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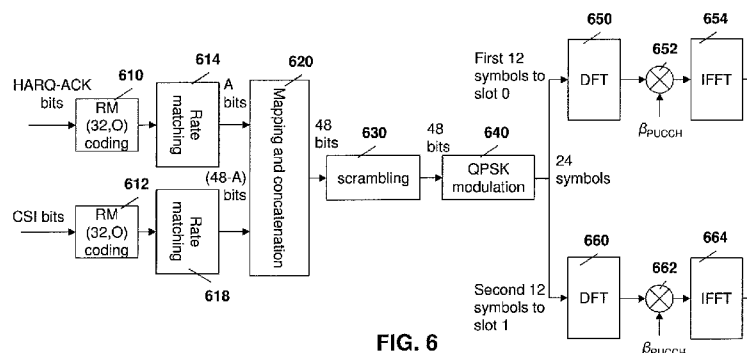


FIG. 6

(57) Abstract: A method and apparatus for operating a user equipment (UE) in a wireless communications network, the method separately encoding and rate matching a first set of information bits and a second set of information bits; mapping and concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulating and transmitting the bit stream.

METHOD AND SYSTEM FOR UPLINK HARQ AND CSI MULTIPLEXING FOR CARRIER AGGREGATION

BACKGROUND

[0001] Data enabled mobile devices, such as smartphones, have become widely adopted, and applications and data requirements for such data enabled mobile devices have increased. As multimedia and data rich applications have become more prevalent, increased data throughput to and from a data enabled mobile device is needed. In response, newer wireless networks contemplate data throughput rates. For example, in a Long Term Evolution-Advanced (LTE-A) system, peak target data rates are 1 Gbps and 500Mbps for downlink and uplink respectively. To achieve such target data rates, one potential approach is to use carrier aggregation techniques that utilize bandwidth aggregation of a variety of different arrangements of component carriers (CCs), including the same or different bandwidths, adjacent or non-adjacent CCs in the same frequency band or different frequency bands.

[0002] For efficient carrier aggregation, signalling overhead should be minimized. For example, in current long term evolution (LTE) systems, a user equipment (UE) may be configured to transmit hybrid automatic repeat request (HARQ) acknowledgements (ACK) on a physical uplink control channel (PUCCH) format 3.

[0003] However, the channel state information (CSI) is also transmitted on a PUCCH format 3 and the periodic CSI may be dropped if HARQ and the periodic CSI happen to be transmitted in the same subframe. The repeated dropping of the CSI may lead to a degradation of downlink throughput since the evolved Node B (eNB) scheduler cannot receive correct CSI reporting from a UE and may not be able to choose a suitable modulation and coding scheme for the transmission. Further, eNB may receive more HARQ-negative acknowledgement (NACK) feedbacks due to the CSI dropping.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present disclosure will be better understood with reference to the drawings, in which:

Figure 1 is a schematic diagram showing an example protocol stack in a wireless communication system;

Figure 2 is a schematic diagram showing an example ACK/NACK transmission;

Figure 3 is a schematic diagram showing CSI payload ordering in LTE;

Figure 4 is a schematic diagram showing a conventional coding structure for HARQ-ACK;

Figure 5 is a block diagram showing PUCCH mapping on a physical resource block;

Figure 6 is a schematic diagram showing a conventional coding structure for HARQ-ACK including a mapping function;

Figure 7 is a block diagram of an example mapping structure for separate coding;

Figure 8 is a schematic diagram showing a conventional coding structure for HARQ-ACK including a repetition and higher order modulation;

Figure 9 is a block diagram of an example mapping structure for separate coding with repetition;

Figure 10 is a block diagram showing a simplified example network element; and

Figure 11 is a block diagram of an example user equipment.

DETAILED DESCRIPTION OF THE DRAWINGS

[0005] The present disclosure provides a method of operating a user equipment (UE) in a wireless communications network, the method comprising: separately encoding and rate matching a first set of information bits and a second set of information bits; mapping and concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulating and transmitting the bit stream.

[0006] The present disclosure further provides a user equipment comprising: a processor; and a communications subsystem, wherein the processor and

communications subsystem are configured to: separately encode and rate match a first set of information bits and a second set of information bits; map and concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulate and transmit the bit stream.

[0007] The present disclosure further provides a method of operating a user equipment (UE) in a wireless communications network, the method comprising: separately encoding and rate matching a first set of information bits and a second set of information bits; concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; modulating the bit stream using a modulation scheme selected depending on a number of configured component carriers; and transmitting the modulated bit stream.

[0008] The present disclosure further provides a user equipment comprising: a processor; and a communications subsystem, wherein the processor and communications subsystem are configured to: separately encode and rate match a first set of information bits and a second set of information bits; concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; modulate the bit stream using a modulation scheme selected depending on a number of configured component carriers; and transmit the modulated bit stream.

[0009] The present disclosure further provides a method of operating a user equipment (UE) in a wireless communications network, the method comprising: separately encoding and rate matching a first set of information bits and a second set of information bits; concatenating and repeating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulating and transmitting the bit stream.

[0010] The present disclosure further provides a user equipment comprising: a processor; and a communications subsystem, wherein the processor and communications subsystem are configured to: separately encode and rate match a first set of information bits and a second set of information bits; concatenate and repeat the encoded and rate matched first set of information

bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulate and transmit the bit stream.

[0011] The present disclosure further provides a method of operating a user equipment (UE) in a wireless communications network, the method comprising: separately encoding a first set of information bits and a second set of information bits; rate matching the encoded first set of information bits using a first puncturing pattern; rate matching the encoded second set of information bits using a second puncturing pattern; concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulating and transmitting the bit stream, wherein the second puncturing pattern has more punctured bits than the first puncturing pattern.

[0012] The present disclosure further provides a user equipment comprising: a processor; and a communications subsystem, wherein the processor and communications subsystem are configured to: separately encode a first set of information bits and a second set of information bits; rate match the encoded first set of information bits using a first puncturing pattern; rate match the encoded second set of information bits using a second puncturing pattern; concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulate and transmit the bit stream, wherein the second puncturing pattern has more punctured bits than the first puncturing pattern.

[0013] The present disclosure further provides a method of operating a user equipment (UE) in a wireless communications network, the method comprising: separately encoding a first set of information bits and a second set of information bits; rate matching the encoded first set of information bits, the rate matching using a first puncturing pattern; rate matching the encoded second set of information bits, the rate matching using a second puncturing pattern; concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulating and transmitting the bit stream, wherein the first puncturing pattern has more punctured bits than the second puncturing pattern when the number of component carriers is less than a threshold.

[0014] The present disclosure further provides a user equipment comprising: a processor; and a communications subsystem, wherein the processor and communications subsystem are configured to: separately encode a first set of information bits and a second set of information bits; rate match the encoded first set of information bits, the rate matching using a first puncturing pattern; rate match the encoded second set of information bits, the rate matching using a second puncturing pattern; concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and modulate and transmit the bit stream, wherein the first puncturing pattern has more punctured bits than the second puncturing pattern when the number of component carriers is less than a threshold.

[0015] Typically, in wireless communication systems, neither the transmitter nor receiver assumes *a priori* knowledge or unequal error protection of the message bits. However in certain cases *a priori* knowledge and unequal error protection of message bits does exist and may be taken advantage of. For example, in Carrier Aggregation in the LTE-A system, such *a priori* knowledge may exist for ACK/NACK transmissions in PUCCH format 3. Further, such knowledge may exist for the channel state information reporting for LTE on a Physical Uplink Shared Channel (PUSCH).

[0016] While the disclosure below relates to the Long Term Evolution and Long Term Evolution-Advanced systems, the disclosure is not meant to be limited to such systems and could equally be applied to other systems which may or may not have carrier aggregation.

[0017] In LTE systems, communication may be temporally divided into subframes, for example of 1ms duration, in which bidirectional communication between the user equipment (UE) and a base station are transmitted on some or all of the available component carriers. Additionally, the ratio of downlink to uplink subframes may vary up to a ratio of 9:1 according to traffic needs in the case of a Time Division Duplex (TDD) system.

[0018] Reference is now made to **Figure 1**, which shows a simplified architecture for communication between various elements in a system for the control plane. A similar protocol stack exists for the user plane. In particular,

eNB **110** provides cell coverage to a first area and may serve a UE **120**, which communicates with eNB **110** through wireless communication link **122**.

[0019] As shown in the example of **Figure 1**, each element includes a protocol stack for the communications with other elements. In the case of eNB **110**, the eNB includes a physical layer **130**, a medium access control (MAC) layer **132**, a radio link control (RLC) layer **134**, a packet data convergence protocol (PDCP) layer **136** and a radio resource control (RRC) layer **138**.

[0020] In the case of UE **120**, the UE includes a physical layer **140**, a MAC layer **142**, an RLC layer **144**, a PDCP layer **146**, an RRC layer **147** and a non-access stratum (NAS) layer **148**.

[0021] Communications between the entities, such as between eNB **110** and UE **120**, generally occur within the same protocol layer between the two entities. Thus, for example, communications from the RRC layer at eNB **110** travels through the PDCP layer, RLC layer, MAC layer and physical layer and get sent over the physical layer to UE **120**. When received at UE **120**, the communications travel through the physical layer, MAC layer, RLC layer, PDCP layer to the RRC level of UE **120**. Such communications are generally done utilizing a communications sub-system and a processor, as described in more detail below.

[0022] The present disclosure is provided below with regards to a 3GPP LTE architecture. However, the present disclosure is not limited to such architecture and other communications systems could equally be utilized in employing the embodiments provided herein. The present disclosure is thus not limited to 3GPP LTE.

[0023] ACK/NACK

[0024] In 3GPP LTE, prior to a data transmission on the physical downlink shared channel (PDSCH) in a subframe, the eNB encodes control information on the physical downlink control channel (PDCCH) that is transmitted in the control region. In one embodiment, the control region may consist of up to 4 Orthogonal Frequency Division Multiplex (OFDM) symbols at the beginning of a subframe.

[0025] A UE attempts PDCCH decoding at the start of each subframe. Once the UE detects a PDCCH containing PDSCH scheduling information for the UE, the UE performs PDSCH decoding according to the scheduling

information included in a detected PDCCH. If a cyclic redundancy check (CRC) of the PDSCH data is successful, which means the PDSCH data is received correctly, the UE transmits an ACK on the physical uplink control channel (PUCCH). In one case, the ACK may be transmitted on the 4th subframe after the PDSCH reception. Alternatively, the ACK transmission may be even later depending on the configuration if the system is TDD. While HARQ-ACK and CSI can be transmitted via Physical Uplink Shared Channel (PUSCH) in certain scenarios, the present disclosure uses transmissions of HARQ-ACK and CSI over PUCCH as an example.

[0026] If the CRC check of the PDSCH data is not successful, which means the PDSCH data is not received correctly, the UE can transmit a NACK on the PUCCH to request a retransmission. Typically if no PDCCH is detected by a UE for frequency division duplex (FDD) in LTE Rel-8 specifications, then no acknowledgement, either positive or negative, is indicated on the uplink PUCCH. This is referred to as discontinuous transmission (DTX). While ideally three HARQ responses (ACK, NACK, DTX) are possible, to simplify the transmission it is also possible to use two HARQ responses (ACK, NACK) for a data packet where DTX and NACK are both represented by NACK. Thus only one bit is needed to represent the HARQ response. For example, each positive acknowledgement (ACK) is encoded as a binary '1' and each negative acknowledgement (NACK) is encoded as a binary '0'. In LTE, a PDSCH may carry one or two transport blocks (TBs). Each TB on the downlink needs one HARQ-ACK bit in response on the uplink. Thus a PDSCH transmission requires one or two HARQ-ACK bits in response, depending on the number of TBs carried by the PDSCH.

[0027] In LTE, carrier aggregation may be used in order to support a wider transmission bandwidth for increased potential peak data rates. In carrier aggregation, multiple component carriers (CCs) are aggregated and can be allocated in a subframe to a UE. Thus, each component carrier may have a bandwidth of, for example, 20 MHz and a total aggregated system bandwidth could reach 100 MHz when five component carriers are aggregated. The UE may receive or transmit on multiple component carriers depending on the UE's capabilities. Further, carrier aggregation may occur with carriers located in the same band and/or carriers located in different bands. For example, one

carrier may be located at 2 GHz band and a second aggregated carrier may be located at 800 MHz band.

[0028] Currently, a UE may receive on a multiple of up to five downlink component carriers, depending on the UE's capabilities and deployment scenario. Multiple PDSCHs can be scheduled to one UE in the same subframe, but on different carriers, and multiple PDSCHs may be decoded in parallel.

[0029] In order to save UE battery power, one example of signaling includes the UE transmitting multiple ACKs or NACKs on one PUCCH in the uplink primary component carrier (PCC).

[0030] As a potential mismatch could arise between the UE and eNB understandings of the HARQ-ACK payload size if a transmitted PDCCH is not detected by the UE, the HARQ-ACK payload size is based on the number of configured CCs and configured TBs per component carrier. Therefore the HARQ-ACK payload size is not dependent on the successful decoding of all PDCCH messages and hence remains constant in a semi-static sense. In other words, the HARQ-ACK payload size does not change dynamically. Since the number of configured CCs is given by RRC signaling, the RRC signaling may change the number of configured CCs. In a TDD system, the number of HARQ-ACK bits can be determined by both the number of configured CCs and the downlink (DL) or uplink (UL) subframe ratio or the value in the downlink assignment index (DAI) information to support the case when the HARQ-ACK bits of multiple downlink subframes are transmitted in one uplink subframe.

[0031] When the number of HARQ-ACK bits is determined based on the number of configured CCs and the number of configured TBs per configured CC, if a PDCCH is received on at least one of the configured CCs, then NACKs are sent for all other CCs on which no PDCCH has been detected. If a PDCCH is detected then the UE makes an attempt to receive the corresponding PDSCH data. If the PDSCH decoding is successful, the UE sends a positive acknowledgement message to the eNB and otherwise a negative acknowledgement is indicated. In the case of a CC being configured for dual-transport block transmission, two HARQ-ACK bits per subframe may

be used for that CC, whereas for a carrier configured for a single transport block only one HARQ-ACK bit per subframe may be necessary.

[0032] Reference is now made to **Figure 2**. As shown in **Figure 2**, a UE receives data from five component carriers, namely component carriers **210**, **212**, **214**, **216** and **218** respectively.

[0033] In a particular subframe, the component carriers **212**, **214** and **216** are scheduled by an eNB to send data to a UE. In this case, the eNB will indicate via the PDCCH that component carriers **212**, **214** and **216** have data and the UE will then try to decode component carriers **212**, **214** and **216**.

[0034] Component carriers **210** and **218** are not used in the subframe. For the HARQ response, the UE signals an ACK or an NACK for component carriers **212**, **214** and **216** depending on whether or not the decoding of the PDSCH was successful for those component carriers. For component carriers **210** and **218**, the UE will send a NACK to represent DTX.

[0035] Thus, an eNB will have *a priori* knowledge for the response of component carriers **210** and **218**. In particular, the eNB knows which component carriers and subframes PDCCH and PDSCH transmissions did not occur on and thus has *a priori* knowledge that NACKs will be indicated for those resources provided at least one PDCCH and therefore one PDSCH was scheduled in the subframe. If no information was scheduled in the subframe then the UE is expected to send NACK (=DTX) and not expected to transmit an ACK in the HARQ response.

[0036] Thus, a UE will signal NACKs for both the case of a non-detection of a PDCCH and the case of an unsuccessful PDSCH decoding when a PDCCH was detected. However, the detection in the eNB can utilize the *a priori* knowledge that any HARQ-ACK bits corresponding to component carriers and subframes where a PDCCH was not transmitted must have a value of "NACK".

[0037] *CSI*

[0038] As defined in section 5.2.2.6.4 of the 3GPP Technical Specification (TS) 36.212, V.10.4.0, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (Release 10)", the contents of which are incorporated herein by reference, CSI transmitted on the physical uplink control channel is coded

using a single Reed-Muller (RM) code in 3GPP LTE Rel-8, Rel-9, and Rel-10. The RM code is a linear error correcting code used in communications. In the case of the 3GPP TS 36.212, the RM code can be used with a 32-bit code word with a payload up to 11 bits. In other embodiments, the CSI transmitted on the PUCCH is coded using a single RM code (20, A) for payload sizes up to 13 bits.

[0039] The encoding with an RM code provides a decreasing reliability for the information bits and an increasing bit error probability as the information bits move from the most significant bit to the least significant bit.

[0040] In particular, as shown in **Figure 3**, the CSI **310** includes the CQI **312** and PMI **314**. The RM encoded bits **322** are shown from the most significant bit to the least significant bit of the CQI and with the PMI appended thereto. As shown by arrow **330**, increased bit error probability occurs when moving from the most significant bit to the least significant bit of the CQI and to the PMI.

[0041] Thus, the payload ordering for the CQI portion of the CSI message is the order of the most significant bit to the least significant bit of the CQI message. This ordering complements the unequal bit error probability characteristics present on RM codes where the most significant information bit of the encoded message is less likely to be in error than the least significant information bit since the most significant bits of a CQI message have a greater impact in an erroneous CQI report than the least significant bits. However, in some embodiments the PMI has greater sensitivity to error, but still occupies the least significant bit positions which are the most likely impacted by decoder failure in a Rel-8 LTE system.

[0042] In one Rel-10 LTE system, dual RM coding is used when the number of HARQ-ACK bits is more than 11 bits. This is to allow a large number of HARQ-ACK bits to be transmitted in the case where multiple carriers are aggregated. This may be most common, for example, in the case of TDD where up to 40 HARQ-ACK bits could be required, assuming 5 carriers are aggregated and 4 subframes are scheduled with two transport blocks per carrier for TDD uplink/downlink configuration 2. However, since such large HARQ-ACK signaling can cause a burden in control signaling, a limit of up to

20 HARQ-ACK bits to be transmitted may be used and spatial bundling may be applied when the number of HARQ-ACK bits is more than 20.

[0043] Since the RM coding used for CSI transmission supports up to 11 bits, two RM encoders are used to transmit up to 22 bits.

[0044] For simplicity, the descriptions below do not include the application of an orthogonal cover sequence and cyclic shift. However, in application these are applied before a discrete Fourier transform (DFT) processing to transmit HARQ-ACK in PUCCH format 3.

[0045] As indicated above, Rel-10 carrier aggregation may cause a periodic CSI to be dropped if HARQ-ACK is transmitted in the same subframe. In the LTE Rel-11 specifications, simultaneous transmission of CSI and HARQ-ACK is proposed when HARQ-ACK is transmitted on PUCCH format 3. In the description below, the uplink transmission focuses on simultaneous transmission of two types of information: HARQ-ACK and CSI. It is appreciated by those skilled in the art that other types of information can be concatenated and/or interleaved on the same uplink transmission as needed by following the same principles. An example of other types of information that can be transmitted simultaneously with HARQ-ACK and CSI includes a scheduling request (SR).

[0046] One possible way to do this is to reuse the dual RM coding to increase the payload size that the UE can transmit on PUCCH format 3. As indicated above, the dual RM code can support a payload of up to 22 bits.

[0047] Reference is now made to **Figure 4** which provides an example of HARQ-ACK coding with dual RM codes. In particular, in the example of **Figure 4**, HARQ ACK/NACK bits are even and odd ordered at block **402**, and each ordered block is RM encoded with 8 bits punctured from the length-32 code thus providing codewords of 24 bits. This is shown with blocks **410** and **412**. However, other types of ordering are also possible, and may include, for example, first half and second half. The present disclosure is not limited to any particular HARQ-ACK coding.

[0048] The output from blocks **410** and **412** are provided to concatenation block **420** which then concatenates the bits and provides a 48-bit output.

[0049] The concatenation block output is provided to a scrambling block **430** which provides an XOR with a random sequence to produce 48 bits, which

are then modulated at modulation block **440**. In the example of **Figure 4**, the modulation is quadrature phase shift keying (QPSK) modulation. However, other modulation techniques are possible.

[0050] The output from the QPSK modulation block **440** is 24 symbols, which are then divided into the first 12 symbols going to a discrete Fourier transform (DFT) block **450**, and the second 12 symbols being provided to a second DFT block **455**.

[0051] The output from DFT block **450** is then multiplied by a power level for the first block, as shown by block **460**. Similarly, the output of DFT block **455** is multiplied by a power level the second block, shown at block **465**.

[0052] The output from the multiplication at block **460** is then provided to an inverse fast Fourier transform (IFFT) block **470** and the output is then sent to the network. In the example of **Figure 4**, the output from block **470** is sent over slot 0 of the subframe.

[0053] Similarly, the output from multiplication block **465** is provided to the IFFT block **475**, and the output of the multiplication is then sent to the network element. In the example of **Figure 4**, the output from block **475** is sent over slot 1 of the subframe

[0054] In an alternative embodiment, instead of providing for concatenation block **420**, separate scrambling and modulation blocks **430** and **440** may be provided for the output from each of blocks **410** and **412** respectively.

[0055] *PUCCH REPORTING AND MAPPING*

[0056] The channel state information report from a UE consists of a channel quality indicator, precoding matrix indicator, precoding type indicator (PTI), and rank indication (RI), which are controlled by the eNB. In addition, HARQ-ACK/NACK is also fed back from a UE to the eNB as the acknowledgement of the downlink transmitted data.

[0057] For uplink control information, both periodic and aperiodic reports may be supported either for wideband or for sub-bands. These periodic or aperiodic reports are provided, for example in 3GPP TS36.211, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channel and modulation", Release 10; the 3GPP TS36.212, "Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding", Release 10; and 3GPP TS36.213, "Evolved Universal Terrestrial Radio Access (E-UTRA);

Physical layer procedures", Release 10, the contents of all of which are incorporated herein by reference.

[0058] A CSI report, including the HARQ-ACK/NACK message, provides the link capability to support spectral efficiency on a downlink transmission. As seen in **Figure 5**, periodic CSI reports are performed on the physical uplink control channel that is located at the edges of the system bandwidth to achieve frequency diversity of the transmitted data and provide fewer constraints on system designs.

[0059] In PUCCH format 3, the actual number of ACK/NACK feedback bits is determined from the number of configured component carriers. For FDD, a maximum payload size of 10 ACK/NACK bits is allowed, while for TDD, the maximum payload size may be up to 20 bits. Thus, the maximum payload size carried by a PUCCH format 3 in Release 10 is 21 bits, corresponding to 20 bits of ACK/NACK information and one bit for an SR appended at the end of the ACK/NACK bits.

[0060] After performing RM encoding as described above with regard to **Figure 4**, the block of 48 bits is then scrambled with a UE-specific scrambling sequence using a modulo-2 operation. The block of scrambled bits is modulated using QPSK modulation resulting in a block of 24 complex-valued modulation symbols.

[0061] Reference is now made to **Table 1**, which shows supported PUCCH formats. As seen, the PUCCH format 3 has up to 24 bits per subframe and is provided for multiple ACK/NACKs for carrier aggregation with up to 20 ACK/NACK bits and an optional SR in 48 codes bits.

PUCCH format	Modulation scheme	Number of bits per subframe, M_{bit}	Uplink control information
1	N/A	N/A	SR
1a	BPSK	1	HARQ-ACK/NAC with(out) SR
1b	QPSK	2	HARQ-ACK/NAC with(out) SR
2	QPSK	20	CSI
2a	QPSK+BPSK	21	CSI and 1-bit HARQ-ACK/NACK
2b	QPSK+QPSK	22	CSI and 2-bit HARQ-ACK/NACK
3	QPSK	48	Multiple ACK/NACKs for carrier aggregation: up to 20 ACK/NACK bits + optional SR, in 48 coded bits

Table 1: Supported PUCCH formats

[0062] In **Table 1**, M_{bit} represents the number of bits for a symbol mapper.

[0063] The complex-valued symbols may be block-wise spread with the two orthogonal sequences of length-5 each in the normal PUCCH 3 format, resulting in 10 symbols of 12 complex-valued modulation symbols. Each set of complex-valued symbols may be cyclically shifted and the shifted set of complex-valued symbols may be transform pre-coded.

[0064] In order to provide for better transmissions, frequency diversity may be exploited. Frequency diversity provides for increased reliability of message signals by transmitting using several frequency channels or spread over wide spectrum that is affected by frequency selective fading.

[0065] PUCCH in LTE is designed to exploit frequency diversity to minimize the resources for transmission of control signalling. The control signal on a PUCCH may be configured on the edges of the system bandwidth. Mapping of modulation symbols for PUCCH onto a physical resource block is shown, for example, with regard to **Figure 5**.

[0066] Referring to **Figure 5**, the PUCCH **502** is provided at either end of a system bandwidth **510**, surrounding a PUSCH **504**. In particular, each slot **512** and **514** may have data for the PUCCH. In the embodiment of **Figure 5**, the data at the beginning of the system bandwidth **510** is alternated between slot 0 and slot 1 at the beginning and at the end of the system bandwidth **510**.

[0067] Locating the PUCCH at the edges of the system bandwidth provides various benefits. A first benefit is that such location of the PUCCH maximizes

frequency diversity via frequency hopping. A second benefit is that smaller out-of-band emissions between PUSCH transmission of adjacent carriers is experienced. Further, such location of the PUCCH prevents system constraints on uplink scheduling.

[0068] Thus, in accordance with the example of **Figure 5**, twelve symbols for PUCCH are provided, six at the beginning of the resource block **510** and six at the end of resource block **510**.

[0069] *Repeat-accumulate code*

[0070] Repeat-accumulate codes are a low complexity class of error-correcting codes. RA codes allow an ensemble weight distribution to be easily derivable. RA codes, for examples, are provided by D. Divsalar, et al, "Coding theorems for 'turbo-like' codes." Proc. 36th Allerton Conf. on Communication, Control and Computing, Allerton, Illinois, Sept. 1998, pp. 201–210.

[0071] In an RA code, an information block of length- N is repeated q times, scrambled by an interleaver of size qN , and then encoded by a rate-1 accumulator. The accumulator may be viewed as a recursive convolutional encoder with a transfer function $1/(1 + D)$. As a block code, input block $(x_1, x_2, \dots, x_n)$ and output block $(y_1, y_2, \dots, y_n)$ are expressed by:

$$\begin{aligned} y_1 &= x_1 \\ y_i &= y_{i-1} + x_i \quad \text{for } i > 1 \end{aligned} \tag{1}$$

[0072] As seen in equation 1 above, if i is greater than 1 then y_i equals a previous value of y plus the current value of x .

[0073] RA codes are linear and nonsystematic, and have a rate of $1/q$.

[0074] *SEPARATE CODING*

[0075] As indicated above, CSI might be dropped if an HARQ-ACK is to be transmitted in the PUCCH format 3 of the CSI. In LTE Release 11 carrier aggregation, especially for FDD, a question exists for whether to support simultaneous transmission of CSI and HARQ-ACK when HARQ-ACK is transmitted on PUCCH format 3, as opposed to simply dropping the periodic CSI reporting.

[0076] One possible approach is to reuse the dual RM coding to increase a payload size that a UE can transmit on PUCCH format 3, such as that used by Rel-10 TDD. Since each RM code can support up to 11bits, the dual RM code can support a payload of up to 22bits.

[0077] One embodiment in accordance with the present disclosure may include information bit mapping and multiplexing/demultiplexing of HARQ-ACK and CSI bits, including the location of HARQ-ACK and CSI bits before encoding.

[0078] A further embodiment may include enablement of differential reliability control for HARQ-ACK and CSI feedbacks. A target reliability of HARQ-ACK is $10^{-4} - 10^{-3}$ NACK to ACK errors. Similarly, the target block error rate of CSI is $10^{-2} - 10^{-1}$. Although HARQ-ACK and CSI are transmitted in the same channel, one issue for simultaneous transmission of CSI and HARQ-ACK is how to meet different reliability for each information type.

[0079] The present disclosure provides for concatenation, rate matching and/or puncturing and mapping for simultaneous transmission for HARQ-ACK and periodic CSI, allowing HARQ-ACK and periodic CSI transmission to achieve a desired error performance. Specifically, in accordance with the present disclosure, modified control signalling schemes are provided that allow more feedback signals at the receiver by maximizing the diversity gain for both HARQ-ACK and periodic CSI signals together by interleaved mapping or different coding rates.

[0080] Various possible ways of multiplexing HARQ and periodic CSI signalling are provided in accordance with the embodiments below. Such schemes include separate coding with bit-interleaved mappers; separate coding with higher order modulation; and separate coding with different coding rates.

[0081] *Separate Coding with Bit-Interleaved Mappers*

[0082] In accordance with one embodiment of the present disclosure, a process is provided for simultaneously transmitting both HARQ-ACK and period CSI reports on PUCCH format 3. Since the error performance of the RM code is degraded depending on the puncturing patterns or the number of punctured bits, mapping rules may improve error performance of the punctured bits.

[0083] In the case where both HARQ-ACK and CSI reports are jointly encoded and rate matching is performed after joint encoding at the joint coding scheme, the differential reliability for HARQ-ACK and CSI feedbacks may not easily be achieved. Thus, in accordance with one embodiment of the present disclosure, bit mapping and concatenation occur after rate matching to achieve improved error performance than only the use of concatenation.

[0084] Reference is now made to **Figure 6**. **Figure 6** shows an exemplary structure of HARQ-ACK and CSI coding utilizing one approach in the accordance with the present disclosure.

[0085] In particular, in the example of **Figure 6**, HARQ-ACK and CSI are each RM encoded, as shown by blocks **610** and **612**, respectively. The example of **Figure 6** has equal puncturing, and thus the encoding at blocks **610** and **612** produce 32 bits for the HARQ-ACK bits and 32 bits for the CSI bits.

[0086] Subsequently, the encoded HARQ-ACK bits are rate matched at block **614** to produce A bits. The encoded CSI bits are rate matched at block **618** to produce (48-A) bits. In one embodiment, the parameter A is signaled by the eNB via higher layer signaling such as RRC signaling. In another embodiment, the parameter A is preconfigured and no signaling is needed.

[0087] The output from blocks **614** and **618** are provided to mapping and concatenation block **620**. At mapping and concatenation block **620** the HARQ-ACK bits are mapped with the CSI bits.

[0088] For example, reference is now made to **Figure 7**, which shows a mapping structure for separate coding, having equal puncturing or rate matching. As seen in **Figure 7**, a slot 0 includes ACK/NACK bit 0 followed by CSI bit 0, followed by ACK/NACK bit 2 and CSI bit 2 etc. Similarly, for slot 1, ACK/NACK bit 1 and CSI bit 1 follow each other, which is then followed by ACK/NACK bit 2 and CSI bit 3. In this way, the ACK/NACK bit is interleaved with the CSI bit.

[0089] The mapping of the HARQ and CSI bits maximizes frequency and time diversity and bit-interleaved effect, such as bit-interleaved coded modulation (BICM).

[0090] In accordance with the embodiment of **Figure 7**, the even numbers bits of each HARQ-ACK and CSI feedback are in the first slot and can be placed in an upper edge of a physical resource block, while the odd numbered bits of

each HARQ-ACK and CSI feedback are in the second slot and can be placed at a lower edge of a physical resource block and vice versa.

[0091] If the number of HARQ-ACK bits does not equal 24 then there could be more or less HARQ-ACK bits than CSI bits. In this case, once the interleaving reaches the end of the HARQ-ACK bits or CSI bits, whichever is shorter, the remaining bits will then be filled with the remainder of the HARQ-ACK or CSI bits, where the odd bits are placed in slot 1 and the even bits are placed in slot 0 in accordance with the embodiment of **Figure 7**.

[0092] The example of **Figure 7** is however not meant to be limiting and shows just one possibility for a mapping structure.

[0093] Referring again to **Figure 6**, the output from mapping and concatenation block **620** provides 48 bits, which are then scrambled at block **630**, and modulated at block **640**. In the example of **Figure 6**, the modulation is QPSK modulation. However, other modulation techniques could also be used, such as high order modulation types.

[0094] The output from modulation block **640** is 24 symbols of which: 12 symbols are provided to a first discrete Fourier transform (DFT) block **650**; and 12 symbols are provided to a second discrete Fourier transform block **660**.

[0095] The output from DFT block **650** is multiplied by a power level for the slot on the PUCCH, as shown by block **652** and then provided to an inverse fast Fourier transform (IFFT) block **654**.

[0096] Similarly, output from block **660** is provided to multiplier block **662** which multiplies by a power level for the second slot of the PUCCH. The output from block **662** is then provided to IFFT block **664**.

[0097] The outputs from block **654** and **664** are then sent to the network.

[0098] Since rate matching occurs after dual RM encoding, both code rates increase, thus providing slightly worse error performance than in the case without puncturing. In accordance with the present disclosure, QPSK symbols consist of 2 bits, each bit of which is from an HARQ-ACK and CSI feedback.

[0099] Thus, from **Figures 6** and **7**, the example shows a mapping structure with equal puncturing or rate matching from both the 1st and 2nd RM codes. The even bits of both coded HARQ and CSI feedbacks are mapped to the top of the band edge while the odd ones are mapped to the bottom of the band

edge, as seen above with regard to **Figure 5**. The separate coding mapping structure above maximizes frequency and time diversity by interleaving the bits from the CSI and HARQ-ACK.

[00100] If the above is implemented for a Long Term Evolution system, the 3GPP Technical Specification (TS) 36.212, V.10.4.0, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding (Release 10)", and specifically Section 5.2.3.1 may be changed in accordance with **Appendix A**.

[00101] As seen in **Appendix A**, the channel coding is now for both the UCI HARQ-ACK and for CSI. Additionally CSI bits can be transmitted simultaneously with HARQ-ACK. Further, as seen in **Appendix A** the channel coding provides for the interleaving of the ACK/NACK bits and the CSI bits.

[00102] ***Separate coding with higher order modulation***

[00103] In a further embodiment of the present disclosure, a higher-order modulation may be used to maximize the frequency diversity or exploit a simple channel coding.

[00104] After performing rate matching, the number of combined output bits is 48 for QPSK modulation. In order to increase capacity of control channels, two alternatives are provided in the present disclosure. A first is to assign new resources for supporting more control channels and the other is to make spectral efficiency higher under the same assumptions.

[00105] With regard to a hybrid modulation scheme, depending on the number of configured CCs, different modulation schemes may be adopted. If the number of configured CCs is small, then the overall code rate for the HARQ-ACK feedback becomes lower. In this case, higher modulation may be used to make the operating signal to noise ratio (SNR) higher instead of using puncturing patterns.

[00106] For example, reference is now made to **Table 2** below.

$N_{HARQ-ACK,in}$	Code rate before rate matching	Modulation Scheme	Puncturing pattern with target $[N_{HARQ-ACK}, N_{CSI}] = [30,18]$
1-2	1/32 – 2/32	16-QAM	No puncturing
3-4	3/32 – 4/32		
5-6	5/32 – 6/32	QPSK	HARQ-ACK: [11111111111111110111111111111110] CSI: [11010101110101001101010111010100]
7-8	7/32 – 8/32		
9-10	9/32 – 10/32		

Table 2: Hybrid modulation schemes depending on the number of the configured CCs

[00107] In **Table 2**, when the number of CCs is lower than a threshold then the 16-Quadrature Amplitude Modulation (QAM) scheme may be used. Thus, for example, in **Table 2** when up to 4 bits of $N_{HARQ-ACK,in}$ are present, then 16-QAM modulation is used with no puncturing.

[00108] When no puncturing is used, all encoded HARQ-ACK feedback is transmitted using 16-QAM and all encoded CSI feedback is repeated two times and mapped onto 16-QAM.

[00109] Alternatively, if the number of $N_{HARQ-ACK,in}$ bits is between 5 and 10, then QPSK modulation is used. In the example of **Table 2**, bit masks are provided which show which bits are transmitted and which bits are punctured. “1” means the corresponding bit is transmitted while “0” means the corresponding bit is punctured. In the embodiment of **Table 2**, 30 HARQ-ACK bits are transmitted while 18 CSI bits are transmitted. The higher puncturing of the CSI bits permits better error performance for the HARQ-ACK bits. The puncturing patterns in **Table 2** are however merely examples and other puncturing patterns are possible.

[00110] Therefore, in accordance with **Table 2** a hybrid modulation scheme is provided where higher order modulation is used when there are fewer $N_{HARQ-ACK}$ bits.

[00111] In an alternative embodiment, instead of hybrid modulation schemes, higher modulation schemes may be used. Reference is now made to **Figure 8**.

[00112] As seen in **Figure 8**, the 48 bits provided after RM blocks **810** and **812** and rate matching blocks **814** and **816** are provided to concatenation and repetition block **820**.

[00113] Concatenation and repetition block **820** repeats each bit two times. The 96 bits are then scrambled at block **830** and modulated with 16-QAM at block **840**. The 16-QAM modulation provides 12 symbols of which the first 12 are provided to DFT block **850** and the second 12 symbols are provided to DFT block **860**.

[00114] Further, the RA codes described above can be used with the present embodiment and may further add performance improvement for the decoding. The RA code may be applied in concatenation and repetition block **820**, for example.

[00115] The output from DFT block **850** is then multiplied by a power level for the PUCCH, as shown at block **852** and output to an IFFT at block **854**. Similarly, the output of DFT block **860** is multiplied with the power for the PUCCH at block **862** and the output from block **862** is provided to IFFT block **864**.

[00116] In accordance with one embodiment of the present disclosure, block **820** can further perform mapping and interleaving in a similar manner to block **620** from **Figure 6**.

[00117] Reference is now made to **Figure 9**. As seen in **Figure 9**, the bits may be interleaved. However, since there are 48 bits within each slot the interleaving can allow for ACK/NACK bit 0 and CSI bit 0 to be followed by ACK/NACK bit 1 and CSI bit 1 in slot 0. Thus, all 24 bits for the ACK/NACK and for the CSI are provided both in slot 0 and in slot 1.

[00118] In one embodiment, interleaving structure may also be applied after scrambling instead of applying the interleaving at the concatenation block.

[00119] To transmit both the HARQ-ACK and CSI feedback simultaneously, 16-QAM may be applied with a proper rate matching and repetition if the QPSK block **640** of **Figure 6** is replaced with a 16-QAM block **840** of **Figure 8**.

[00120] ***Separate Coding With Different Coding Rates***

[00121] In a further alternative embodiment, a process is provided for different rate matching schemes depending on how much reliability is required by the receiver. As provided in **Figure 4** above, input bits for mapping and concatenation block consist of two different punctured code bits, each of which is for HARQ-ACK and CSI feedbacks respectively. The error performance required for the HARQ-ACK feedback is, in general, better than that for the CSI feedback. Thus, different code rates may be required for both the HARQ-ACK and CSI coded bits. In other words, under the same wireless channel conditions, a lower code rate for the HARQ-ACK feedback is required than that of CSI feedback.

[00122] The number of the output bits after rate matching are given by equation 2 below.

$$N_{HARQ-ACK} = f_1 \left(\frac{N_{HARQ-ACK,in}}{32} \right) \quad (2)$$

$$N_{CSI} = f_2 \left(\frac{N_{CSI,in}}{32} \right)$$

[00123] In equation 2, the $N_{HARQ-ACK}$ and N_{CSI} are the number of coded bits from a dual RM codes after rate matching respectively. f_1 and f_2 are puncturing functions for rate matching respectively, and $N_{HARQ-ACK,in}$ and $N_{CSI,in}$ are the number of input bits for the dual RM codes, respectively.

[00124] The number 32 in equation 2 represent the number of output bits after the RM coding.

[00125] Puncturing functions f_1 and f_2 may be configured depending on the importance of HARQ-ACK and CSI feedbacks. Various assumptions may exist for the input and output bits and may include, for example, that the number of HARQ-ACK bits and the number of CSI bits is equal to 48. Further, the number of input bits for the HARQ-ACK is between 0 and 10 for a frequency division duplex. Further, the number of input bits for CSI is between 0 and 11.

[00126] Based on the above assumptions, each code rate is given in accordance with equation 3 below.

$$CR_{HARQ-ACK} = \frac{N_{HARQ-ACK,in}}{N_{HARQ-ACK}} \quad (3)$$

$$CR_{CSI} = \frac{N_{CSI,in}}{N_{CSI}}$$

[00127] In Equation 3, $CR_{HARQ-ACK}$ and CR_{CSI} are the actual code rate for HARQ-ACK and CSI feedbacks after rate matching, respectively. To achieve a better error performance for HARQ-ACK, the actual code rate for the $CR_{HARQ-ACK}$ is less than or equal to CR_{CSI} .

[00128] An appropriate code rate for each RM code or value of A ($= N_{HARQ-ACK}$) is a function of $N_{HARQ-ACK,in}$, $N_{CSI,in}$, f_1 , f_2 , and the required SNRs for HARQ-ACK and CSI feedbacks to achieve an error performance dependent on wireless channel conditions.

[00129] In accordance with the present disclosure, two alternative embodiments exist. In a first alternative, the $N_{HARQ-ACK}$ is fixed, regardless of the number of the configured CCs. In a second alternative, variable puncturing is provided for $CR_{HARQ-ACK}$.

[00130] In the fixed $N_{HARQ-ACK}$ solution, regardless of the configured CCs, the number of output bits from the HARQ-ACK feedback remains fixed. Furthermore, the CSI feedback has higher puncturing than the HARQ-ACK feedback in order to achieve an error performance for the HARQ-ACK feedback that is better than that for the CSI feedback.

[00131] One example is shown below with regard to **Table 3**. **Table 3** illustrates puncturing patterns where the $N_{HARQ-ACK} = 30$ $N_{CSI} = 18$.

$N_{HARQ-ACK}$	Code rate before rate matching	Puncturing pattern with target $[N_{HARQ-ACK}, N_{CSI}] = [30, 18]$
1-2	$1/32 - 2/32$	HARQ-ACK: [111111111111110111111111111110] CSI: [11010101110101001101010111010100]
3-4	$3/32 - 4/32$	
5-6	$5/32 - 6/32$	
7-8	$7/32 - 8/32$	
9-10	$9/32 - 10/32$	

Table 1: Puncturing patterns for fixed
 $N_{HARQ-ACK}$

[00132] As seen from **Table 3** above, the puncturing pattern remains the same, regardless of the number of CCs configured. In **Table 3**, a “0” indicates punctured bits and a “1” indicates non-punctured bits.

[00133] In a second alternative embodiment, variable puncturing may be provided for the code rate for HARQ-ACK. In this alternative, the payload size of HARQ-ACK feedback is dependent on the number of configured CCs. As seen above with regard to **Figure 4**, the number of output bits from the RM code for the HARQ-ACK feedback is 32 bits. That is, the code rate becomes lower if the number of configured CCs is smaller.

[00134] Thus, in the alternative embodiment, depending on the number of configured CCs, the puncturing rate may be varied. In other words, the smaller the number of configured CCs, the more output bits are punctured. Higher numbers of HARQ-ACK bits that are punctured lead to more CSI reporting information that can be transmitted.

[00135] One example is shown below with regard to **Table 4**, which shows that more coded bits for HARQ-ACK feedback are punctured from the outputs of the RM code if the number of configured CCs is less than 7, while less coded bits are punctured if $N_{HARQ-ACK,in}$ is more than 6.

$N_{HARQ-ACK,in}$	Code rate before rate matching	Puncturing pattern with target $CR_{HARQ-ACK}$
1-2	1/32 – 2/32	HARQ-ACK: [10101010101010101010101010101010] (16) CSI: [11111111111111111111111111111111] (32)
3-4	3/32 – 4/32	
5-6	5/32 – 6/32	HARQ-ACK: [11101110111011101110111011101110] (24) CSI: [11101110111011101110111011101110] (24)
7-8	7/32 – 8/32	
9-10	9/32 – 10/32	

Table 2: Puncturing patterns for variable $CR_{HARQ-ACK}$

[00136] Specifically, for **Table 4**, the puncturing for the HARQ-ACK when the number of input HARQ bits is less than 7 includes 16 bits for puncturing the HARQ-ACK and 32 bits for puncturing the CSI.

[00137] Once the number of input HARQ bits reaches 7 then the puncturing results in 24 HARQ bits and 24 CSI bits.

[00138] The variable puncturing allows better error performance for the HARQ-ACK to be maintained while allowing more CSI bits if there are fewer CCs configured. In one embodiment, the variable puncturing may be configured by the eNB or preconfigured by the standards.

[00139] The above may be implemented by any network element. A simplified network element is shown with regard to **Figure 10**.

[00140] In **Figure 10**, network element **1010** includes a processor **1020** and a communications subsystem **1030**, where the processor **1020** and communications subsystem **1030** cooperate to perform the methods described above.

[00141] Further, the above may be implemented by any UE. One exemplary device is described below with regard to **Figure 11**.

[00142] UE **1100** is typically a two-way wireless communication device having voice and data communication capabilities. UE **1100** generally has the capability to communicate with other computer systems on the Internet. Depending on the exact functionality provided, the UE may be referred to as a data messaging device, a two-way pager, a wireless e-mail device, a cellular telephone with data messaging capabilities, a wireless Internet appliance, a

wireless device, a mobile device, or a data communication device, as examples.

[00143] Where UE **1100** is enabled for two-way communication, it may incorporate a communication subsystem **1111**, including both a receiver **1112** and a transmitter **1114**, as well as associated components such as one or more antenna elements **1116** and **1118**, local oscillators (LOs) **1113**, and a processing module such as a digital signal processor (DSP) **1120**. As will be apparent to those skilled in the field of communications, the particular design of the communication subsystem **1111** will be dependent upon the communication network in which the device is intended to operate. The radio frequency front end of communication subsystem **1111** can be any of the embodiments described above.

[00144] Network access requirements will also vary depending upon the type of network **1119**. In some networks network access is associated with a subscriber or user of UE **1100**. A UE may require a removable user identity module (RUIM) or a subscriber identity module (SIM) card in order to operate on a network. The SIM/RUIM interface **1144** is normally similar to a card-slot into which a SIM/RUIM card can be inserted and ejected. The SIM/RUIM card can have memory and hold many key configurations **1151**, and other information **1153** such as identification, and subscriber related information.

[00145] When required network registration or activation procedures have been completed, UE **1100** may send and receive communication signals over the network **1119**. As illustrated in **Figure 11**, network **1119** can consist of multiple base stations communicating with the UE.

[00146] Signals received by antenna **1116** through communication network **1119** are input to receiver **1112**, which may perform such common receiver functions as signal amplification, frequency down conversion, filtering, channel selection and the like. A/D conversion of a received signal allows more complex communication functions such as demodulation and decoding to be performed in the DSP **1120**. In a similar manner, signals to be transmitted are processed, including modulation and encoding for example, by DSP **1120** and input to transmitter **1114** for digital to analog conversion, frequency up conversion, filtering, amplification and transmission over the communication network **1119** via antenna **1118**. DSP **1120** not only

processes communication signals, but also provides for receiver and transmitter control. For example, the gains applied to communication signals in receiver **1112** and transmitter **1114** may be adaptively controlled through automatic gain control algorithms implemented in DSP **1120**.

[00147] UE **1100** generally includes a processor **1138** which controls the overall operation of the device. Communication functions, including data and voice communications, are performed through communication subsystem **1111**. Processor **1138** also interacts with further device subsystems such as the display **1122**, flash memory **1124**, random access memory (RAM) **1126**, auxiliary input/output (I/O) subsystems **1128**, serial port **1130**, one or more keyboards or keypads **1132**, speaker **1134**, microphone **1136**, other communication subsystem **1140** such as a short-range communications subsystem and any other device subsystems generally designated as **1142**. Serial port **1130** could include a USB port or other port known to those in the art.

[00148] Some of the subsystems shown in **Figure 11** perform communication-related functions, whereas other subsystems may provide “resident” or on-device functions. Notably, some subsystems, such as keyboard **1132** and display **1122**, for example, may be used for both communication-related functions, such as entering a text message for transmission over a communication network, and device-resident functions such as a calculator or task list.

[00149] Operating system software used by the processor **1138** may be stored in a persistent store such as flash memory **1124**, which may instead be a read-only memory (ROM) or similar storage element (not shown). Those skilled in the art will appreciate that the operating system, specific device applications, or parts thereof, may be temporarily loaded into a volatile memory such as RAM **1126**. Received communication signals may also be stored in RAM **1126**.

[00150] As shown, flash memory **1124** can be segregated into different areas for both computer programs **1158** and program data storage **1150**, **1152**, **1154** and **1156**. These different storage types indicate that each program can allocate a portion of flash memory **1124** for their own data storage requirements. Processor **1138**, in addition to its operating system

functions, may enable execution of software applications on the UE. A predetermined set of applications that control basic operations, including at least data and voice communication applications for example, will normally be installed on UE **1100** during manufacturing. Other applications could be installed subsequently or dynamically.

[00151] Applications and software may be stored on any computer readable storage medium. The computer readable storage medium may be a tangible or in transitory/non-transitory medium such as optical (e.g., CD, DVD, etc.), magnetic (e.g., tape) or other memory known in the art.

[00152] One software application may be a personal information manager (PIM) application having the ability to organize and manage data items relating to the user of the UE such as, but not limited to, e-mail, calendar events, voice mails, appointments, and task items. Naturally, one or more memory stores would be available on the UE to facilitate storage of PIM data items. Such PIM application may have the ability to send and receive data items, via the wireless network **1119**. Further applications may also be loaded onto the UE **1100** through the network **1119**, an auxiliary I/O subsystem **1128**, serial port **1130**, short-range communications subsystem **1140** or any other suitable subsystem **1142**, and installed by a user in the RAM **1126** or a non-volatile store (not shown) for execution by the processor **1138**. Such flexibility in application installation increases the functionality of the device and may provide enhanced on-device functions, communication-related functions, or both. For example, secure communication applications may enable electronic commerce functions and other such financial transactions to be performed using the UE **1100**.

[00153] In a data communication mode, a received signal such as a text message or web page download will be processed by the communication subsystem **1111** and input to the processor **1138**, which may further process the received signal for output to the display **1122**, or alternatively to an auxiliary I/O device **1128**.

[00154] A user of UE **1100** may also compose data items such as email messages for example, using the keyboard **1132**, which may be a complete alphanumeric keyboard or telephone-type keypad, among others, in conjunction with the display **1122** and possibly an auxiliary I/O device **1128**.

Such composed items may then be transmitted over a communication network through the communication subsystem **1111**.

[00155] For voice communications, overall operation of UE **1100** is similar, except that received signals would typically be output to a speaker **1134** and signals for transmission would be generated by a microphone **1136**. Alternative voice or audio I/O subsystems, such as a voice message recording subsystem, may also be implemented on UE **1100**. Although voice or audio signal output is generally accomplished primarily through the speaker **1134**, display **1122** may also be used to provide an indication of the identity of a calling party, the duration of a voice call, or other voice call related information for example.

[00156] Serial port **1130** in **Figure 11** would normally be implemented in a personal digital assistant (PDA)-type UE for which synchronization with a user's desktop computer (not shown) may be desirable, but is an optional device component. Such a port **1130** would enable a user to set preferences through an external device or software application and would extend the capabilities of UE **1100** by providing for information or software downloads to UE **1100** other than through a wireless communication network. The alternate download path may for example be used to load an encryption key onto the device through a direct and thus reliable and trusted connection to thereby enable secure device communication. As will be appreciated by those skilled in the art, serial port **1130** can further be used to connect the UE to a computer to act as a modem.

[00157] Other communications subsystems **1140**, such as a short-range communications subsystem, is a further optional component which may provide for communication between UE **1100** and different systems or devices, which need not necessarily be similar devices. For example, the subsystem **1140** may include an infrared device and associated circuits and components or a Bluetooth™ communication module to provide for communication with similarly enabled systems and devices. Subsystem **1140** may further include non-cellular communications such as WiFi or WiMAX.

[00158] The embodiments described herein are examples of structures, systems or methods having elements corresponding to elements of the techniques of this application. This written description may enable those

skilled in the art to make and use embodiments having alternative elements that likewise correspond to the elements of the techniques of this application. The intended scope of the techniques of this application thus includes other structures, systems or methods that do not differ from the techniques of this application as described herein, and further includes other structures, systems or methods with insubstantial differences from the techniques of this application as described herein.

APPENDIX A

5.2.3.1 Channel coding for UCI HARQ-ACK and CSI

In case the transmission of HARQ-ACK feedback using PUCCH format 3 [0057] coincides with a sub-frame configured to the UE by higher layers for transmission of scheduling request, the scheduling request bit (1 = positive SR; 0 = negative SR) is appended at the end of the sequence of concatenated HARQ-ACK bits. **Additionally, CSI can be transmitted simultaneously with HARQ-ACK.**

For $N_{A/N}^{\text{PUCCH format 3}} \leq 11$, the bit sequence $a_0, a_1, a_2, \dots, a_{N_{A/N}^{\text{PUCCH format 3}}-1}$ is obtained by setting $a_i = \tilde{o}_i^{\text{ACK}}$ and for $N_{\text{CSI}}^{\text{PUCCH format 3}} \leq 11$, the bit sequence $c_0, c_1, c_2, \dots, c_{N_{\text{CSI}}^{\text{PUCCH format 3}}-1}$ is obtained by setting $c_i = \tilde{o}_i^{\text{CSI}}$.

For $11 < N_{A/N}^{\text{PUCCH format 3}} \leq 21$, the bit sequence $a_0, a_1, a_2, \dots, a_{N_{A/N}^{\text{PUCCH format 3}}-1}$ is obtained by setting $a_{i/2} = \tilde{o}_i^{\text{ACK}}$ if i is even and $a_{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil + (i-1)/2} = \tilde{o}_i^{\text{ACK}}$ if i is odd.

For $N_{A/N}^{\text{PUCCH format 3}} \leq 11$ and $N_{\text{CSI}}^{\text{PUCCH format 3}} \leq 11$, the sequence of bits $a_0, a_1, a_2, \dots, a_{N_{A/N}^{\text{PUCCH format 3}}-1}$ and $c_0, c_1, c_2, \dots, c_{N_{\text{CSI}}^{\text{PUCCH format 3}}-1}$ is encoded as follows

$$\tilde{b}_i = \sum_{n=0}^{N_{A/N}^{\text{PUCCH format 3}}-1} (a_n \cdot M_{i,n}) \bmod 2 \quad \text{and} \quad \bar{b}_i = \sum_{n=0}^{N_{\text{CSI}}^{\text{PUCCH format 3}}-1} (c_n \cdot M_{i,n}) \bmod 2$$

where $i = 0, 1, 2, \dots, 31$ and the basis sequences $M_{i,n}$ are defined in Table 5.2.2.6.4-1.

The output bit sequence $b_0, b_1, b_2, \dots, b_{B-1}$ and the output bit sequence $b_0^C, b_1^C, b_2^C, \dots, b_{B-1}^C$ are obtained by circular repetition of the sequence $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, \dots, \tilde{b}_{31}$ and $\bar{b}_0, \bar{b}_1, \bar{b}_2, \dots, \bar{b}_{31}$, respectively

$$b_i = \tilde{b}_{(i \bmod 32)} \quad \text{and} \quad b_i^C = \bar{b}_{(i \bmod 32)}$$

where $i = 0, 1, 2, \dots, B-1$ and where $B = 4 \cdot N_{\text{sc}}^{\text{RB}}$.

For $11 < N_{A/N}^{\text{PUCCH format 3}} \leq 21$, the sequences of bits $a_0, a_1, a_2, \dots, a_{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil-1}$ and $a_{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil}, a_{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil+1}, a_{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil+2}, \dots, a_{N_{A/N}^{\text{PUCCH format 3}}-1}$ are encoded as follows

$$\tilde{b}_i = \sum_{n=0}^{\lceil N_{A/N}^{\text{PUCCH format 3}}/2 \rceil-1} (a_n \cdot M_{i,n}) \bmod 2$$

and

$$\tilde{b}_i = \sum_{n=0}^{N_{A/N}^{\text{PUCCH format 3}} - \lceil N_{A/N}^{\text{PUCCH format 3}/2} \rceil - 1} \left(a_{\lceil N_{A/N}^{\text{PUCCH format 3}/2} \rceil + n} \cdot M_{i,n} \right) \bmod 2$$

where $i = 0, 1, 2, \dots, 23$ and the basis sequences $M_{i,n}$ are defined in Table 5.2.2.6.4-1.

The output bit sequence $b_0, b_1, b_2, \dots, b_{B-1}$ where $B = 4 \cdot N_{\text{sc}}^{\text{RB}}$ is obtained by the alternate concatenation of the bit sequences $\tilde{b}_0, \tilde{b}_1, \tilde{b}_2, \dots, \tilde{b}_{23}$ and $\tilde{\tilde{b}}_0, \tilde{\tilde{b}}_1, \tilde{\tilde{b}}_2, \dots, \tilde{\tilde{b}}_{23}$ as follows

Set $i, j = 0$

while $i < 4 \cdot N_{\text{sc}}^{\text{RB}}$

$$b_i = \tilde{b}_j, \quad b_{i+1} = \tilde{b}_{j+1}$$

$$b_{i+2} = \tilde{\tilde{b}}_j, \quad b_{i+3} = \tilde{\tilde{b}}_{j+1}$$

$$i = i + 4$$

$$j = j + 2$$

end while

When PUCCH format 3 is not used for transmission of HARQ-ACK feedback, the HARQ-ACK bits are processed for transmission according to section 10.1.

CLAIMS

1. A method of operating a user equipment (UE) in a wireless communications network, the method comprising:
 - separately encoding and rate matching a first set of information bits and a second set of information bits;
 - mapping and concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and
 - modulating and transmitting the bit stream.
2. The method of claim 1, wherein the encoding comprises using a Reed-Muller encoder.
3. The method of claim 1 or claim 2, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.
4. The method of any one of claims 1 to 3, wherein the transmission is done on a physical uplink control channel (PUCCH).
5. The method of claim 4, wherein the mapping creates a constellation of an information bit from the first set of information bits with a second information bit from the second set of information bits within a quadrature phase shift keying (QPSK) symbol.
6. The method of claim 5, wherein even numbered bits of the first set of information bits and the second set of information bits are located within a first constellation and are mapped to one band edge of a physical resource block and the odd numbered bits of the first set of information bits and the second set of information bits are located within a second constellation and are mapped to a second band edge of the physical resource block.

7. The method of any one of claims 1 to 6, wherein the mapping comprises interleaving the first set of information bits with the second set of information bits.

8. The method of claim 7, wherein, if the first set of information bits has more bits than the second set of information bits, any remaining bits in the first set of information bits after interleaving are mapped after the interleaved bits.

9. A user equipment comprising:
a processor; and
a communications subsystem,

wherein the processor and communications subsystem are configured to:

separately encode and rate match a first set of information bits and a second set of information bits;

map and concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and

modulate and transmit the bit stream.

10. The user equipment of claim 9, wherein the processor and communications subsystem are configured to encode by using a Reed-Muller encoder.

11. The user equipment of claim 9 or claim 10, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.

12. The user equipment of any one of claims 9 to 11, wherein the transmission is done on a physical uplink control channel (PUCCH).

13. The user equipment of claim 12, wherein the processor and communications subsystem are configured to map by creating a constellation of an information bit from the first set of information bits with a second information bit from the second set of information bits within a quadrature phase shift keying (QPSK) symbol.

14. The user equipment of claim 13, wherein even numbered bits of the first set of information bits and the second set of information bits are located within a first constellation and are mapped to one band edge of a physical resource block and the odd numbered bits of the first set of information bits and the second set of information bits are located within a second constellation and are mapped to a second band edge of the physical resource block.

15. The user equipment of any one of claims 9 to 14, wherein the processor and communications subsystem are configured to map by interleaving the first set of information bits with the second set of information bits.

16. The user equipment of claim 15, wherein, if the first set of information bits has more bits than the second set of information bits, any remaining bits in the first set of information bits after interleaving are mapped after the interleaved bits.

17. A method of operating a user equipment (UE) in a wireless communications network, the method comprising:

- separately encoding and rate matching a first set of information bits and a second set of information bits;

- concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream;

- modulating the bit stream using a modulation scheme selected depending on a number of configured component carriers; and

- transmitting the modulated bit stream.

18. The method of claim 17, wherein, if the number of component carriers configured is less than a threshold, the modulation using a higher order modulation technique than a default modulation technique.

19. The method of claim 18, wherein the higher order modulation technique is 16-Quadrature Amplitude Modulation.

20. The method of claim 18 or 19, wherein the encoding uses no puncturing if the number of component carriers configured is less than the threshold.

21. The method of any one of claims 17 to 20, wherein, if the number of component carriers configured is higher than a threshold, the modulation using a default modulation technique.

22. The method of claim 21, wherein the default modulation technique is Quadrature Phase Shift Keying.

23. The method of claim 21 or 22, wherein the encoding uses puncturing if the number of component carriers configured is greater than the threshold.

24. The method of claim 23, wherein first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits, and wherein the puncturing provides more non-punctured bits for the HARQ acknowledgement bits.

25. A user equipment comprising:
a processor; and
a communications subsystem,

wherein the processor and communications subsystem are configured to:

separately encode and rate match a first set of information bits and a second set of information bits;

concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream;

modulate the bit stream using a modulation scheme selected depending on a number of configured component carriers; and

transmit the modulated bit stream.

26. The user equipment of claim 25, wherein, if the number of component carriers configured is less than a threshold, the processor and communications subsystem are configured to modulate uses a higher order modulation technique than a default modulation technique.

27. The user equipment of claim 26, wherein the higher order modulation technique is 16-Quadrature Amplitude Modulation.

28. The user equipment of claim 26 or 27, wherein the processor and communications subsystem are configured to encode using no puncturing if the number of component carriers configured is less than the threshold.

29. The user equipment of any one of claims 25 to 28, wherein, if the number of component carriers configured is higher than a threshold, the processor and communications subsystem are configured to modulate using a default modulation technique.

30. The user equipment of claim 29, wherein the default modulation technique is Quadrature Phase Shift Keying.

31. The user equipment of claim 29 or 30, wherein the processor and communications subsystem are configured to encode using puncturing if the number of component carriers configured is greater than the threshold.

32. The user equipment of claim 31, wherein first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits, and wherein the puncturing provides more non-punctured bits for the HARQ acknowledgement bits.

33. A method of operating a user equipment (UE) in a wireless communications network, the method comprising:

separately encoding and rate matching a first set of information bits and a second set of information bits;

concatenating and repeating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and

modulating and transmitting the bit stream.

34. The method of claim 33, wherein the repetition doubles the number of bits in the bit stream.

35. The method of claim 34, wherein the modulation uses a higher order modulation technique to transmit the repeated bit stream than a default modulation technique.

36. The method of claim 35, wherein the higher order modulation technique is 16-Quadrature Amplitude Modulation.

37. The method of any one of claims 33 to 36, further comprising, prior to the concatenating and repeating, mapping the first set of information bits with the second set of information bits.

38. The method of claim 37, wherein the mapping comprises interleaving the first set of information bits with the second set of information bits.

39. The method of any one of claims 33 to 38, wherein the transmission is done on a physical uplink control channel.

40. The method of claim 39, wherein the mapping maps the first set of information bits and second set of information bits to both a first transmission slot and a second transmission slot.

41. The method of any one of claims 33 to 40, wherein the encoding uses a Reed-Muller encoder.

42. The method of any one of claims 33 to 41, wherein the encoding uses repeat accumulate (RA) encoding.

43. A user equipment comprising:
a processor; and
a communications subsystem,
wherein the processor and communications subsystem are configured to:
separately encode and rate match a first set of information bits and a second set of information bits;
concatenate and repeat the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and
modulate and transmit the bit stream.

44. The user equipment of claim 43, wherein the processor and communications subsystem are configured to repeat to double the number of bits in the bit stream.

45. The user equipment of claim 44, wherein the processor and communications subsystem are configured to modulate using a higher order modulation technique to transmit the repeated bit stream than a default modulation technique.

46. The user equipment of claim 45, wherein the higher order modulation technique is 16-Quadrature Amplitude Modulation.

47. The user equipment of any one of claims 43 to 46, wherein the processor and communications subsystem are further configured to, prior to the concatenating and repeating, map the first set of information bits with the second set of information bits.

48. The user equipment of claim 47, wherein the processor and communications subsystem are configured to map by interleaving the first set of information bits with the second set of information bits.

49. The user equipment of any one of claims 43 to 48, wherein the transmission is done on a physical uplink control channel.

50. The user equipment of claim 49, wherein the processor and communications subsystem are configured to map the first set of information bits and second set of information bits to both a first transmission slot and a second transmission slot.

51. The user equipment of any one of claims 43 to 50, wherein the processor and communications subsystem are configured to encode using a Reed-Muller encoder.

52. The user equipment of any one of claims 43 to 51, wherein the processor and communications subsystem are configured to encode using repeat accumulate (RA) encoding.

53. A method of operating a user equipment (UE) in a wireless communications network, the method comprising:

- separately encoding a first set of information bits and a second set of information bits;

- rate matching the encoded first set of information bits using a first puncturing pattern;

- rate matching the encoded second set of information bits using a second puncturing pattern;

concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and

modulating and transmitting the bit stream,
wherein the second puncturing pattern has more punctured bits than the first puncturing pattern.

54. The method of claim 53, wherein the encoding uses a Reed-Muller encoder.

55. The method of claim 53 or claim 54, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.

56. The method of any one of claims 53 to 55, wherein the transmission is done on a physical uplink control channel.

57. A user equipment comprising:
a processor; and
a communications subsystem,

wherein the processor and communications subsystem are configured to:

separately encode a first set of information bits and a second set of information bits;

rate match the encoded first set of information bits using a first puncturing pattern;

rate match the encoded second set of information bits using a second puncturing pattern;

concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and

modulate and transmit the bit stream,
wherein the second puncturing pattern has more punctured bits than the first puncturing pattern.

58. The user equipment of claim 57, wherein the processor and communications subsystem are configured to encode using a Reed-Muller encoder.

59. The user equipment of claim 57 or claim 58, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.

60. The user equipment of any one of claims 57 to 59, wherein the transmission is done on a physical uplink control channel.

61. A method of operating a user equipment (UE) in a wireless communications network, the method comprising:

- separately encoding a first set of information bits and a second set of information bits;

- rate matching the encoded first set of information bits, the rate matching using a first puncturing pattern;

- rate matching the encoded second set of information bits, the rate matching using a second puncturing pattern;

- concatenating the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and

- modulating and transmitting the bit stream,

wherein a number of punctured bits within the first puncturing pattern and the number of punctured bits within the second puncturing pattern depend on a number of configured component carriers.

62. The method of claim 61, wherein the encoding uses a Reed-Muller encoder.

63. The method of claim 61 or claim 62, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.

64. The method of any one of claims 61 to 63, wherein the transmission is done on a physical uplink control channel.

65. A user equipment comprising:
a processor; and
a communications subsystem,
wherein the processor and communications subsystem are configured to:
separately encode a first set of information bits and a second set of information bits;
rate match the encoded first set of information bits, the rate matching using a first puncturing pattern;
rate match the encoded second set of information bits, the rate matching using a second puncturing pattern;
concatenate the encoded and rate matched first set of information bits with the encoded and rate matched second set of information bits, thereby creating a bit stream; and
modulate and transmit the bit stream,
wherein a number of punctured bits within the first puncturing pattern and the number of punctured bits within the second puncturing pattern depend on a number of configured component carriers.

66. The user equipment of claim 65, wherein the processor and communications subsystem are configured to encode using a Reed-Muller encoder.

67. The user equipment of claim 65 or claim 66, wherein the first set of information bits comprise hybrid automatic repeat request (HARQ) acknowledgement bits and the second set of information bits comprise channel state indicator bits.

68. The user equipment of any one of claims 65 to 67, wherein the transmission is done on a physical uplink control channel.

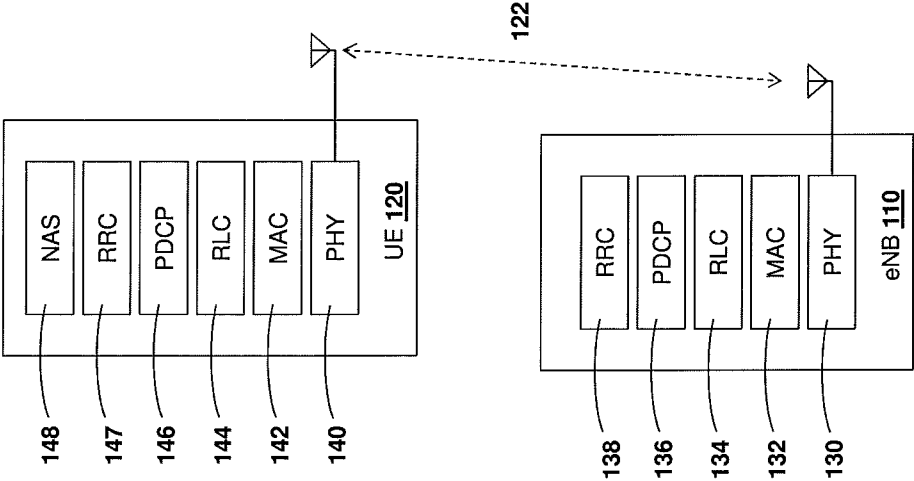


FIG. 1

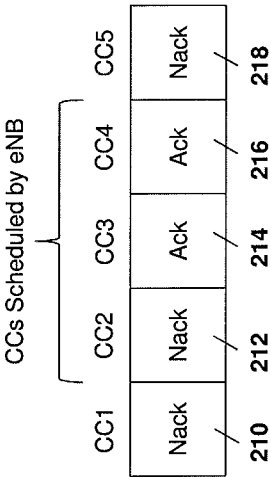


FIG. 2

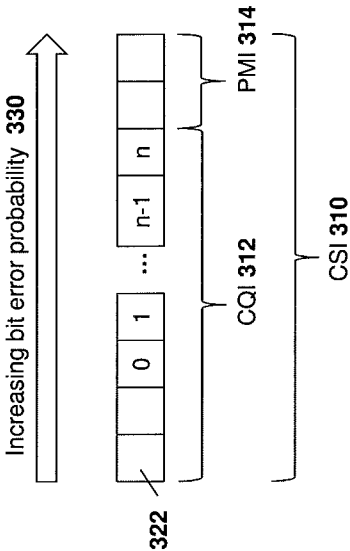


FIG. 3

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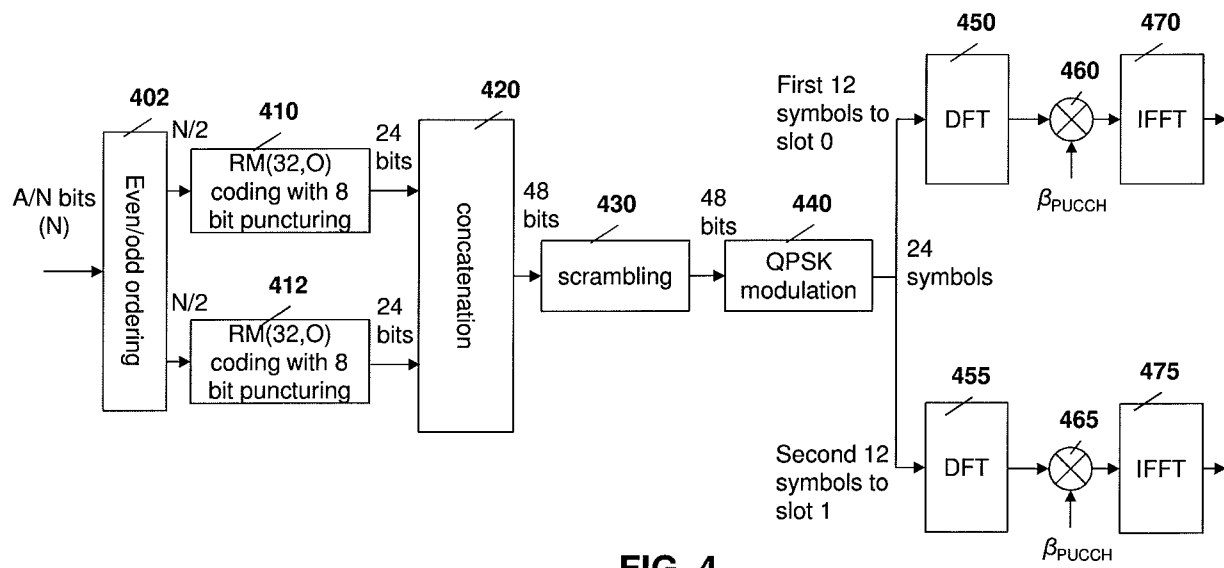
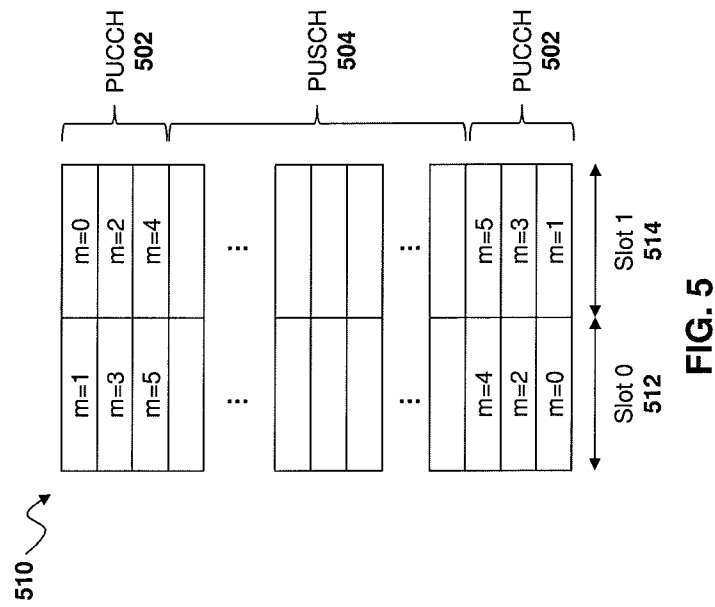


FIG. 4



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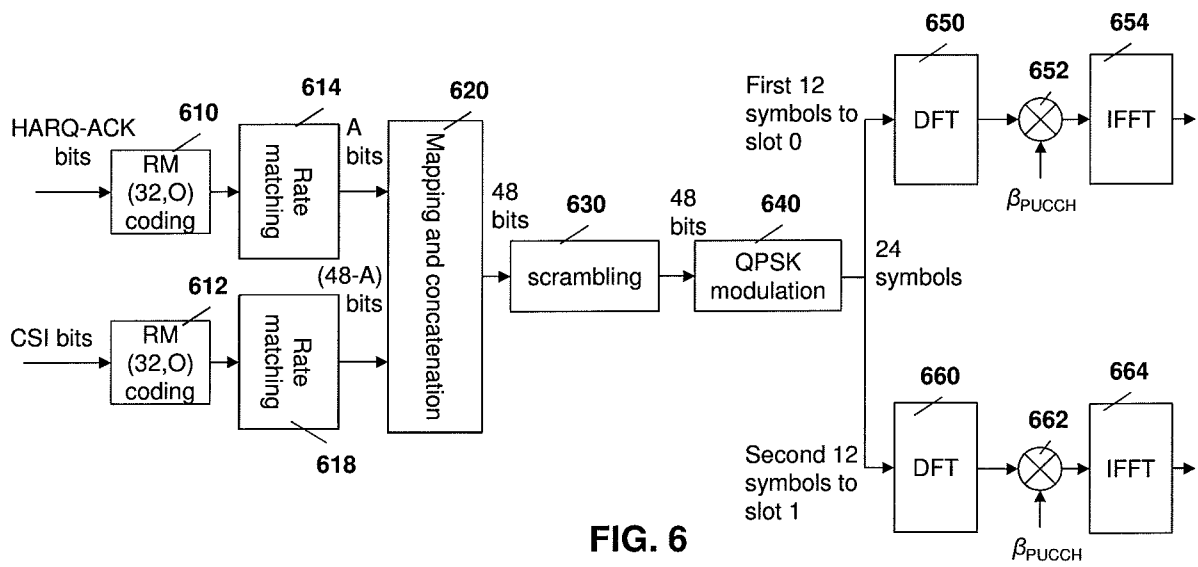


FIG. 6

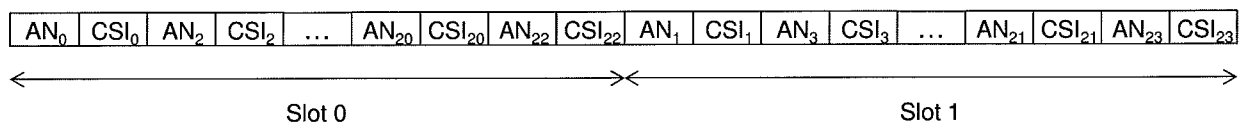
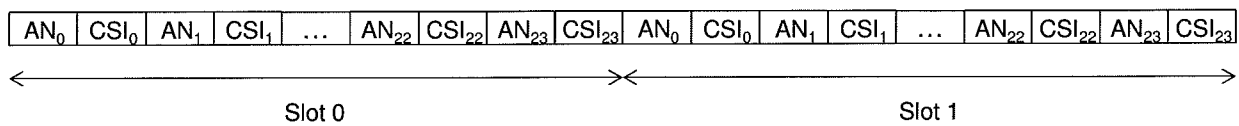
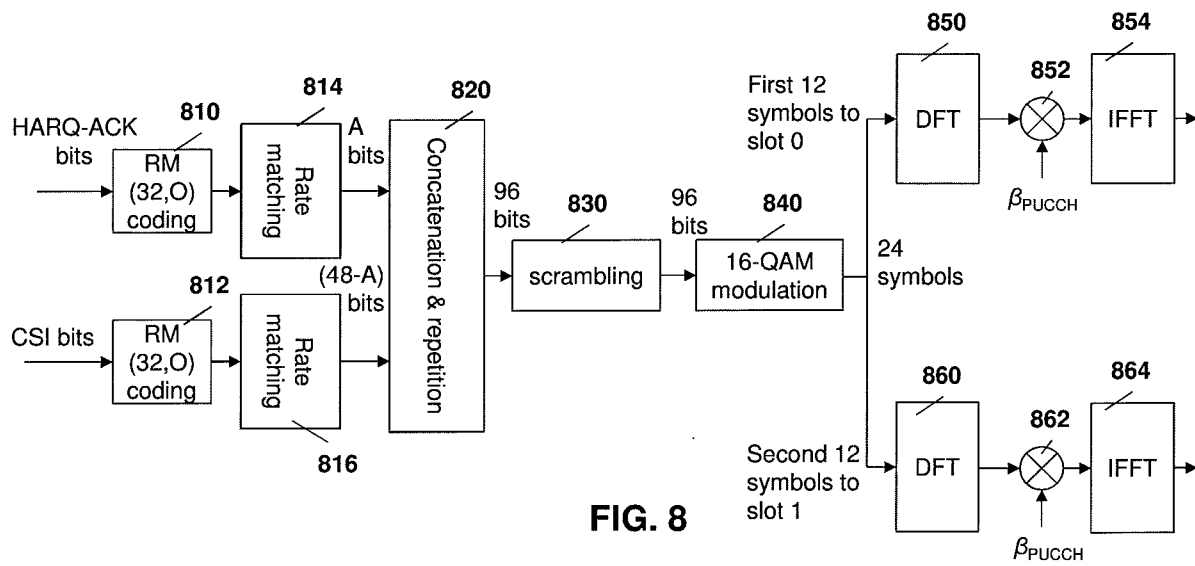


FIG. 7

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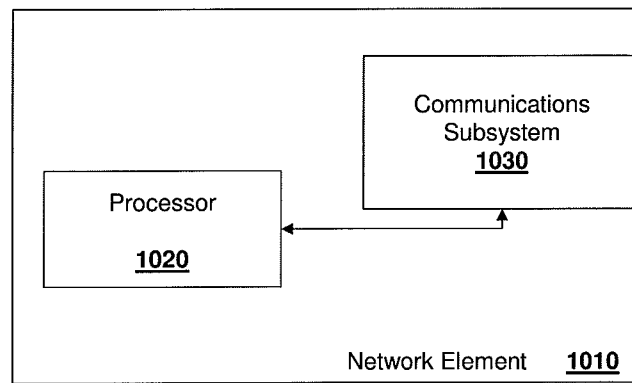


FIG. 10

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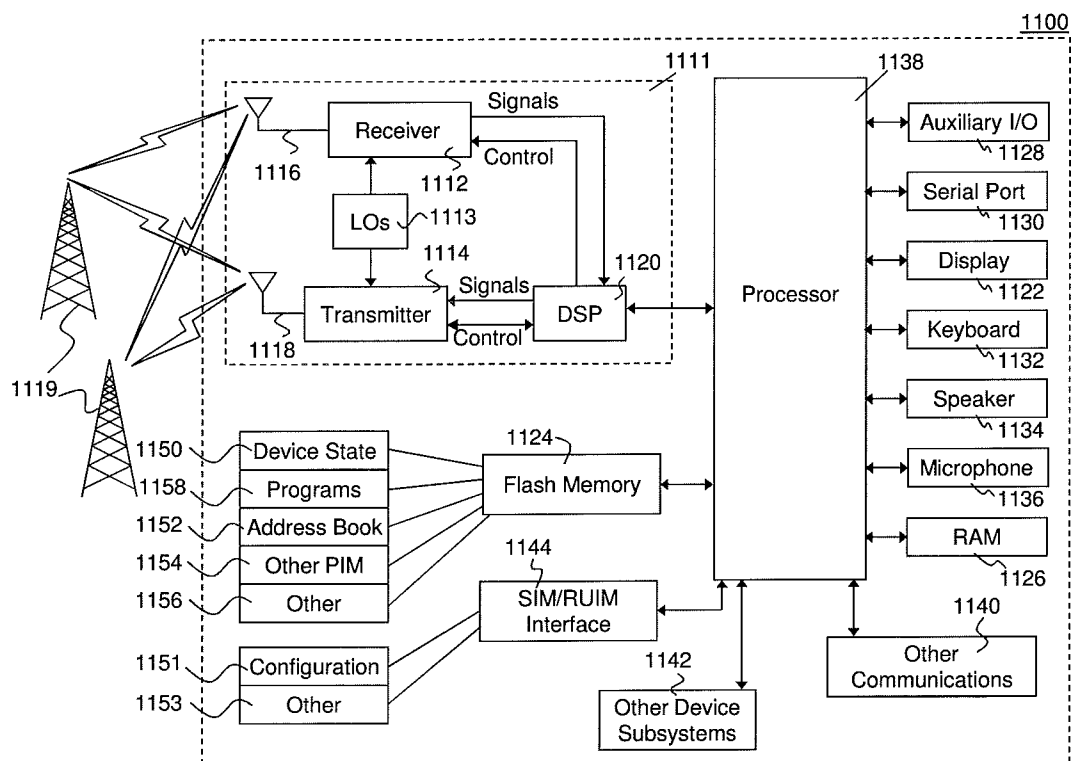


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 13/29416

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - H04B 7/00 (2013.01) USPC - 370/310 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) IPC(8): H04B 7/00 (2013.01) USPC: 370/310 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC: 370/252; 370/280; 370/329; 370/330; 370/331 (keyword search - view terms below) Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatBase; Google Patents; Google Scholar Search Terms: Encoder, rate, value, range, measure, match, first set, second set, information, bit, map, concatenate, link, string, join, chain, Reed-Muller, reedmuller, reed muller, hadamard, walsh-hadamard, reed-solomon, code, encode, interleave		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2012/0082075 A1 (LUO et al.) 05 April 2012 (05.04.2012) entire document especially Abstract; para [0006], [0008], [0023], [0025], [0045]	1, 9, 17, 18, 25, 26 ----- 2, 3/(1,2), 10, 11/(9,10), 19, 20/(18,19), 27, 28/(26,27), 33-36, 37/(33-36), 43-46, 47/(43-46), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)
X --- Y	US 2002/0141433 A1 (KWON et al.) 03 October 2002 (03.10.2002) entire document especially Abstract; para [0043]	53, 57 ----- 33-36, 37/(33-36), 43-46, 47/(43-46), 53, 54, 55/(53,54), 57, 58, 59/(57,58)
Y	US 2011/0205981 A1 (KOO et al.) 25 August 2011 (25.08.2011) entire document especially Abstract; para [0096], [0101], [0102]	2, 3/(1,2), 10, 11/(9,10), 54, 55/(53,54), 58, 59/(57,58), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)
☒ Further documents are listed in the continuation of Box C. ☐		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 10 April 2013 (10.04.2013)		Date of mailing of the international search report 07 MAY 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 13/29416

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/0274059 A1 (BROWN et al.) 10 November 2011 (10.11.2011) entire document especially Abstract; para [0021]	19, 20/(18,19), 27, 28/(26,27), 35, 36, 37/(33-36), 45, 46, 47/(43-46)
Y	US 2012/0113831 A1 (PELLETIER et al.) 10 May 2012 (10.05.2012) entire document especially Abstract; para [0237]	19, 20/(18,19), 35, 36, 37/(33-36), 45, 46
A	US 2011/0269490 A1 (EARNSHAW et al.) 03 November 2011 (03.11.2011) entire document	1, 2, 3/(1,2), 9, 10, 11/(9,10), 17-19, 20/(18,19), 25-27, 28/(26,27), 33-36, 37/(33-36), 43-46, 47/(43-46), 53, 54, 55/(53,54), 57, 58, 59/(57,58), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)
A	US 2011/0268045 A1 (HEO et al.) 03 November 2011 (03.11.2011) entire document	1, 2, 3/(1,2), 9, 10, 11/(9,10), 17-19, 20/(18,19), 25-27, 28/(26,27), 33-36, 37/(33-36), 43-46, 47/(43-46), 53, 54, 55/(53,54), 57, 58, 59/(57,58), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)
A	US 2011/0149894 A1 (LUO et al.) 23 June 2011 (23.06.2011) entire document	1, 2, 3/(1,2), 9, 10, 11/(9,10), 17-19, 20/(18,19), 25-27, 28/(26,27), 33-36, 37/(33-36), 43-46, 47/(43-46), 53, 54, 55/(53,54), 57, 58, 59/(57,58), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)
A	US 2010/0098012 A1 (BALA et al.) 22 April 2010 (22.04.2010) entire document	1, 2, 3/(1,2), 9, 10, 11/(9,10), 17-19, 20/(18,19), 25-27, 28/(26,27), 33-36, 37/(33-36), 43-46, 47/(43-46), 53, 54, 55/(53,54), 57, 58, 59/(57,58), 61, 62, 63/(61,62), 65, 66, 67/(65, 66)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 13/29416

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 4-8, 12-16, 21-24, 29-32, 38-42, 48-52, 56, 60, 64 and 68
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.