based on the uplink control information (UCI) **121**. The scheduling module **148** may be used by the eNB **102** to schedule communication resources (e.g., bandwidth, time slots, frequency channels, spatial channels, etc.). The scheduling module **148** may use the uplink control information (UCI) **121** to determine whether (and when) to schedule communication resources for the user equipment (UE) **104**.

The operations module **146** may provide data **145** to the encoder **144**. For example, the data **145** may include packets for retransmission and/or a scheduling grant for the user equipment (UE) **104**. The encoder **144** may encode the data **145**, which may then be provided to the transmitter **140**. The transmitter **140** may modulate the encoded data using the modulator **141**. The transmitter **140** may transmit the modulated data to the user equipment (UE) **104** using one or more antenna ports, which may be realized by the one or more physical antennas **110***a-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 radio resource control (RRC) connection establishment/re-establishment/handover, one serving cell **107** (i.e., the primary cell (PCell) **107***a*) provides the non-access stratum (NAS) mobility information (e.g., Tracking Area Identity (TAI)) and the security input.

In the downlink, the component carrier (CC) **108** corresponding to the primary cell (PCell) **107***a* is the downlink primary component carrier (DL PCC) **108***a*. In the uplink, the component carrier (CC) **106** corresponding to the primary cell (PCell) **107***a* is the uplink primary component carrier (UL PCC) **106***a*. Depending on the capabilities of the user equipment (UE) **104**, one or more secondary component carriers (SCC) **106***b*, **108***b* or secondary cells (SCell) **107***b* may be configured to form a set of serving cells with the primary cell (PCell) **107***a*. In the downlink, the component carrier (CC) **108** corresponding to the secondary cell (SCell) **107***b* is the downlink secondary component carrier (DL SCC) **108***b*. In the uplink, the component carrier (CC) **106** corresponding to the secondary cell (SCell) **107***b* is the uplink secondary component carrier (UL SCC) **106***b*. 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) **107***a* and one or more secondary cells (SCell) **107***b*. From a network perspective, a serving cell **107** may be used as the primary cell (PCell) **107***a* by one user equipment (UE) **104** and used as a secondary cell (SCell) **107***b* by another user equipment (UE) **104**. If carrier aggregation is not configured, a primary cell (PCell) **107***a* operates a single serving cell. There may be one or more secondary cells (SCell) **107***b* in addition to the primary cell (PCell) **107***a* if carrier aggregation is configured. 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.

A UE **104** is in RRC_CONNECTED state when an RRC (radio resource control) connection has been established. If no RRC connection has been established, the UE **104** is in RRC_IDLE state.

A number of spatial channels may be available on each serving cell **107** by using multiple antenna ports at a transmitter and a receiver. Therefore, multiple codewords (up to two codewords) may be transmitted simultaneously.

A channel state information (CSI) report may be used to inform the eNB **102** to adjust the transmission rate (modulation scheme and coding rate) dynamically based on the existing channel conditions at the user equipment (UE) **104**. For example, if a channel state information (CSI) report indicates a good channel quality at the user equipment (UE) **104**, the eNB **102** may select a higher order modulation and coding rate, thereby achieving a higher transmission rate for the downlink transmission of data on the physical downlink shared channel (PDSCH). If a channel state information (CSI) report indicates a poor channel quality at the user equipment (UE) **104**, the eNB **102** may select a lower order modulation and coding rate, thereby achieving higher reliability for the transmission.

In Type 1 CSI measurement/reporting (the existing measurement used in Release 11 of the 3GPP specification), a UE **104** in transmission mode 10 may derive the channel measurements for computing the CQI value reported in uplink subframe n (that corresponds to a CSI process) based on only the non-zero power CSI-RS within a configured CSI-RS resource associated with the CSI process. However, it is possible that subframe n carries the CSI-RS in radio frame k and does not carry the CSI-RS in radio frame k+m. If the UE **104** measures the channel in both subframes and includes both measurements in generating a report (such as a weighted averaging of measurements), then the generated report includes erroneous measurements.

The use of Type 2 CSI measurement/reporting provides meaningful and reliable reports to the eNB **102** regardless of whether the CSI-RS is transmitted on the subframe corresponding to the CSI report. Furthermore, since the eNB **102** schedules the transmission of the CSI-RS, the eNB **102** is aware of whether the reported measurement is a valid channel state measurement or simply an interference measurement.

A UE **104** may be configured with multiple CSI processes. A UE **104** in transmission mode 10 can be configured with one or more CSI processes per serving cell by higher layers **114**. Each CSI process may be associated with a CSI-RS resource (including time and frequency resources allocated for transmission of CSI-RS, a CSI-RS sequence, an antenna port at which the CSI-RS is transmitted and the transmit power of the CSI-RS) and with a CSI-interference measurement (CSI-IM) resource (including the time and frequency resources on which the UE should perform interference measurement). Each CSI process is also associated with a reporting configuration which includes configurations for periodic and aperiodic reporting such as the CQI format (sub-band or wideband CQI), the resource indices (S1 or S2), the periodicity of periodic reports, the subframe offset associated with the periodic reports, etc. For simplicity, only one CSI process is considered, with the configured CSI resource and periodic and aperiodic CSI reporting configurations.

In one configuration, the same CSI process may be used for both Type 1 measurement/reporting and Type 2 measurement/reporting. The measurement configuration may be semi-static, dynamic or periodic. If the measurement configuration is semi-static, this enables Type 2 measurement/reporting in a CSI process. A set of subframes for Type 2 channel measurement may also be configured.

If the measurement configuration is dynamic, triggering may be used for Type 2 aperiodic CSI reporting. In this configuration, a field (which may be one bit or two bits) in the uplink DCI (e.g., DCI format 0 or DCI format 4) may specify whether Type 2 aperiodic reporting is triggered.

Downlink control information may be sent in packets of pre-specified length, known as DCI. The DCI may be carried by the PDCCH or the enhanced physical downlink control channel (EPDCCH). Das may carry different information. For example, one DCI may be used to inform UEs **104** about downlink resource allocation and another DCI may be used to inform a specific UE **104** about uplink resource allocation. Depending on the functionality of a DCI, different Das may have different lengths. Different Das may be distinguished by the way they are formatted and coded, which is referred to as the DCI format. A DCI may be used to transport downlink or uplink scheduling information, requests for periodic CQI reports, notifications of multicast control channel (MCCH) changes or uplink power control commands for one cell and one Radio Network Temporary Identifier (RNTI). The RNTI may be implicitly encoded in the cyclic redundancy check (CRC).

An uplink DCI allocates resources for uplink transmission. An uplink DCI may also be referred to as an uplink grant (e.g., DCI format 0/4). A downlink DCI allocates resources for downlink transmission. A downlink DCI may also be referred to as a downlink grant (e.g., DCI format 1/1A/2/2A/2B/2C/2D).

A bit field in the DCI indicates which reports of a type (i.e., Type 1 and/or Type 2) should be included in the UCI. The bit field may include multiple bits (e.g., 2 bits for a set of CSI reports corresponding to one or more CSI processes, 1 bit for a type 2 trigger, etc.). If Type 1 aperiodic CSI reporting is triggered, the UE **104** may be required to include a Type 1 CSI report **120** in the UCI. If Type 2 aperiodic CSI reporting is triggered, the UE **104** may be required to include a specified number of Type 2 CSI reports **122** (predefined or signaled by RRC) and a Type 1 CSI report **120** for each CSI process within the set of CSI processes with corresponding CSI reports include in the UCI.

If the measurement configuration is periodic, the UE **104** may periodically generate and send CSI reports to the eNB **102**. For Type 1 periodic CSI reporting, the periodicity and relative reporting offset for the subframe set S1 and the periodicity and relative reporting offset for the subframe set S2 are configured for each CSI process. For Type 2 periodic CSI reporting, additional periodicity and relative reporting offset is configured for each CSI process.

In another configuration, two CSI processes are used for Type 1 measurement/reporting and Type 2 measurement/reporting. One CSI process may be dedicated for Type 1 CSI reporting and another CSI process may be dedicated for Type 2 CSI reporting. If the measurement configuration is semi-static, a CSI process configuration may include a configuration of either Type 1 CSI reporting or Type 2 CSI reporting. Furthermore, a set of subframes for Type 2 channel measurement may be configured.

The triggering for Type 2 aperiodic CSI reporting is included in a DCI. A bit field in the DCI may indicate which CSI processes should be included in the UCI. If a triggered CSI process is for Type 2 aperiodic CSI reporting, the UE **104** may be required to include X numbers of Type 2 reports (X may be predefined or signaled by the RRC).

For CSI processes for Type 1 periodic CSI reporting, the periodicity and relative reporting offset for the subframe set 1 (S1) and the periodicity and relative reporting offset for subframe set 2 (S2) are configured. For CSI processes for Type 2 periodic CSI reporting, the periodicity and relative reporting offset is configured.

FIG. **2** is a flow diagram of a method **200** for Type 2 measurement/reporting. The method **200** may be performed by a UE **104**. The UE **104** may receive **202** a non-zero reference signal on a downlink channel. The UE **104** may measure **204** the downlink channel for a single subframe. The UE **104** may then generate a Type 2 CSI report **122** for a CSI reference resource based on the measured downlink channel for the single subframe. The Type 2 CSI report **122** may be computed from a channel measurement based on a non-zero reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process. The UE **104** may send **208** the Type 2 CSI report to an eNB **102**.

FIG. **3** is a flow diagram of another method **300** for Type 2 measurement/reporting. The method **300** may be performed by an eNB **102**. The eNB **102** may transmit **302** a reference signal on a downlink channel to a UE **104**. The eNB **102** may receive **304** a Type 2 CSI report **122** for a CSI reference resource from the UE **104**. The Type 2 CSI report **122** may be computed from a channel measurement based on a non-zero power reference signal on a single subframe within a configured CSI-RS resource associated with a CSI process. The eNB **102** may schedule **306** resources based on the Type 2 CSI report **122** for a CSI reference resource.

FIG. **4** is a block diagram illustrating the layers realized by a user equipment (UE) **404**. The user equipment (UE) **404** of FIG. **4** may be one configuration of the user equipment (UE) **104** of FIG. **1**. The user equipment (UE) **404** may include a radio resource control (RRC) layer **450**, a radio link control (RLC) layer **451**, a medium access control (MAC) layer **452** and a physical (PHY) layer **453**. The RRC layer **450**, RLC layer **451** and MAC layer **452** may be referred to as higher layers **118**. Mainly the procedures described herein relate to the PHY layer **453**. As used herein, the phrase "configured by higher layers" means that the PHY layer **453** is configured by the higher layer. The user equipment (UE) **404** may include additional layers not shown in FIG. **4**.

FIG. **5** illustrates the slot and subframe structure for Frame Structure Type 2. Frame Structure Type 2 may be applicable to TDD. Each radio frame **554** of length $T_f=307200\cdot T_s=10$ ms, includes two half-frames of length $153600\cdot T_s=5$ ms each. Each half-frame includes five subframes **555** of length $30720\cdot T_s=1$ ms. The Type 2 Frame Structure may be a downlink subframe **555**, an uplink subframe **555** or a special subframe **555**. The special subframe **555** may be preceded by a downlink subframe **555** and succeeded by an uplink subframe **555**. The special subframe **555** may be divided into three parts: DwPTS, GP and UpPTS. DwPTS is the downlink part of the special subframe **555**, GP is the guard period and UpPTS is the uplink part of the special subframe **555**.

FIG. **6** illustrates the procedures for determining the CSI reference resources for periodic Type 2 CSI measurement/reporting. The computation of PMI and RI of a CSI report may be linked to the value of the CQI. Multiple radio frames **654** are illustrated. Each radio frame includes **654** ten subframes **655**, numbered from 0 to 9. The radio frame number may also be referred to as the System Frame Number (SFN).

In Release 10 and 11 of the 3GPP specification, a UE **104** is configured with two subframe sets for measuring CSI. The first subframe set $C_{CSI,0}$ is referred to as S1 **656** herein. The second subframe set $C_{CSI,1}$ is referred to as S2 **657** herein. For a UE **104** in transmission mode 10, one subframe **655** belongs to either S1 **656** or S2 **657** but not both. A dedicated RRC configuration can identify the set of subframes **655** for Type 2 channel measurement, which is referred to as S3 **662**. In one example, the UE **104** may assume that S3 **662** is the same as the set of subframes **655** associated with the CSI-RS resources corresponding to the CSI process. In another example, the UE **104** is configured with S3 **662** independent of the set of subframes **655** associated with the CSI-RS resources corresponding to the CSI process. A dedicated RRC configuration can identify the set of subframes **655** for Type 2 interference measurement, which is referred to as S4.

The valid downlink subframes **658** for S1 **656** are illustrated. The valid downlink subframes **659** for S2 **657** are also illustrated. The subframes **660** that the UE **104** is configured to receive a reference signal are labeled with 'z' and the observations/measurements **661** of the reference signal by the UE **104** are labeled m. The valid downlink subframes **663** for S3 **662** are also illustrated.

The procedure for periodic reporting of Type 2 CSI reports is the same for cases when one CSI process is used for both Type 1 measurement/reporting and Type 2 measurement/reporting and for cases when a dedicated CSI process is used for either Type 1 CSI reporting or Type 2 CSI reporting. A dedicated RRC configuration may determine the periodicity **666** and relative reporting offset **667**. For each reporting instance **664**, the UE **104** may identify the corresponding CSI reference resource **665**. The UE **104** may then generate the Type 2 periodic CSI report **122** based on the non-zero power CSI-RS corresponding to the CSI process in the CSI reference resource **665**. The UE **104** may further include interference measurement when generating the Type 2 periodic CSI report **122** based on at least the configured resources for interference measurement in the CSI reference resource **665**.

In the Figure, the UE **104** is configured for periodic reporting with a periodicity **666** of 4 ms (4 subframes **655**, where each subframe **655** has a duration of 1 ms) and an offset of 3 subframes **655** (or 3 ms). For the periodic Type 2 CSI reporting scheduled in the uplink subframe 7 of radio frame k+3, the UE **104** identifies the CSI reference resource **665** for Type 2 CSI reporting to be the subframe 3 in radio frame k+3. The UE **104** generates the periodic Type 2 CSI report **122** for the CSI reference resource **665** (i.e., subframe 3 in radio frame k+3) based on the non-zero power CSI-RS and the CSI-RS resources corresponding to the CSI process in subframe 3 of radio frame k+3. The UE **104** may also include the interference measurement when generating the Type 2 periodic CSI report **122**, based on at least the configured resources for interference measurement in subframe 3 of radio frame k+3.

For a UE **104** in transmission mode 10 or transmission mode 11 (or any transmission mode that enables Type 2 measurement), the UE **104** may derive the interference measurements for computing the CQI value reported in uplink subframe n and corresponding to a CSI process based on the interference measurement signal only on subframe n-delta within the configured CSI-IM resource associated with the CSI process. The subframe n-delta may be a CSI reference resource **665** subframe (i.e., subframe $n\text{-}n_{CQI\_ref}$). This interference measurement is referred to as a Type 2 interference measurement. The interference measurement signal may be a zero-power CSI-RS.

For a UE **104** in transmission mode 10 or transmission mode 11 (or any transmission mode that enables Type 2 measurement), the UE **104** may derive the channel measurement for computing the CQI value reported in uplink subframe n and corresponding to a CSI process based on only a non-zero power CSI-RS only on subframe n-delta within the configured CSI-RS resource associated with the CSI process. The subframe n-delta may be a CSI reference resource **665** subframe (i.e., subframe $n\text{-}n_{CQI\_ref}$). This channel measurement is referred to as a Type 2 channel measurement. A Type 2 CSI measurement may include a Type 2 channel measurement, a Type 2 interference measurement, or both.

For Type 1 and Type 2 periodic CSI reporting, n_{CQI_ref} is the smallest value greater than or equal to p, such that the subframe $n\text{-}n_{CQI\_ref}$ corresponds to a valid downlink subframe **665**. For FDD, p=5. For TDD with up to three CSI processes, p=4. For TDD with more than three CSI processes, p=5.

In Type 1 channel measurement, a UE **104** may derive the channel measurement for computing the CQI value reported in uplink subframe n (and corresponding to a CSI process) based on only the non-zero power CSI-RS within a configured CSI-RS resource associated with the CSI process.

As used herein, Type 2 CSI reporting may be computed based on a) a combination of Type 1 channel measurement and Type 2 interference measurement, b) a combination of Type 2 channel measurement and Type 2 interference measurement or c) a combination of Type 2 channel measurement and Type 2 interference measurement. The valid downlink subframe **665** may be in a set of subframes **665** for a Type 1 interference measurement. The valid downlink subframe **665** may also be in a set of subframes **665** in which the CSI-IM resource is configured. Type 1 interference measurement is defined by the UE **104** deriving the interference measurements for computing the CQI value reported in uplink subframe n (corresponding to a CSI process) based on only the zero power CSI-RS within the configured CSI-IM resource associated with the CSI process. Unlike a Type 1 interference measurement, a Type 2 interference measurement may not be restricted to the zero power CSI-RS within the configured CSI-IM resource associated with the CSI process and may be based on the interference measurement signal only on subframe n-delta within the configured CSI-IM resource associated with the CSI process.

FIG. **7** illustrates the procedures for determining the CSI reference resources for aperiodic Type 2 CSI measurement/reporting. Multiple radio frames **775** are illustrated. Each radio frame **775** may include ten subframes **755**, numbered from 0 to 9. The subframe set S1 **756**, the subframe set S2 **757** and the subframe set S3 **762** are illustrated. Further, the valid downlink subframes **758** for S1 **756**, the valid downlink subframes **759** for S2 **757** and the valid downlink subframes **763** for S3 are illustrated.

To trigger aperiodic CSI reporting, the eNB **102** sends an uplink DCI (e.g., DCI format 0 or 4) that includes a field requesting aperiodic CSI reporting. If one CSI process is used for both Type 1 CSI reporting and Type 2 CSI reporting, then the aperiodic CSI report may include only Type 1, only Type 2 or both Type 1 and Type 2 CSI reports. The CSI report may also include multiple Type 2 CSI reports. In one configuration, one bit may indicate whether the report includes Type 2 reports or not, as illustrated in Table 6 below.

TABLE 6

Type Indicator Bit	Aperiodic Report Includes
0	Only Type 1 CSI reports
1	Both Type 1 and Type 2 CSI reports

An additional one or two bits can be used to signal a collection of CSI reports as given in Table 3 above. It is also possible to not include the type indicator bit. Thus, the CSI request field of two bits may indicate sets of CSI reports including Type 1, Type 2 or both Type 1 and Type 2 CSI reports as illustrated in Table 7 below.

TABLE 7

Value of CSI request field	Description
'00'	Aperiodic CSI report of Type 1 for a set of CSI process(es) configured by higher layers for serving cell
'01'	Aperiodic CSI reports of Type 1 and Type 2 is triggered for a set of CSI process(es) configured by higher layers for serving cell
'10'	Aperiodic CSI report is triggered for a 1^{st} set of CSI process(es) configured by higher layers
'11'	Aperiodic CSI report of Type 2 for a set of CSI process(es) configured by higher layers for serving cell

If a CSI process can be configured with only one CSI reporting type, then there is no need for the type indicator bit in the uplink DCI. In this case, the CSI request field in the uplink DCI can be used for identifying the aperiodic CSI reports as illustrated in Table 8 below.

TABLE 8

Value of CSI request field	Description
'00'	No aperiodic CSI report is triggered
'01'	Aperiodic CSI report is triggered for a set of CSI process(es) configured by higher layers for serving cell
'10'	Aperiodic CSI report is triggered for a 1^{st} set of CSI process(es) configured by higher layers
'11'	Aperiodic CSI report is triggered for a 2^{nd} set of CSI process(es) configured by higher layers

The number of Type 2 CSI reports in an aperiodic CSI report may be configured by dedicated RRC signaling.

The subframes **769** where an aperiodic Type 2 CSI request is transmitted are illustrated. The scheduled subframes **770** for aperiodic CSI reporting are also illustrated. The CSI reference resource subframes **771** are further illustrated. For aperiodic reporting with X number of Type 2 CSI reports **122** (i.e., r1, r2, r3, . . . rX) included in the UCI, n_{CQI_ref} is evaluated for each Type 2 CSI report **122**. For report r1, $n_{CQI\_ref\_1}$ is the smallest value greater than or equal to p, such that subframe n-$n_{CQI\_ref\_1}$ corresponds to a valid downlink subframe **763**, with the above candidates for p. Likewise, for report r2, $n_{CQI\_ref\_2}$ is the smallest value greater than or equal to $n_{CQI\_ref\_1}$, such that subframe n-$n_{CQI\_ref\_2}$ corresponds to a valid downlink subframe **763**. The ith report (i.e., ri), $1<i\leq X$, denoted by $n_{CQI\_ref\_i}$, is the smallest value greater than $n_{CQI\_ref\_i\text{-}1}$ such that subframe n-$n_{CQI\_ref\_i}$ corresponds to a valid downlink subframe **763**.

A downlink subframe **755** is considered to be valid if a) the downlink subframe **755** is configured as a downlink subframe **755** for that UE **104**, b) except for transmission mode 9 or 10, the downlink subframe **755** is not an MBSFN subframe (discussed below), c) the downlink subframe **755** does not include a DwPTS field in cases where the length of DwPTS is $7680 \cdot T_s$ and less, d) the downlink subframe **755** does not fall within a configured measurement gap for that UE **104**, and e) specific parameters for Type 1 CSI reporting and Type 2 CSI reporting are met. For Type 1 periodic CSI reporting, the additional specific parameters required are that a downlink subframe **755** is considered to be valid if the downlink subframe **755** is an element of the CSI subframe set linked to the periodic CSI report when that UE **104** is configured with CSI subframe sets.

In a multimedia broadcast/multicast service (MBMS) network, the same content may be transmitted simultaneously in a specific area (referred to as an MBMS service area) which may geographically include multiple transmission points (TPs) or eNBs **102**. If the transmissions of all transmission points (TPs) are time synchronized, from the perspective of a UE **104**, the transmissions appear to originate from a single transmission point (TP). This transmission is referred to as a MBMBS single-frequency network (MBSFN).

For Type 2 periodic and aperiodic CSI reporting, the additional specific criteria required (for a subframe **755** to be considered a valid downlink subframe **755**) are a) that the downlink subframe **755** is in the set of subframes **755** for Type 2 channel measurement (i.e., S3 **762**), b) the downlink subframe **755** is in the set of subframes **755** in which the reference signal (e.g., the CSI-RS resource associated with the CSI process) is configured, c) the downlink subframe **755** is in the set of subframes **755** for Type 2 channel measurement if the set of subframes **755** for Type 2 channel measurement is configured, d) the downlink subframe **755** is in the set of subframes **755** for a Type 2 interference measurement (i.e., the subset S4 which is similar to the subset S3 **762**) or e) the downlink subframe **755** is in the set of subframes **755** in which the CSI-IM resource is configured.

Depending on the method for computing a Type 2 CSI report (e.g., based on a Type 1 channel measurement and a Type 2 interference measurement, based on a Type 2 channel measurement and a Type 2 interference measurement, or based on a Type 2 channel measurement and a Type 1 interference measurement), a combination of the above criteria might be applied for determining a valid downlink subframe **755**.

As an example, the UE **104** may receive an uplink DCI with an aperiodic CSI reporting request in subframe 1 of radio frame k+3. The PUSCH resources are scheduled for a transmission of an aperiodic CSI report in subframe 6 of radio frame k+3. Moreover, the UE **104** is configured by RRC signaling to include two Type 2 CSI reports **122** in the aperiodic CSI reporting. The UE **104** may identify the CSI reference resource **771** for the first Type 2 CSI report **122** (which is subframe 8 of radio frame k+2) and the second CSI reference resource **771** for the second Type 2 CSI report **122** (which is subframe 9 of radio frame k+2) (e.g., based on n_{CQI_ref} and the valid downlink subframe **775** definition described above).

The UE **104** may generate a first Type 2 CSI report **122** based on the non-zero power CSI-RS within the configured CSI-RS resource corresponding to the CSI process in subframe 8 of radio frame k+2. The UE **102** may further include interference measurements when generating the first Type 2 CSI report **122**, based on at least the configured resources for interference measurement in subframe 8 of radio frame k+2. The UE **104** may also generate a second Type 2 CSI report **122** based on the non-zero power CSI-RS within the configured CSI-RS resource corresponding to the CSI process in subframe 9 of radio frame k+2. The UE **104** may include interference measurements when generating the second Type 2 CSI report **122**, based on at least the configured resources for interference measurement in subframe 9 of radio frame k+2. For this example, a combination of Type 2 channel measurement and Type 1 interference measurement is used. However, a similar method may also be applied to a combination of Type 1 channel measurement and Type 2 interference measurement by replacing the valid downlink subframe **763** for S3 **762** with a valid downlink subframe for S4 (not shown). The UE **104** may generate a first Type 2 CSI report **122** based on the CSI-IM resources corresponding to the CSI process in subframe 8 of radio frame k+2. The UE **104** may also generate a second Type 2 CSI report **122** based on the CSI-IM corresponding to the CSI process in subframe 9 of radio frame k+2. Also, a similar method may be applied using a combination of Type 2 channel measurement and Type 2 interference measurement on a CSI reference resource that is a valid downlink subframe **755** considering the criteria related to both channel measurement and interference measurements.

FIG. **8** illustrates various components that may be utilized in a user equipment (UE) **804**. The user equipment (UE) **804** may be utilized as the user equipment (UE) **104** illustrated previously. The user equipment (UE) **804** includes a processor **854** that controls operation of the user equipment (UE) **804**. The processor **854** may also be referred to as a CPU. Memory **874**, which may include both read-only memory (ROM), random access memory (RAM) or any type of device that may store information, provides instructions **856***a* and data **858***a* to the processor **854**. A portion of the memory **874** may also include non-volatile random access memory (NVRAM). Instructions **856***b* and data **858***b* may also reside in the processor **854**. Instructions **856***b* and/or data **858***b* loaded into the processor **854** may also include instructions **856***a* and/or data **858***a* from memory **874** that were loaded for execution or processing by the processor **854**. The instructions **856***b* may be executed by the processor **854** to implement the systems and methods disclosed herein.

The user equipment (UE) **804** may also include a housing that includes a transmitter **872** and a receiver **873** to allow transmission and reception of data. The transmitter **872** and receiver **873** may be combined into a transceiver **871**. One or more antennas **806***a-n* are attached to the housing and electrically coupled to the transceiver **871**. An antenna port may be realized by one or more antennas.

The various components of the user equipment (UE) **804** are coupled by a bus system **877**, 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 FIG. **8** as the bus system **877**. The user equipment (UE) **804** may also include a digital signal processor (DSP) **875** for use in processing signals. The user equipment (UE) **804** may also include a communications interface **876** that provides user access to the functions of the user equipment (UE) **804**. The user equipment (UE) **804** illustrated in FIG. **8** is a functional block diagram rather than a listing of specific components.

FIG. **9** illustrates various components that may be utilized in an eNB **902**. The eNB **902** may be utilized as the eNode B **102** illustrated previously. The eNB **902** may include components that are similar to the components discussed above in relation to the user equipment (UE) **804**, including a processor **978**, memory **986** that provides instructions **979***a* and data **980***a* to the processor **978**, instructions **979***b* and data **980***b* that may reside in or be loaded into the processor **978**, a housing that includes a transmitter **982** and a receiver **984** (which may be combined into a transceiver **981**), one or more antenna ports **908***a-n* electrically coupled to the transceiver **981**, a bus system **992**, a DSP **988** for use in processing signals, a communications interface **990**, antennas **910***a-n* 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. In addition, "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, subroutines, 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 wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless 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.

What is claimed is:

1. A method for receiving uplink control information (UCI), comprising:

receiving a first channel state information (CSI) report for a CSI reference resource from a user equipment (UE) if triggered; and

receiving a second CSI report for the CSI reference resource from the UE if triggered,

wherein the second CSI report is computed from a channel measurement based on only a non-zero power CSI reference signal only on a single subframe within a configured CSI reference signal resource associated with a CSI process, wherein the first CSI report is computed from a channel measurement based on only non-zero power CSI reference signals within a configured CSI reference signal resource associated with a CSI process based on an unrestricted observation interval in time and frequency, wherein the single subframe is a subframe of the CSI reference resource, and the CSI reference resource for the second CSI report reported in uplink subframe n is defined by a valid downlink subframe n-k.

2. The method of claim **1**, wherein the valid downlink subframe is in a set of subframes for a channel measurement for the Type 2 CSI report.

3. The method of claim **1**, wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured.

4. The method of claim **1**, wherein the valid downlink subframe is in a set of subframes for Type 2 channel measurement if the set of subframes for Type 2 channel measurement is configured, and wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured if the set of subframes for Type 2 channel measurement is not configured.

5. The method of claim **1**, wherein the Type 2 CSI report is a periodic CSI report.

6. The method of claim **5**, wherein Type 2 CSI reporting is configured in a CSI process configuration.

7. The method of claim **1**, wherein the Type 2 CSI report is an aperiodic CSI report.

8. The method of claim **7**, wherein a field in a downlink control information (DCI) specifies whether Type 2 aperiodic CSI reporting is triggered.

9. The method of claim **1**, wherein the Type 2 CSI report corresponds to a configured CSI process.

10. A method for reporting uplink control information (UCI), comprising:

transmitting a first channel state information (CSI) report for a CSI reference resource from a user equipment (UE) if triggered; and

transmitting a second CSI report for the CSI reference resource if triggered,

wherein the second CSI report is computed from a channel measurement based on only a non-zero power CSI reference signal only on a single subframe within a configured CSI reference signal resource associated with a CSI process, wherein the first CSI report is computed from a channel measurement based on only non-zero power CSI reference signals within a configured CSI reference signal resource associated with a CSI process based on an unrestricted observation interval in time and frequency, wherein the single subframe is a subframe of the CSI reference resource, and the CSI reference resource for the second CSI report reported in uplink subframe n is defined by a valid downlink subframe n-k.

11. The method of claim 10, wherein the valid downlink subframe is in a set of subframes for a channel measurement for the Type 2 CSI report.

12. The method of claim 10, wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured.

13. The method of claim 10, wherein the valid downlink subframe is in a set of subframes for Type 2 channel measurement if the set of subframes for Type 2 channel measurement is configured, and wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured if the set of subframes for Type 2 channel measurement is not configured.

14. The method of claim 10, wherein the Type 2 CSI report is a periodic CSI report.

15. The method of claim 14, wherein Type 2 CSI reporting is configured in a CSI process configuration.

16. The method of claim 10, wherein the Type 2 CSI report is an aperiodic CSI report.

17. The method of claim 16, wherein a field in a downlink control information (DCI) specifies whether Type 2 aperiodic CSI reporting is triggered.

18. The method of claim 10, wherein the Type 2 CSI report corresponds to a configured CSI process.

19. A base station configured for receiving uplink control information (UCI), comprising:

a processor;

memory in electronic communication with the processor; and

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

receive a first channel state information (CSI) report for a CSI reference resource from a user equipment (UE) if triggered; and

receive a second CSI report for the CSI reference resource from the UE if triggered,

wherein the second CSI report is computed from a channel measurement based on only a non-zero power CSI reference signal only on a single subframe within a configured CSI reference signal resource associated with a CSI process, wherein the first CSI report is computed from a channel measurement based on only non-zero power CSI reference signals within a configured CSI reference signal resource associated with a CSI process based on an unrestricted observation interval in time and frequency, wherein the single subframe is a subframe of the CSI reference resource, and the CSI reference resource for the second CSI report reported in uplink subframe n is defined by a valid downlink subframe n-k.

20. The base station of claim 19, wherein the valid downlink subframe is in a set of subframes for a channel measurement for the Type 2 CSI report.

21. The base station of claim 19, wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured.

22. The base station of claim 19, wherein the valid downlink subframe is in a set of subframes for Type 2 channel measurement if the set of subframes for Type 2 channel measurement is configured, and wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured if the set of subframes for Type 2 channel measurement is not configured.

23. The base station of claim 19, wherein the Type 2 CSI report is a periodic CSI report.

24. The base station of claim 23, wherein Type 2 CSI reporting is configured in a CSI process configuration.

25. The base station of claim 19, wherein the Type 2 CSI report is an aperiodic CSI report.

26. The base station of claim 25, wherein a field in a downlink control information (DCI) specifies whether Type 2 aperiodic CSI reporting is triggered.

27. The base station of claim 23, wherein the Type 2 CSI report corresponds to a configured CSI process.

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

a processor;

memory in electronic communication with the processor; and

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

transmit a first channel state information (CSI) report for a CSI reference resource from a user equipment (UE) if triggered; and

transmit a second CSI report for the CSI reference resource if triggered,

wherein the second CSI report is computed from a channel measurement based on only a non-zero power CSI reference signal only on a single subframe within a configured CSI reference signal resource associated with a CSI process, wherein the first CSI report is computed from a channel measurement based on only non-zero power CSI reference signals within a configured CSI reference signal resource associated with a CSI process based on an unrestricted observation interval in time and frequency, wherein the single subframe is a subframe of the CSI reference resource, and the CSI reference resource for the second CSI report reported in uplink subframe n is defined by a valid downlink subframe n-k.

29. The UE of claim 28, wherein the valid downlink subframe is in a set of subframes for a channel measurement for the Type 2 CSI report.

30. The UE of claim 28, wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured.

31. The UE of claim 28, wherein the valid downlink subframe is in a set of subframes for Type 2 channel measurement if the set of subframes for Type 2 channel measurement is configured, and wherein the valid downlink subframe is in a set of subframes in which the non-zero power CSI reference signal is configured if the set of subframes for Type 2 channel measurement is not configured.

32. The UE of claim 28, wherein the Type 2 CSI report is a periodic CSI report.

33. The UE of claim 32, wherein Type 2 CSI reporting is configured in a CSI process configuration.

34. The UE of claim 28, wherein the Type 2 CSI report is an aperiodic CSI report.

35. The UE of claim 34, wherein a field in a downlink control information (DCI) specifies whether Type 2 aperiodic CSI reporting is triggered.

36. The UE of claim 28, wherein the Type 2 CSI report corresponds to a configured CSI process.

37. The UE of claim 1, wherein a downlink subframe is determined to be valid based, in part, on whether it is a multimedia broadcast/multicast service single-frequency network (MBSFN) frame.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,271,279 B2
APPLICATION NO. : 13/891162
DATED : February 23, 2016
INVENTOR(S) : Ahmad Khoshnevis et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Specification
In column 11, line 54 please delete “Das” and replace it with --DCIs--.
In column 11, line 58 please delete “Das” and replace it with --DCIs--.
In column 11, line 59 please delete “Das” and replace it with --DCIs--.

Signed and Sealed this
Twenty-sixth Day of July, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office