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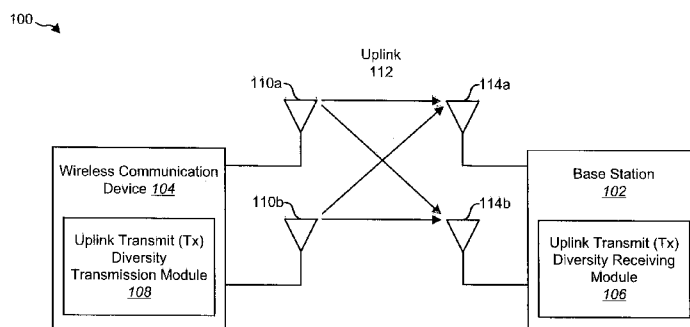
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(54) Title: WIRELESS COMMUNICATION DEVICE, BASE STATION AND METHOD FOR A TRANSMISSION DIVERSITY SCHEME ON PHYSICAL UPLINK CONTROL CHANNEL (PUCCH) WITH ACK/NACK DIFFERENTIATION

FIG. 1



(57) Abstract: A method for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is described. A UCI is coded with a Forward Error Correction code to obtain a coded UCI. The coded UCI is mapped to quadrature phase shift keying (QPSK) symbols to obtain a mapped coded UCI. A phase shift pattern is selected. A phase shift from the phase shift pattern is applied to the mapped coded UCI based on an acknowledge/negative-acknowledge (ACK/NACK) to obtain a phase shifted mapped coded UCI. The mapped coded UCI is sent using a PUCCH resource on a first antenna. The phase shifted mapped coded UCI is sent using a PUCCH resource on a second antenna.

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DESCRIPTION

TITLE OF INVENTION: WIRELESS COMMUNICATION DEVICE,
BASE STATION AND METHOD FOR A TRANSMISSION
DIVERSITY SCHEME ON PHYSICAL UPLINK CONTROL
5 CHANNEL (PUCCH) WITH ACK/NACK DIFFERENTIATION

TECHNICAL FIELD

The present invention relates generally to wireless communications and wireless communications-related technology. More specifically, the present invention relates to
10 a wireless communication device, base station and method for a transmission diversity scheme on the physical uplink control channel (PUCCH) with ACK/NACK differentiation.

BACKGROUND ART

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

communicates with mobile stations.

Various signal processing techniques may be used in wireless communication systems to improve efficiency and quality of wireless communication. One such technique may include using multiple antennas for multiple-input and multiple-output (MIMO) or transmit diversity (TxD). Additional gains may be realized within these channels. Benefits may be realized by providing gains within these control channels while maintaining or increasing reliability and sustaining compatibility with older equipment. Therefore, benefits may be realized by improved coding techniques.

SUMMARY OF INVENTION

In one embodiment of the present invention a method for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is disclosed. The method comprises: coding UCI with a Forward Error Correction code to obtain a coded UCI; mapping coded UCI to quadrature phase shift keying (QPSK) symbols to obtain a mapped coded UCI; selecting a phase shift pattern; applying a phase shift from the phase shift pattern to the mapped coded UCI based on an acknowledge/negative-acknowledge (ACK/NACK) to obtain a phase shifted mapped coded UCI; sending the mapped coded UCI using a PUCCH resource on a first antenna; and sending the phase shifted

mapped coded UCI using a PUCCH resource on a second antenna.

In another embodiment of the present invention a method for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is disclosed. The method comprises: receiving a first set of symbols by a first signal receiver for a first PUCCH transmission; receiving a second set of symbols by a second signal receiver for a second PUCCH transmission; computing a differential phase shift between the first set of symbols and the second set of symbols; estimating a first acknowledge/negative-acknowledge (ACK/NACK) estimate, wherein the first ACK/NACK estimate is based on the differential phase shift; extracting a second ACK/NACK estimate from one or more reference symbols in the first set of symbols and the second set of symbols; using joint coding to combine the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate; removing a phase shift from the second set of symbols based on the third ACK/NACK estimate to obtain a third set of symbols; combining the first set of symbols with the third set of symbols to obtain a fourth set of symbols; and decoding the fourth set of symbols to obtain the UCI.

In another embodiment of the present invention a method for receiving uplink control information (UCI) using a

physical uplink control channel (PUCCH) transmit diversity scheme is disclosed. The method comprises: receiving a first set of symbols by a first signal receiver for a first PUCCH transmission; receiving a second set of symbols by a second
5 signal receiver for a second PUCCH transmission; computing a differential phase shift between the first set of symbols and the second set of symbols using symbols with 0 or π as virtual reference symbols; estimating a first acknowledge/negative-acknowledge (ACK/NACK) estimate based on the differential
10 phase shift; removing a phase shift from the second set of symbols based on the first ACK/NACK estimate to obtain a third set of symbols; combining the first set of symbols with the third set of symbols to obtain a fourth set of symbols; and decoding the fourth set of symbols to obtain a first UCI,
15 wherein the first UCI comprises a joint decoded ACK/NACK estimate.

In another embodiment of the present invention a wireless communication device configured for transmitting uplink control information (UCI) using a physical uplink
20 control channel (PUCCH) transmit diversity scheme is disclosed. The wireless communication device comprises: a Forward Error Correction (FEC) coder; a quadrature phase shift keying (QPSK) symbol mapper; a phase shifter, wherein the phase shifter applies a phase shift from a selected phase
25 shift pattern based on the ACK/NACK; a first antenna; and a

second antenna.

In another embodiment of the present invention a base station configured for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is disclosed. The base station comprises: a first signal receiver for a first PUCCH transmission, wherein the first signal receiver receives a first set of symbols; a second signal receiver for a second PUCCH transmission, wherein the second signal receiver receives a second set of symbols; a differential phase shift computer, wherein the differential phase shift computer computes the differential phase shift between the first set of symbols and the second set of symbols using symbols with 0 or π as virtual reference symbols; a phase shift estimation module, wherein the phase shift estimation module estimates a first acknowledge/negative-acknowledge (ACK/NACK) estimate based on the differential phase shift; a phase shift removal module, wherein the phase shift removal module removes a phase shift from the second set of symbols to obtain a third set of symbols; a first combiner; wherein the first combiner combines the first set of symbols and the third set of symbols to obtain a fourth set of symbols; and a first decoder, wherein the first decoder decodes the fourth set of symbols to obtain the UCI.

The foregoing and other objectives, features, and

advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

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BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a block diagram illustrating a wireless communication system with a wireless communication device and a base station;

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Figure 2 is a block diagram illustrating the transmission of a message from a wireless communication device to a base station via the physical uplink control channel (PUCCH);

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Figure 3A is a flow diagram of a method for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme;

Figure 3B is a flow diagram of a method for generating a phase shift pattern;

20

Figure 4 is a block diagram illustrating data flows for transmitting uplink control information (UCI) using a format 2 PUCCH transmit diversity scheme;

Figure 5 is a flow diagram of a method for transmitting uplink control information (UCI) using a format 2 PUCCH transmit diversity scheme;

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Figure 6 is a block diagram illustrating data flows for transmitting uplink control information (UCI) using a format

2a/2b PUCCH transmit diversity scheme;

Figure 7 is a flow diagram of a method for transmitting uplink control information (UCI) using a format 2a/2b PUCCH transmit diversity scheme;

5 Figure 8 is a flow diagram illustrating a method for receiving uplink control information (UCI) using a PUCCH transmit diversity scheme;

Figure 9 is a block diagram illustrating data flows for receiving uplink control information (UCI) using a format 2 PUCCH transmit diversity scheme;

10 Figure 10 is a flow diagram of a method for receiving uplink control information (UCI) using a format 2 PUCCH transmit diversity scheme;

Figure 11 is a block diagram illustrating data flows for receiving uplink control information (UCI) using a format 2a/2b PUCCH transmit diversity scheme;

15 Figure 12A is a flow diagram of a method for receiving uplink control information (UCI) using a format 2a/2b PUCCH transmit diversity scheme;

20 Figure 12B is a flow diagram of a method for enhanced joint soft ACK/NACK decoding;

Figure 13 illustrates various components that may be utilized in a wireless communication device; and

25 Figure 14 illustrates various components that may be utilized in a base station.

DESCRIPTION OF EMBODIMENTS

A method for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is described. UCI is coded with a Forward Error Correction code to obtain a coded UCI. The coded UCI is mapped to quadrature phase shift keying (QPSK) symbols to obtain a mapped coded UCI. A phase shift pattern is selected. A phase shift from the phase shift pattern is applied to the mapped coded UCI based on an acknowledge/negative-acknowledge (ACK/NACK) to obtain a phase shifted mapped coded UCI. The mapped coded UCI is sent using a PUCCH resource on a first antenna. The phase shifted mapped coded UCI is sent using a PUCCH resource on a second antenna.

The phase shift may be selected such that a phase shifted version of the mapped coded UCI will not collide with other sequences. Selecting a phase shift may include evenly dividing a number of reference symbols and a number of ACK/NACK coded symbols to increase a reference reliability. Selecting a phase shift may include maximizing a sequence distance. The phase shift pattern may include a bipolar coding that adds a simplex coding of ACK/NACK bits on the phase shifted mapped coded UCI. The phase shift pattern may include an orthogonal design that allows reference symbol noise to be removed using pair symbol estimation.

The UCI may include a channel quality indicator (CQI), a precoding matrix index (PMI) and the ACK/NACK. The CQI, PMI and ACK/NACK may be concatenated to obtain a concatenated UCI. Coding the UCI with a FEC code may include joint coding the concatenated UCI using a Reed-Muller code. The UCI may include a channel quality indicator (CQI) and a precoding matrix index (PMI). The ACK/NACK may be coded on reference symbols of the PUCCH resource of the first antenna to obtain a first set of ACK/NACK coded reference symbols. The first set of ACK/NACK coded reference symbols may be combined with the mapped coded UCI prior to sending the mapped coded UCI.

The ACK/NACK may be coded on reference symbols of the PUCCH resource of the second antenna to obtain a second set of ACK/NACK coded reference symbols. The second set of ACK/NACK coded reference symbols may be combined with the phase shifted mapped coded UCI prior to sending the phase shifted mapped coded UCI. The coded UCI may be twenty bits. The coded UCI may be mapped to ten QPSK symbols. The method may be performed by a wireless communication device. The UCI may be transmitted using PUCCH format 2. The UCI may also be transmitted using PUCCH format 2a/2b. The wireless communication device may use a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

A method for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is described. A first set of symbols is received by a first signal receiver for a first PUCCH transmission. A second set of symbols is received by a second signal receiver for a second PUCCH transmission. A differential phase shift between the first set of symbols and the second set of symbols is computed. A first acknowledge/negative-acknowledge (ACK/NACK) estimate that is based on the differential phase shift is estimated. A second ACK/NACK estimate is extracted from one or more reference symbols in the first set of symbols and the second set of symbols. A joint coding is used to combine the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate. A phase shift is removed from the second set of symbols based on the third ACK/NACK estimate to obtain a third set of symbols. The first set of symbols is combined with the third set of symbols to obtain a fourth set of symbols. The fourth set of symbols is decoded to obtain the UCI.

Symbols with 0 or π may be used as virtual reference symbols. A maximum likelihood sequence may be determined using convex optimization. The method may be performed by a base station configured to operate using a single or multiple antennas. Decoding may be performed using a Reed-Muller

decoder if the UCI was encoded using a Reed-Muller coder. The UCI may be sent using PUCCH format 2a/2b. The base station may use a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

5 A method for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is also described. A first set of symbols is received by a first signal receiver for a first PUCCH transmission. A second set of symbols is received by a
10 second signal receiver for a second PUCCH transmission. A differential phase shift between the first set of symbols and the second set of symbols is computed using symbols with 0 or π as virtual reference symbols. A first
acknowledge/negative-acknowledge (ACK/NACK) estimate is
15 estimated based on the differential phase shift. A phase shift is removed from the second set of symbols based on the first ACK/NACK estimate to obtain a third set of symbols. The
first set of symbols is combined with the third set of symbols to obtain a fourth set of symbols. The fourth set of symbols
20 is decoded to obtain a first UCI that includes a joint decoded ACK/NACK estimate.

 A maximum likelihood sequence may be determined using convex optimization. Whether the first ACK/NACK estimate and the joint decoded ACK/NACK estimate differ by
25 less than a threshold may also be determined. The joint

decoded ACK/NACK estimate may be selected as the ACK/NACK if the first ACK/NACK estimate and the joint decoded ACK/NACK estimate differ by less than a threshold. Whether the first ACK/NACK estimate and the joint decoded ACK/NACK estimate differ by less than a threshold may also be determined. The first set of symbols may be decoded to obtain a second ACK/NACK estimate if the first ACK/NACK estimate and the joint decoded ACK/NACK estimate differ by more than a threshold.

The first ACK/NACK estimate and the second ACK/NACK estimate may be combined using joint coding to obtain a third ACK/NACK estimate. A phase shift may be removed from the second set of symbols based on the third ACK/NACK estimate to obtain a fifth set of symbols. The fifth set of symbols may be combined with the first set of symbols to obtain a sixth set of symbols. The sixth set of symbols may be decoded to obtain a second UCI that includes a joint decoded fourth ACK/NACK estimate.

Whether the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by less than a threshold may be determined. The joint decoded ACK/NACK estimate may be selected as the ACK/NACK if the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by less than a threshold. A fifth ACK/NACK estimate based on the first ACK/NACK estimate may be

determined if the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by more than a threshold. A phase shift may be removed from the second set of symbols based on the fifth ACK/NACK estimate to obtain a seventh set of symbols. The seventh set of symbols may be combined with the first set of symbols to obtain an eighth set of symbols. The eighth set of symbols may be decoded to obtain a third UCI that includes a joint decoded sixth ACK/NACK estimate.

Whether the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by less than a threshold may be determined. The joint decoded sixth ACK/NACK estimate may be selected as the ACK/NACK if the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by less than a threshold. The ACK/NACK may be determined based on the number of bits in the third UCI if the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by more than a threshold. The method may be performed by a base station configured to operate using a single or multiple antennas. Decoding may be performed using a Reed-Muller decoder if the UCI was encoded using a Reed-Muller coder. The UCI may have been sent using PUCCH format 2. The base station may use a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

A wireless communication device configured for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is described. The wireless communication device includes a
5 Forward Error Correction (FEC) coder, a quadrature phase shift keying (QPSK) symbol mapper, a phase shifter that applies a phase shift from a selected phase shift pattern based on the ACK/NACK, a first antenna, and a second antenna.

10 The FEC coder may be a Reed-Muller encoder that joint codes a channel quality indicator (CQI)/precoding matrix index (PMI) and an acknowledge/negative-acknowledge (ACK/NACK). The wireless communication device may also include a first ACK/NACK reference symbol coder and a
15 second ACK/NACK reference symbol coder. An ACK/NACK reference symbol coder may code an ACK/NACK onto one or more reference symbols of a slot. The wireless communication device may be configured to operate using single or multiple antennas. The UCI may be transmitted
20 using PUCCH format 2. The UCI may be transmitted using PUCCH format 2a/2b.

A base station configured for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme is described. The base
25 station includes a first signal receiver for a first PUCCH

transmission that receives a first set of symbols, a second
signal receiver for a second PUCCH transmission that receives
a second set of symbols, a differential phase shift computer
that computes the differential phase shift between the first
5 set of symbols and the second set of symbols using symbols
with 0 or π as virtual reference symbols, and a phase shift
estimation module that estimates a first
acknowledge/negative-acknowledge (ACK/NACK) estimate
based on the differential phase shift. The base station also
10 includes a phase shift removal module that removes a phase
shift from the second set of symbols to obtain a third set of
symbols, a first combiner that combines the first set of
symbols and the third set of symbols to obtain a fourth set of
symbols, and a first decoder that decodes the fourth set of
15 symbols to obtain the UCI.

The base station may also include an ACK/NACK
extraction module that extracts a second ACK/NACK estimate
from one or more reference symbols of the first set of symbols
and the second set of symbols. The base station may further
20 include a second combiner that combines the first ACK/NACK
estimate and the second ACK/NACK estimate to obtain a third
ACK/NACK estimate. The second combiner may use joint
coding. The phase shift removed from the second set of
symbols may be based on the third ACK/NACK estimate.

25 The base station may also include second decoder that

decodes a second ACK/NACK estimate from the first set of symbols. The base station may further include a second combiner that combines the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate. The UCI output by the first decoder may include a channel quality indicator (CQI), a precoding matrix index (PMI) and a fourth ACK/NACK estimate. The base station may also include a validation module that determines the validity of the fourth ACK/NACK estimate.

Figure 1 is a block diagram illustrating a wireless communication system 100 with a wireless communication device 104 and a base station 102. A base station 102 may be in wireless communication with one or more wireless communication devices 104. A base station 102 may be referred to as an access point, a Node B, an eNodeB, or some other terminology. Likewise, a wireless communication device 104 may be referred to as a mobile station, a subscriber station, an access terminal, a remote station, a user terminal, a terminal, a handset, a subscriber unit, user equipment, or some other terminology. The wireless communication device may transmit data to the base station over a radio frequency (RF) communication channel.

A wireless communication device 104 may communicate with zero, one or multiple base stations 102 on the downlink and/or uplink 112 at any given moment. The downlink refers

to the communication link from a base station 102 to a wireless communication device 104. The uplink 112 refers to the communication link from a wireless communication device 104 to a base station 102.

5 Communication between a wireless communication device 104 and a base station 102 may be accomplished using transmissions over a wireless link including an uplink 112 and a downlink. The communication link may be established using a single-input and single-output (SISO), multiple-input
10 and single-output (MISO) or a multiple-input and multiple-output (MIMO) system. A MIMO system may include both a transmitter and a receiver equipped with multiple transmit and receive antennas. A MIMO system may provide improved performance if the additional dimensionalities created by the
15 multiple transmit and receive antennas are utilized.

 The use of multiple antennas 110a-b on the wireless communication device 104 may allow transmit diversity on the uplink 112. In transmit diversity, signals originating from the two or more independent sources that have been
20 modulated with identical information-bearing signals may be used. Transmit diversity may help overcome the effects of fading, outages, and circuit failures.

 In 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) - Advanced, additional control feedback will
25 have to be sent on control channels to accommodate MIMO

and carrier aggregation (CA). Carrier aggregation refers to transmitting data on multiple sub-bands which are contiguously located. Both the acknowledge/negative-acknowledge (ACK/NACK) bits and other control information may be transmitted using the PUCCH. A transmit diversity format for the PUCCH may significantly enhance the ACK/NACK performance while maintaining the diversity gain on other uplink control information (UCI). The other UCI may include the channel quality indicator (CQI) and the precoding matrix index (PMI). In other words, by using a transmit diversity format for the PUCCH, the reliability of the transmission of the ACK/NACK bits on the uplink may be improved while maintaining the reliability of the transmission of other control information on the uplink.

In current LTE release-8 specifications, only one antenna is used. With LTE-Advanced, a wireless communication device 104 may have multiple antennas 110. Typically, a wireless communication device 104 may use two or four antennas 110, although other quantities of antennas 110 may be used. Transmit diversity schemes with multiple antennas 110 are being considered and are in the discussion phase.

Transmit diversity methods are studied separately for PUCCH and PUSCH. In the recent 3GPP meetings, it was agreed that for PUCCH, uplink single antenna port mode

should be supported even with multiple antennas 110. It was also agreed that spatial orthogonal resource transmit diversity (SORTD) may be applied for a multiple resource PUCCH. The PUCCH may use one of six formats for transmission: format 1/1a/1b or format 2/2a/2b. For format 1/1a/1b, it was agreed that the same modulated symbols are transmitted on different orthogonal resources for different antennas 110. The PUCCH formats 2/2a/2b were left for future study. With SORTD, separate orthogonal resources may be allocated for the PUCCH. The structure of the PUCCH of each resource should be the same as release 8 to ensure backward compatibility. The PUCCH transmit diversity scheme may introduce another level of protection for ACK/NACK bits when transmit diversity is used.

Solutions for using the formats 2/2a/2b include simple repetition and joint coding. In simple repetition, a wireless communication device 104 may transmit the same modulated symbols on different orthogonal resources for different antennas 110. Simple repetition has backward compatibility and is consistent with formats 1/1a/1b. In joint coding, a longer sequence of codewords is used and part of the codeword is transmitted on each antenna 110. Joint coding achieves a coding gain but no diversity gain. Moreover, joint coding loses the backward compatibility of single antenna transmission. Joint coding is also vulnerable to antenna gain

imbalance (AGI). Similarly, the space code blocking coding and multiple sequence coding/modulation approaches break the backward compatibility for release-8 payload sizes.

Existing transmit diversity proposals assume the same coding method for all uplink channel information (UCI) including ACK/NACK, channel quality indicator (CQI) and precoding matrix index (PMI). However, ACK/NACK requires a higher error protection than other information bits (such as CQI and PMI) during system operation. By using a combination of simple repetition and joint coding, the backward compatibility may be retained while introducing an enhancement on the more important messages such as ACK/NACK. For simplicity, all "more important messages" are denoted as "ACK/NACK" herein, with the understanding that ACK/NACK refers to any element from a set of all "more important messages" and not merely ACK/NACK.

The target PUCCH performance qualities are given in Table 1 below according to 3GPP TS 36.300.

Event	Target Quality
ACK miss detection (for DL-SCH)	(10^{-2})
DTX to ACK error (for DL-SCH)	$(10^{-2} - 10^{-1})$
NACK to ACK error (for DL-SCH)	$(10^{-4} - 10^{-3})$
CQI block error rate	FFS $(10^{-2} - 10^{-1})$

Table 1

As shown in Table 1, the ACK/NACK in general requires a higher reliability than the CQI. This is because the CQI is concerned with the block error rate and the ACK/NACK is concerned with the bit error rate. The NACK to ACK error should have better protection than the ACK to NACK miss detection.

The existing PUCCH formats cannot fully satisfy these requirements. Because ACK/NACK bits are treated equally, the NACK to ACK and ACK to NACK performances are also the same. Furthermore, with the existing schemes, the ACK/NACK performance is not sufficient. The use of carrier aggregation (CA) in LTE-A may require ACK/NACK bundling in PUCCH feedback. Thus, improvements in ACK/NACK performance may be desirable.

The current Release 8 PUCCH formats may not provide enough protection on the ACK/NACK. The existing PUCCH formats may be especially unable to achieve the NACK to ACK error probability. In PUCCH transmit diversity design, the unequal error protection for different types of control feedback may be considered. It is desirable to find new formats that can further differentiate the performance of ACK/NACK from other control bits, such as the CQI and the PMI.

In format 2, the ACK/NACK and the CQI/PMI are jointly coded. Thus, the ACK/NACK and the CQI/PMI have the same

bit error rate (BER) performance. As the number of control bits increases, the ACK/NACK and CQI/PMI performance may degrade. Thus, the ACK/NACK may not get enough protection compared to the CQI/PMI. Also, the ACK/NACK performance
5 degrades with the increase of CQI/PMI bits.

With normal cyclic prefix (CP) in format 2a and 2b, the ACK/NACK bits are transmitted on the four reference symbols with differential binary phase-shift keying (BPSK) and differential quadrature phase-shift keying (QPSK) respectively,
10 i.e. the ACK/NACK bits are coded on the second reference symbol by a differential phase shift over the first reference symbol. Thus, the ACK/NACK is independent of other control bits with a simple 2x (two times) differential coding repetition redundancy. The CQI/PMI bits are coded independently to
15 twenty bits. Thus, the CQI/PMI may have a Reed-Muller (RM) code gain with a coding rate between $1/5$ and $11/20$. Differential coding may have worse performance when compared with non-differential coding, e.g. QPSK performance is ~3 dB worse than normal QPSK. Therefore, with format
20 2a/2b, the ACK/NACK performance may be worse than the CQI when the payload size is small.

The wireless communication device 104 may send uplink 112 transmissions using either two antennas 110 or four antennas 110. When four antennas 110 are used by the
25 wireless communication device 104, the four antennas 110

may be formed into two virtual antennas. Then, the same scheme used by two antennas 110 may be used by the two virtual antennas. The base station 102 may receive the uplink 112 transmissions using multiple antennas, e.g. two antennas 114a-b, four antennas or eight antennas.

The wireless communication device 104 may include an uplink transmit (Tx) diversity transmission module 108. The uplink transmit (Tx) diversity transmission module 108 may facilitate the transmission of uplink control information (UCI) from the wireless communication device 104 on the uplink 112 using multiple antennas 110. For example, the uplink transmit (Tx) diversity transmission module 108 may select the format of the uplink 112 transmissions and apply format specific coding/mapping. The base station 102 may include an uplink transmit (Tx) diversity receiving module 106. The uplink transmit (Tx) diversity receiving module 106 may facilitate the receiving of UCI on the uplink 112 using multiple antennas 114. For example, the uplink transmit (Tx) diversity receiving module 106 may determine the format of a received UCI on the uplink 112 and apply techniques to improve performance of the uplink 112 transmission.

By differentiating the ACK/NACK from other control information, the bit error rate of ACK/NACK bits may be reduced. Thus, packet loss due to miss detection of NACK to ACK may be prevented. Furthermore, unnecessary

retransmission from miss detection of ACK to NACK may be reduced. The full diversity gain of repetition on different antennas with SORTD may be maintained with negligible impact from ACK/NACK residue.

5 Figure 2 is a block diagram illustrating the transmission of a message 218 from a wireless communication device 204 to a base station 202 via the physical uplink control channel (PUCCH) 216. The wireless communication device 204 of Figure 2 may be one configuration of the wireless
10 communication device 104 of Figure 1. Likewise, the base station 202 of Figure 2 may be one configuration of the base station 102 of Figure 1. The wireless communication device 204 may transmit the message 218 via the physical uplink control channel (PUCCH) 216 to the base station 202.

15 The message 218 may include uplink control information (UCI) 222. The UCI 222 may include a channel quality indicator (CQI) 224a and/or a precoding matrix index (PMI) 224b. The message 218 may also include ACK/NACK 228 information. The message 218 may further include a format
20 220 for which the message was transmitted. For example, the message 218 may be transmitted using format 1/1a/1b or format 2/2a/2b.

 In Release 8, the formats 220 and coding for the PUCCH 216 are defined as illustrated in Table 2.

PUCCH format	Modulation scheme	Number of bits per subframe, M_{bit}	CQI/PMI etc.	ACK/ NACK
1	N/A	N/A	N/A	1
1a	BPSK	1	N/A	1
1b	QPSK	2	N/A	2
2	QPSK	20	4-11	0-2
2a	QPSK+BPSK	21	4-11	1
2b	QPSK+QPSK	22	4-11	2

Table 2

Release 8 supports only single antenna transmission on the uplink. For format 1, information is carried by the presence/absence of the transmission of the PUCCH 216 from the wireless communication device 204. For format 1a and 1b, one or two explicit bits are transmitted with binary phase-shift keying (BPSK) and quadrature phase-shift keying (QPSK) modulation respectively.

For format 2, the uplink control information (UCI) 222 such as the channel quality indicator (CQI) 224a and the precoding matrix index (PMI) 224b along with the ACK/NACK 228 may be concatenated and joint coded with a Forward Error Correction (FEC) code such as a Reed-Muller (RM) (20, O) code to twenty bits. With extended cyclic prefix (CP), only format 2 may be used. Formats 2a and 2b are the default formats for normal CP. With format 2a/2b, the UCI 222 may be coded with an RM code to twenty bits and transmitted on PUCCH 216 symbols while the ACK/NACK 228 bits may be coded and transmitted on the PUCCH 216 reference symbols

(RS).

A PUCCH resource is allocated within a subframe, which consists of two slots. With normal CP, each slot has seven symbols. Two of the symbols are used as reference symbols and five are used for the PUCCH 216 message. Thus, with normal CP, the PUCCH 216 has ten message carrying symbols and four reference symbols. With format 2a/2b, four reference symbols may be used for the ACK/NACK 228 and the other ten symbols may be used for the other UCI 222. The ACK/NACK 228 may be coded with a differential phase-shift coded on the second reference symbol with the first reference symbol as a phase reference.

With extended CP, each slot has six symbols. One of the symbols may be used as a reference symbol and the five other symbols may be used for the PUCCH 216 message. Thus, the PUCCH 216 has ten message carrying symbols and two reference symbols. Because there is only one reference symbol in each slot, ACK/NACK coding is not possible with extended CP. Therefore, with format 2, the ACK/NACK 228 may be joint coded with the other UCI 222 (such as the CQI 224a and the PMI 224b) and transmitted in the ten message carrying symbols. The block of complex-valued symbols $z(i)$ may be multiplied with the amplitude scaling factor β_{PUCCH} in order to conform to the transmit power. The block of complex-valued symbols may then be mapped in sequence

starting with $z(0)$ to the resource elements.

A wireless communication device 204 with multiple transmit antennas 110 may be required to behave as wireless communication devices with a single antenna port from a base station's 202 perspective in Uplink Single Antenna Port Mode. The PUCCH 216, PUSCH or SRS transmission may be configured to enter Uplink Single Antenna Port Mode. Alternatively, the wireless communication device 204 may enter the Uplink Single Antenna Port Mode without instruction from the base station 202 in some scenarios.

SORTD may be the baseline for a PUCCH 216 transmit diversity scheme. Multiple resources may be allocated for each antenna 110 when there are two transmit antennas 110. The virtual antenna concept may be used for scenarios where there are four transmit antennas 110. Backward compatibility is important in PUCCH 216 transmit diversity design. The two options with SORTD are simple repetition and joint coding. In simple repetition, the same coded information may be transmitted on the second antenna 110b as on the first antenna 110a. Simple repetition has diversity gain but no coding gain (or it could be viewed as repetition coding gain). In joint coding, a higher redundancy code may be used, and half of the codeword may be transmitted on each channel. Joint coding has coding gain but no diversity gain. Joint coding supports a larger payload but has no backward

compatibility. The splitting of a codeword makes joint coding vulnerable to AGI.

Figure 3A is a flow diagram of a method 300 for transmitting uplink control information (UCI) 222 using a physical uplink control channel (PUCCH) 216 transmit diversity scheme. The method 300 may be performed by a wireless communication device 104. The method 300 of Figure 3A may apply to a PUCCH message 218 using format 2, format 2a or format 2b. In one configuration, the wireless communication device 104 may be a UE. The UCI 222 may be part of a PUCCH message 218. In one configuration, the UCI 222 may include a CQI 224a, a PMI 224b and an ACK/NACK 228. The wireless communication device 104 may code 302 a UCI 222 with a Forward Error Correction (FEC) code such as a Reed-Muller code to twenty bits. The wireless communication device 104 may then map 304 the coded UCI 222 to ten QPSK symbols. Alternatively, the wireless communication device 104 may map 304 the coded UCI 222 to a different number of QPSK symbols.

The wireless communication device 104 may apply 306 a phase shift to the mapped coded UCI 224a based on an ACK/NACK 228. The phase shift applied may depend on the format 220 of the PUCCH message 218. A method of generating phase shifts and examples of phase shift patterns are discussed below in relation to Figure 3B.

The wireless communication device 104 may then send 308 the mapped coded UCI 224a and reference symbols using a PUCCH resource on a first antenna 110a. The wireless communication device 104 may send 310 the phase shifted mapped coded UCI 222 and reference symbols using a PUCCH resource on a second antenna 110b. The wireless communication device 104 may send 310 the phase shifted mapped coded UCI 222 and reference symbols using the PUCCH resource on the second antenna 110b while concurrently sending 308 the mapped coded UCI 222 and reference symbols using the PUCCH resource on the first antenna 110a. The ACK/NACK may be coded on the reference symbols in the same manner as in release - 8 and no phase shift coding is applied on the reference symbols between the two PUCCH transmissions.

Figure 3B is a flow diagram of a method 340 for generating a phase shift pattern. The method 340 may be performed by a wireless device such as a base station 102 or a wireless communication device 104. In one configuration, the method 340 may be performed prior to setting up a wireless communication system 100. For example, a phase shift pattern may be generated and agreed upon between the base station 102 and the wireless communication device 104 during network configuration.

The joint coded control bits on the first antenna 110a

are the same as those used in LTE Release 8. Table 3 shows an example of phase shifts applied to the mapped coded UCI 222 for format 2 PUCCH messages 218 with transmit diversity.

PUCCH format	ACK/NACK bits	Joint coded control bits (CQI + A/N) on 1 st antenna	Phase shift on 2 nd antenna
2	0	Same as Release - 8	0
	1	Same as Release - 8	π
	00	Same as Release - 8	0
	01	Same as Release - 8	$-\pi/2$
	10	Same as Release - 8	$\pi/2$
	11	Same as Release - 8	π

Table 3

An example of phase shifts applied to the mapped coded UCI 222 for format 2a/2b PUCCH messages 218 with transmit diversity is shown in Table 4.

PUCCH format	ACK/NACK bits on reference symbols	Coded control bits (CQI/PMI) on 1 st antenna	Phase shift on 2 nd antenna
2a	0	Same as Release - 8	0
	1	Same as Release - 8	π
2b	00	Same as Release - 8	0
	01	Same as Release - 8	$-\pi/2$
	10	Same as Release - 8	$\pi/2$
	11	Same as Release - 8	π

Table 4

No phase shift coding is applied on the reference symbols between the two PUCCH transmissions. The received symbols may be detected with channel compensation from the demodulation reference symbol. With the pattern sets in Table 3 and Table 4, since all symbols in a slot are shifted

with the same phase shift, a phase shifted symbol sequence may be treated as another sequence, and is thus vulnerable to reference missed detection. A missed detection of a reference symbol will cause a missed detection of the symbol sequence of the whole slot, thus error propagation occurs.

To avoid this, phase shift pattern design guidelines may be used. The use of modified phase shift patterns may maximize code distance, increase reference reliability and reduce symbol error propagation. The extra ACK/NACK 228 information may be differentially coded on the symbols. Since there is no phase shift on the reference symbols between the two PUCCH transmissions, for the differential coded information between the two antenna transmissions, the second reference symbol may be used as a virtual reference symbol for differential decoding. The same rule applies if another symbol is designed to have no phase shift. An increase in the number of reference symbols and virtual reference symbols may provide a better reference estimation and thus better information detection accuracy.

A good pattern may evenly divide the number of virtual reference symbols and ACK/NACK 228 coded symbols to increase the reference reliability. Thus, all symbols may be considered in the decoding process. The extra symbol(s) may be designed with a 0 or π phase shift to be used as virtual reference symbols.

A good pattern set may select 344 sequences such that a phase shifted version of one sequence will not collide with other sequences (i.e., if a sequence is phase shifted by $\pi/2$, π , or $-\pi/2$, it is not the same as all other sequences in the pattern set). A good pattern set selection may aim to maximize 346 the sequence distance. The sequence distance defines a metric of the difference among all sequences. The sequence distance may be defined as the minimum number of different phase shift bits. The sequence distance may also be defined as the minimum sum of the mean squared distance of all bits. Other definitions of the sequence may be used.

Any phase shift pattern that matches the criteria in steps 342 - 346 may be a good design. As a direct improvement over the patterns in Table 3 and Table 4, Table 5 shows an example of phase shifts applied to the mapped coded UCI 222 for format 2 PUCCH messages 218 with transmit diversity. Again, the joint coded control bits on the first antenna 110a are the same as those used in LTE Release 8. No phase shift coding is applied on the reference symbols between the two PUCCH transmissions.

PUCCH format	ACK/NACK bits on reference symbols $b(20), \dots, b(M_{\text{bit}} - 1)$	Coded control bits (CQI/PMI) on 1 st antenna	Phase shift on 2 nd antenna
2/2a/2b	0	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	1	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$
	00	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	01	Same as Release - 8	$-\pi/2 \ -\pi/2 \ 0 \ -\pi/2 \ -\pi/2 \ -\pi/2$ $-\pi/2 \ 0 \ -\pi/2 \ -\pi/2$
	10	Same as Release - 8	$\pi/2 \ \pi/2 \ 0 \ \pi/2 \ \pi/2 \ \pi/2 \ \pi/2$ $0 \ \pi/2 \ \pi/2$
	11	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$

Table 5

Table 5 differs from Table 3 and Table 4 in that no phase shift is applied on symbol number 3 and symbol number 8 of the coded control sequence in Table 5. Thus, symbol number 3 and symbol number 8 may be used as virtual reference symbols together with other reference symbols, which may provide better reference reliability.

Any phase shifted version of one sequence is not the same as any other sequences. Although the sequence distance on the pattern set illustrated in Table 5 is not optimal, it is a simple approach. Table 5 provides a method to add format 1a/1b ACK/NACK 228 coding over format 2/2a/2b control coding on the second antenna 110b, so that the ACK/NACK 228 performance can be increased.

Another example of phase shift sequences that may be used for Format 2/2a/2b is shown in Table 6. The pattern used in Table 6 is a bipolar coding that adds a simplex coding of ACK/NACK 228 bits on the second antenna 110b transmission. This pattern has better distance properties than the phase shift pattern of Table 5 and thus will achieve better performance. Furthermore, a bipolar phase shift may be regarded as differential binary phase shift keying (DBPSK) modulation, which provides better performance than differential quadrature phase shift keying (DQPSK).

PUCCH format	ACK/NACK bits on reference symbols $b(20), \dots, b(M_{\text{bit}} - 1)$	Coded control bits (CQI/PMI) on 1 st antenna	Phase shift on 2 nd antenna
2/2a/2b	0	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	1	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$
	00	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	01	Same as Release - 8	0 $\pi \pi 0 \pi 0 \pi \pi 0 \pi$
	10	Same as Release - 8	$\pi 0 \pi \pi 0 \pi 0 \pi \pi 0$
	11	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$

Table 6

Yet another example of phase shift sequences that may be used for Format 2/2a/2b is shown in Table 7. The phase shift pattern used in Table 7 employs an orthogonal design so that the reference symbol noise can be removed by pair

symbol estimation. With Format 2a/2b, together with the reference symbols, the pattern used in Table 7 becomes a cyclic phase shift pattern sequence. Therefore, the demodulation phase shift error will not cause extra noise in the detection, and optimization may be used on this pattern by varying the phase estimation.

PUCCH format	ACK/NACK bits on reference symbols $b(20), \dots, b(M_{\text{bit}} - 1)$	Coded control bits (CQI/PMI) on 1 st antenna	Phase shift on 2 nd antenna
2/2a/2b	0	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	1	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$
	00	Same as Release - 8	0 0 0 0 0 0 0 0 0 0
	01	Same as Release - 8	$-\pi/2 \pi/2 \pi -\pi/2 \pi/2 -\pi/2$ $\pi/2 \pi -\pi/2 \pi/2$
	10	Same as Release - 8	$\pi/2 -\pi/2 \pi \pi/2 -\pi/2 \pi/2 -$ $\pi/2 \pi \pi/2 -\pi/2$
	11	Same as Release - 8	$\pi \pi 0 \pi \pi \pi \pi 0 \pi \pi$

Table 7

Figure 4 is a block diagram illustrating data flows for transmitting uplink control information (UCI) 218 using a format 2 PUCCH transmit diversity scheme. A wireless communication device 404 may include an uplink transmit (Tx) diversity transmission module 408. The uplink transmit (Tx) diversity transmission module 408 may include uplink control information (UCI) to be transmitted to a base station 102 via the PUCCH 216. For example, the uplink transmit

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(Tx) diversity transmission module 408 may include a CQI/PMI 424 and an ACK/NACK 428. A Forward Error Correction (FEC) coder such as a Reed-Muller (20, 0) joint coder 430 may code a concatenation of the CQI/PMI 424 and the ACK/NACK 428 to twenty bits. The coder 430 may output a joint coded concatenated UCI 421. The joint coded concatenated UCI 421 may then be mapped to ten QPSK symbols by a mapper 432. The mapper 432 may output a mapped joint coded concatenated UCI 423.

A phase shifter 434 may apply a phase shift to the mapped joint-coded concatenated UCI 423. The phase shift may be based on the ACK/NACK 428 input. Different phase shift patterns may be used, potentially increasing the ACK/NACK 428 payload. Examples of phase shift patterns were illustrated above in relation to Tables . The phase shifter 434 may then output a phase shifted mapped joint-coded concatenated UCI 436 mapped to ten QPSK symbols. A PUCCH resource on a first antenna 410a of the wireless communication device 404 may transmit the mapped joint-coded concatenated UCI 423. A PUCCH resource on a second antenna 410b of the wireless communication device 404 may transmit the phase shifted mapped joint-coded concatenated UCI 436.

Figure 5 is a flow diagram of a method 500 for transmitting uplink control information (UCI) using a format

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2 PUCCH transmit diversity scheme. The method 500 may be performed by a wireless communication device 404. The wireless communication 404 device may concatenate 502 uplink control information (UCI). The UCI may include a channel quality indicator (CQI), a precoding matrix index (PMI), and an ACK/NACK 428. The wireless communication device 104 may then joint code 504 the concatenated UCI with a Forward Error Correction (FEC) code such as a Reed-Muller (RM) code to twenty bits to obtain a joint-coded concatenated UCI 421. The wireless communication device 404 may then map 506 the joint-coded concatenated UCI 421 to ten QPSK symbols.

The wireless communication device 404 may apply 508 a phase shift to the mapped joint-coded concatenated UCI 423 based on the ACK/NACK 428. The mapped joint-coded concatenated UCI 423 and PUCCH reference symbols may be sent 510 using a PUCCH resource on a first antenna 410a of the wireless communication device 404. The phase shifted mapped joint-coded concatenated UCI 436 and PUCCH reference symbols may be sent 512 using a PUCCH resource on a second antenna 410b of the wireless communication device 404. The phase shifted mapped joint-coded concatenated UCI 436 and the associated PUCCH reference symbols may be sent 512 at the same time as the mapped joint-coded concatenated UCI 423 and the associated PUCCH

reference symbols.

Figure 6 is a block diagram illustrating data flows for transmitting uplink control information (UCI) using a format 2a/2b PUCCH transmit diversity scheme. A wireless communication device 604 may include an uplink transmit (Tx) diversity transmission module 608. The uplink transmit (Tx) diversity transmission module 608 of Figure 6 may be one configuration of the uplink transmit (Tx) diversity transmission module 108 of Figure 1. The uplink transmit (Tx) diversity transmission module 608 may include uplink control information (UCI). The uplink control information (UCI) may include a channel quality indicator (CQI)/precoding matrix index (PMI) 624 and an ACK/NACK 628.

An encoder 638 may receive the CQI/PMI 624. In one configuration, the encoder 638 may be a Forward Error Correction (FEC) coder such as a Reed-Muller (20, 0) coder. The encoder 638 may output a coded CQI/PMI 652. The coded CQI/PMI 652 may then be input into a quadrature phase shift keying (QPSK) symbol mapper 640. The QPSK symbol mapper 640 may map the coded CQI/PMI 652 to ten QPSK symbols. The QPSK symbol mapper 640 may output a mapped coded CQI/PMI 654.

In one configuration, the mapped coded CQI/PMI 658 may be transmitted on one allocated PUCCH resource. Each format 2a/2b PUCCH resource may include two slots 646a-b

with seven symbols. In each slot 646a-b, two of the symbols may be reference symbols 648a-b and five of the symbols may be QPSK mapped symbols 650a-b. A first ACK/NACK reference symbols coder 644a may code the ACK/NACK 628 to
5 create reference symbols with coded ACK/NACK 648. The reference symbols with coded ACK/NACK 648 may be coded the same way for the first slot 646a and the second slot 646b. The mapped coded CQI/PMI 654 may then be multiplexed with the reference symbols with coded ACK/NACK 648 into a
10 mapped coded CQI/PMI with ACK/NACK coded reference symbols 658 using a first multiplexer 651a.

A phase shifter 642 may also receive the mapped coded CQI/PMI 654. The phase shifter 642 may also receive the ACK/NACK 628. Based on the ACK/NACK 628, the phase
15 shifter 642 may apply a phase shift to the mapped coded CQI/PMI 654. The applied phase shift was discussed above in relation to Table 4. The phase shifter 642 may output a phase shifted mapped coded CQI/PMI 656. A second ACK/NACK reference symbol coder 644b may receive the
20 ACK/NACK 628. The second ACK/NACK reference symbol coder 644b may code the ACK/NACK 628 to create reference symbols with coded ACK/NACK 648. The phase shifted mapped coded CQI/PMI 656 may then be multiplexed with the reference symbols with coded ACK/NACK 648 into a phase
25 shifted mapped coded CQI/PMI with ACK/NACK coded

reference symbols 658 using a second multiplexer 651b.

The mapped coded CQI/PMI with ACK/NACK coded reference symbols 658 may be sent using a PUCCH resource (i.e. the two slots 646a-b) on a first antenna 610a of the wireless communication device 604. The phase shifted mapped coded CQI/PMI with ACK/NACK coded reference symbols 660 may be sent using a PUCCH resource on a second antenna 610b of the wireless communication device 604. The phase shifted mapped coded CQI/PMI with ACK/NACK coded reference symbols 660 may be sent at the same time as the mapped coded CQI/PMI with ACK/NACK coded reference symbols 658.

Figure 7 is a flow diagram of a method 700 for transmitting uplink control information (UCI) 222 using a format 2a/2b PUCCH transmit diversity scheme. The method 700 may be performed by a wireless communication device 604. The wireless communication device 604 may code 702 a channel quality indicator (CQI)/precoding matrix index (PMI) 624 with a Forward Error Correction (FEC) code such as a Reed-Muller (RM) code to twenty bits. The wireless communication device 604 may then map 704 the coded CQI/PMI 652 to ten QPSK symbols. The wireless communication device 604 may next apply 706 a phase shift to the mapped coded CQI/PMI 654. The phase shift may be based on the ACK/NACK 628.

The wireless communication device 604 may code 708 the ACK/NACK 628 on the reference symbols 648a of a first physical uplink control channel (PUCCH) resource for the mapped coded CQI/PMI 654. The wireless communication device 604 may also code 710 the ACK/NACK 628 on the reference symbols 648 of a second PUCCH resource for the phase shifted mapped coded CQI/PMI 656. The wireless communication device 604 may then combine 712 the coded ACK/NACK on the reference symbols 648 of the first PUCCH antenna 610a with the mapped coded channel quality indicator (CQI)/precoding matrix index (PMI) 658. The wireless communication device 604 may also combine 714 the coded ACK/NACK on the reference symbols 648 of the second PUCCH antenna 610b with the phase shifted mapped coded channel quality indicator (CQI)/precoding matrix index (PMI) 656. The wireless communication device 604 may then send 716 the mapped coded CQI/PMI with ACK/NACK coded reference symbols 658 using a PUCCH resource on a first antenna 610a of the wireless communication device 604. The wireless communication device 604 may also send 718 the phase shifted mapped coded CQI/PMI with ACK/NACK coded reference symbols 660 using a PUCCH resource on a second antenna 610b of the wireless communication device 604.

Figure 8 is a flow diagram illustrating a method 800 for receiving uplink control information (UCI) 222 using a PUCCH

transmit diversity scheme. The method 800 may be performed by a base station 102. The method 800 of Figure 8 may apply to a PUCCH message 218 using format 2, format 2a or format 2b as per 3GPP TS 36.211. The base station 102 may recover two copies of the ACK/NACK 228. One copy of the ACK/NACK 228 may be from phase shift detection and the other copy of the ACK/NACK 228 may be from the format 2/2a/2b coding. Better performance may be achieved by combining the two ACK/NACK 228 copies to obtain a more reliable ACK/NACK 228 detection. The phase shift may be removed after the detection of the ACK/NACK 228 bits. Thus, the diversity gain for other control information may remain the same as for repetition on the second antenna 110b.

The base station 102 may receive 802 a first set of symbols on a first antenna 110a. The base station 102 may also receive 804 a second set of symbols on a second antenna 110b. The base station 102 may compute 806 the differential phase shift between the first set of symbols and the second set of symbols. Based on the differential phase shift, the base station may estimate 808 a first ACK/NACK estimate. Based on the reference symbols of the first set of symbols and the second set of symbols, the base station 102 may estimate 810 a second ACK/NACK estimate. The base station 102 may then combine 812 the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK

estimate. Based on the first ACK/NACK estimate, the second ACK/NACK estimate and the third ACK/NACK estimate, the base station 102 may determine 814 the ACK/NACK.

Based on the determined ACK/NACK, the base station 102 may remove 816 a phase shift from the second set of symbols to obtain a second set of symbols (phase shift removed), which can also be referred to as a third set of symbols. The base station 102 may then combine 818 the first set of symbols with the second set of symbols (phase shift removed) to obtain a fourth set of symbols. The base station 102 may decode 820 the combined symbols using a Reed-Muller (RM) decoder to obtain the CQI/PMI. The base station 102 may decode 820 the combined symbols using a Reed-Muller (RM) decoder in cases where a Reed-Muller code was used to encode the UCI. The UCI can be a first UCI that comprises a joint decoded ACK/NACK estimate.

In the current 3GPP Rel-8/9 specification, simultaneous UCI, i.e. CQI/PMI/RI, and ACK/NACK transmission is supported on PUCCH if configured. There are two messages to be carried: UCI, i.e. CQI and/or PMI and/or RI and ACK/NACK from HARQ process.

In Rel-8/9, two PUCCH formats are specified: Format 2a/2b for normal cyclic prefix (CP), ACK/NACK is carried on the second reference symbol of each slot and Format 2 for extended CP, ACK/NACK is concatenated with CQI/PMI/RI,

and joint coded.

At the receiver, two messages are obtained by separate decoding in normal CP, and joint decoding in extended CP. The UCI and ACK/NACK estimations are separated.

5 The present invention provides a method that further differentiates the ACK/NACK performance when PUCCH transmit diversity is used. The basic idea is to apply a phase shift sequence based on the ACK/NACK on the second PUCCH transmission.

10 Normal CP case with Format 2a/2b

Figure 8 of the present invention discloses a situation where, for normal CP, one ACK/NACK is obtained as in the standard Format 2a/2b, a second ACK/NACK is estimated by comparing the phase shift of two PUCCH signal transmissions.
15 By combining them, better ACK/NACK performance is achieved. Then, the UCI (CQI/PMI/RI) is decoded by removing the phase shift on the second PUCCH signal with the combined ACK/NACK detection. This is a small change to current specifications with a significant performance gain based on
20 our simulation results.

- First set of symbols: symbols received on the first antenna port.
- Second set of symbols: symbols received on the second antenna port.
- 25 ● Third set of symbols: symbols obtained from the

second set of symbols by removing the phase shift based on the third ACK/NACK estimate.

- Fourth set of symbols: symbols obtained by combining the first set of symbols and the third set of symbols.
- First ACK/NACK estimate: ACK/NACK estimate by phase shift.
- Second ACK/NACK estimate: ACK/NACK estimate by the ACK/NACK on the reference symbols.
- Third ACK/NACK estimate: soft combining of the first ACK/NACK estimate and the second ACK/NACK estimate.

In the process there is no loop and other conditions for normal CP.

1) Receive the first set of symbols on the first antenna port and the second set of symbols on the second antenna port.

2) Get the first ACK/NACK estimate based on the phase difference of the first set of symbols and the second set of symbols.

3) Get the second ACK/NACK estimate based on the reference symbols.

4) Get the third ACK/NACK estimate by combining the first ACK/NACK estimate and the second ACK/NACK estimate.

5) Determine ACK/NACK based on the third ACK/NACK

estimate.

6) Get the third set of symbols from the second set of symbols by removing the phase shift based on the determined ACK/NACK (or the third ACK/NACK estimate).

7) Get the fourth set of symbols by combining the first set of symbols and the third set of symbols.

8) Decode the fourth set of symbols to get the UCI (CQI/PMI/RI).

Figure 9 is a block diagram illustrating data flows for receiving uplink control information (UCI) using a format 2 PUCCH transmit diversity scheme. A base station 902 may include an uplink transmit (Tx) diversity receiving module 906. The uplink transmit (Tx) diversity receiving module 906 of Figure 9 may be one configuration of the uplink transmit (Tx) diversity receiving module 106 of Figure 1. The base station 902 may also include a first signal receiver for the first PUCCH transmission 914a and a second signal receiver for the second PUCCH transmission 914b. The signal receiver for the first PUCCH transmission 914a may receive a first set of symbols 962a. The signal receiver for the second PUCCH transmission 914b may receive a second set of symbols 962b. The signal receivers 914 may include two or more antennas. In one configuration, the signal receivers 914 may include four or eight antennas.

The uplink transmit (Tx) diversity receiving module 906

may include a differential phase shift computer 964. The differential phase shift computer 964 may compute a differential phase shift 966 between the first set of symbols 962a and the second set of symbols 962b. The uplink transmit (Tx) diversity receiving module 906 may also include a phase shift estimation module 968. The phase shift estimation module 968 may estimate a first ACK/NACK estimate 970 based on the computed differential phase shift 966. The first set of symbols 962a and the second set of symbols 962b may be received and evaluated separately on their respective PUCCH resources. A soft output may be calculated on the log likelihood ratio (LLR) of the second set of symbols 962b against each phase shift version of the first set of symbols 962a. Then the LLR of each ACK/NACK bit may be obtained.

The first ACK/NACK estimate 970 is approximately equivalent to a 10x differential QPSK (DQPSK) repetition code. The 10x DQPSK repetition code alone is better than the ACK/NACK performance in format 2a/2b with single antenna transmission, which is equivalent to 2x DQPSK repetitions. An ACK/NACK validation process may provide another level of protection on the ACK/NACK bits. For other information bits, the full transmit diversity gain may be maintained when the ACK/NACK is received correctly. The target bit error rate (BER) of ACK/NACK bits is very small (less than 0.0001). The

PUCCH transmit diversity scheme may achieve an even lower BER. Thus, the diversity gain on control is negligible.

The uplink transmit (Tx) diversity receiving module 906 may further include a second decoder 972a. The second decoder 972a may be a Reed-Muller decoder. The second decoder 972a may decode the first set of symbols 962a to obtain a second ACK/NACK estimate 974. The first ACK/NACK estimate 974 and the second ACK/NACK estimate 970 may be combined using a second soft combiner 976a to obtain a third ACK/NACK estimate 978. Furthermore, besides the first ACK/NACK estimate 970, the phase shift estimation module 968 may provide the likelihoods of ACK/NACK estimation to a second most likely ACK/NACK selection module 980. The second most likely ACK/NACK selection module 980 may then find out which ACK/NACK is to be chosen in case of an ACK/NACK validation conflict.

The uplink transmit (Tx) diversity receiving module 906 may include an ACK/NACK selection module 984. The ACK/NACK selection module 984 may receive the first ACK/NACK estimate 970, the second most likely ACK/NACK estimate 929, and the third ACK/NACK estimate 978. The ACK/NACK selection module 984 may then output a selected ACK/NACK estimate 986. The ACK/NACK selection module 984 may initially select the selected ACK/NACK estimate 986 as the first ACK/NACK estimate 970. Depending on a

validation module 998 discussed below, the ACK/NACK selection module 984 may adjust the selected ACK/NACK estimate 986.

5 The uplink transmit (Tx) diversity receiving module 906 may include a phase shift removal module 988. The phase shift removal module 988 may receive the second set of symbols 962b and the selected ACK/NACK estimate 986. Based on the selected ACK/NACK estimate 986, the phase shift removal module 988 may remove a phase shift from the
10 second set of symbols 962b. The phase shift removal module 988 may output a second set of symbols (phase shift removed) (third set of symbols) 990.

15 The uplink transmit (Tx) diversity receiving module 906 may include a first soft combiner 976b. The first soft combiner 976b may receive the first set of symbols 962a and the second set of symbols (phase shift removed) 990. The first soft combiner 976b may then combine the first set of symbols 962a and the second set of symbols (phase shift removed) 990 to output combined symbols (fourth set of
20 symbols) 992. The combined symbols 992 may be input into a first decoder 972b. The first decoder 972b may be a Reed-Muller decoder. The first decoder 972b may output the CQI/PMI 994 and a joint decoded ACK/NACK estimate 996.

25 The uplink transmit (Tx) diversity receiving module 906 may include a validation module 998. The validation module

998 may receive the selected ACK/NACK estimate 986 and the joint decoded ACK/NACK estimate 996. Normally, the independent estimates of the ACK/NACK should verify each other. Thus, the selected ACK/NACK estimate 986 should match the joint decoded ACK/NACK estimate 996. If the selected ACK/NACK estimate 986 matches the joint decoded ACK/NACK estimate 996, the joint decoded ACK/NACK estimate 996 may be output by the validation module 998 as the determined ACK/NACK 931.

In rare cases when different results are obtained (i.e. when the selected ACK/NACK estimate 986 and the joint decoded ACK/NACK estimate 996 differ by more than a threshold), the ACK/NACK selection module 984 may select the third ACK/NACK estimate 978 as the selected ACK/NACK estimate 986. The phase shift removing module 988, first soft combiner 976b and first decoder 972b may then restart to obtain a new joint decoded ACK/NACK estimate 996. If the results match, the validation module 998 may output the joint decoded ACK/NACK estimate 986 as the determined ACK/NACK 931. If the results are still different, the ACK/NACK selection module 984 may select the second most likely ACK/NACK 929 as the selected ACK/NACK estimate 986. The phase shift removing module 988, first soft combiner 976b and first decoder 972b may then restart to obtain a new joint decoded ACK/NACK estimate 996. If the results match,

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the validation module 998 may output the joint decoded ACK/NACK estimate 996 as the determined ACK/NACK 931.

If the new joint decoded ACK/NACK estimate 996 still does not match the selected ACK/NACK estimate 986, the validation module 998 may select the determined ACK/NACK 931 based on the number of bits of the CQI/PMI and the ACK/NACK, along with the first decoder 972b output when the selected ACK/NACK estimate 986 is the third ACK/NACK estimate 978 and when the selected ACK/NACK estimate 986 is the second most likely ACK/NACK 929. The decision from the phase shift estimation module 968 will be more reliable when the number of information bits is large. Furthermore, with multiple orthogonal resources, the reference symbols may also be used to convey the ACK/NACK signal in format 2 with extended CP. The coding/decoding process may then be simplified and become very similar to that of format 2a/2b discussed below in relation to Figure 11 and Figure 12A.

Figure 10 is a flow diagram of a method 1000 for receiving uplink control information (UCI) 222 using a format 2 PUCCH transmit diversity scheme. The method 1000 may be performed by a base station 902. The base station 902 may receive 1002 a first set of symbols 962a from a signal receiver for the first physical uplink control channel (PUCCH) transmission 914a. The base station 902 may receive 1004 a second set of symbols 962b from a signal receiver of a second

physical uplink control channel (PUCCH) transmission 914b.

The base station 902 may compute 1006 a differential phase shift 966 between the first set of symbols 962a and the second set of symbols 962b. The base station 902 may then
5 estimate 1008 a first ACK/NACK estimate 970 using the differential phase shift 966. The base station 902 may select 1010 the first ACK/NACK estimate 970 as the selected ACK/NACK estimate 986.

The base station 902 may next remove 1012 a phase
10 shift from the second set of symbols 962b based on the selected ACK/NACK estimate 986 to obtain a second set of symbols (phase shift removed) 990. The base station 902 may combine 1013 the first set of symbols 962a with the second set of symbols (phase shift removed) 990. The base station
15 902 may then decode 1014 the combined symbols 992 to obtain a CQI/PMI 994 and a joint decoded ACK/NACK estimate 996. The base station 902 may compare 1016 the joint decoded ACK/NACK estimate 996 with the selected ACK/NACK estimate 986. The base station 902 may then
20 determine 1018 whether the joint decoded ACK/NACK estimate 996 and the selected ACK/NACK estimate 986 differ by less than a threshold. If the joint decoded ACK/NACK estimate 996 and the selected ACK/NACK estimate 986 differ by less than a threshold, the base station 902 may select
25 1020 the joint decoded ACK/NACK estimate 996 as the

ACK/NACK 931 with great confidence.

If the joint decoded ACK/NACK estimate 996 and the selected ACK/NACK estimate 986 do not differ by less than a threshold, the base station 902 may next determine 1022 if the selected ACK/NACK estimate 986 is the first ACK/NACK estimate 970. If the selected ACK/NACK estimate 986 is the first ACK/NACK estimate 970, the base station 902 may decode 1024 the first set of symbols 962a to obtain a second ACK/NACK estimate 974. The base station 902 may decode 1024 the first set of symbols 962a using a Reed-Muller decoder. The base station 902 may then combine 1026 the first ACK/NACK estimate 970 and the second ACK/NACK estimate 974 to obtain a third ACK/NACK estimate 978. The base station 902 may select 1028 the third ACK/NACK estimate 978 as the selected ACK/NACK estimate 986. The base station 902 may then remove 1012 a phase shift 966 from the second set of symbols 962b based on the selected ACK/NACK estimate 986.

If the selected ACK/NACK estimate 986 is not the first ACK/NACK estimate 970, the base station 902 may determine 1036 whether the selected ACK/NACK estimate 986 is the third ACK/NACK estimate 978. If the selected ACK/NACK estimate 986 is the third ACK/NACK estimate 978, the base station 902 may determine 1038 a second most likely ACK/NACK 929 based on the first ACK/NACK estimate 970.

The base station 902 may select 1040 the second most likely ACK/NACK 929 as the selected ACK/NACK estimate 986. The base station 902 may then remove 1012 a phase shift 966 from the second set of symbols 962b based on the selected
5 ACK/NACK estimate 986.

If the selected ACK/NACK estimate 986 is not the third ACK/NACK estimate 978, the base station 902 may determine 1042 the ACK/NACK 931 based on the number of bits in the CQI/PMI 994 and the ACK/NACK 996. The base station 902
10 may also determine the ACK/NACK 929 based on the first decoder 972b output when the selected ACK/NACK estimate 986 is the third ACK/NACK estimate 978. The base station 902 may further determine the ACK/NACK 929 based on the first decoder 972b output when the selected ACK/NACK
15 estimate 986 is the second most likely ACK/NACK 929.

Extended CP case with Format 2:

Figures 9 and 10 show situations which use detailed decoding algorithms for the proposed method of the present invention when extended CP is used. Because ACK/NACK is
20 joint coded with UCI for extended CP, it is more complicated and the performance is not as good as for normal CP. We keep it to make the method complete and covers all cases. To make the ACK/NACK more reliable, a validation module is used to compare the ACK/NACK estimation from phase shift and the
25 output from RM decode.

Since there are several loops in the process, the output from one module may correspond to multiple terms used previously in the specification. This process takes several steps of trials and iterations.

5 1) Use the ACK/NACK estimate based on phase shift only, then remove phase shift on the second set of symbols and decode. If ACK/NACK results agree, done.

 2) Otherwise, try to combine a second ACK/NACK estimate with the first ACK/NACK estimate, and try again.

10 3) If ACK/NACK results still not agree, try again using the second most likely ACK/NACK from the phase shift estimation.

 4) If ACK/NACK results still do not agree, make a arbitrary decision.

15 First set of symbols: symbols received on the first antenna port.

 Second set of symbols: symbols received on the second antenna port.

20 Third set of symbols: symbols obtained from the second set of symbols by removing the phase shift based on the first ACK/NACK estimate.

 Fourth set of symbols: symbols obtained by combining the first set of symbols and the third set of symbols.

25 Fifth set of symbols: symbols obtained from the second set of symbols by removing the phase shift based on the third

ACK/NACK estimate.

Sixth set of symbols: symbols obtained by combining the first set of symbols and the fifth set of symbols.

Seventh set of symbols: symbols obtained from the second set of symbols by removing the phase shift based on the fifth ACK/NACK estimate.

Eighth set of symbols: symbols obtained by combining the first set of symbols and the seventh set of symbols.

First ACK/NACK estimate: ACK/NACK estimate by phase shift.

Second ACK/NACK estimate: ACK/NACK estimate by RM decoding with the first set of symbols (NOTE: this is different from normal CP case).

Third ACK/NACK estimate: soft combining of the first ACK/NACK estimate and the second ACK/NACK estimate.

Fourth ACK/NACK estimate: ACK/NACK from RM decoding of the sixth set of symbols.

Fifth ACK/NACK estimate: choose the second first ACK/NACK estimate if the fourth ACK/NACK estimate is different from the third ACK/NACK estimate.

Sixth ACK/NACK estimate: ACK/NACK from RM decoding of the eighth set of symbols.

First UCI: RM decode output based on the fourth set of symbols.

Second UCI: RM decode output based on the sixth set of

symbols.

Third UCI: RM decode output based on the eighth set of symbols.

Process:

- 5 1) Receive the first set of symbols on the first antenna port and the second set of symbols on the second antenna port.
- 2) Get the first ACK/NACK estimate based on the phase difference of the first set of symbols and the second set of symbols.
- 10 3) Get the third set of symbols from the second set of symbols by removing the phase shift based on the first ACK/NACK estimate.
- 4) Get the fourth set of symbols by combining the first set of symbols and the third set of symbols.
- 15 5) Decode the fourth set of symbols to get a first UCI (CQI/PMI/RI and ACK/NACK).
- 6) Compare the selected ACK/NACK estimate (in this step the first ACK/NACK estimate) with the ACK/NACK in the first UCI. If they are the same (differ by less than a threshold), done. The first UCI gives the CQI/PMI/RI and A/N.
- 20 7) If they are different, get the second ACK/NACK estimate by decoding only the first set of symbols.
- 25 8) Get the third ACK/NACK estimate by combining the

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first ACK/NACK estimate and the second ACK/NACK estimate.

a. Another condition should be added here, if the third ACK/NACK estimate is the same as the first ACK/NACK estimate, jump directly to step 13), i.e. box 1038 in Fig 10.

9) Get the fifth set of symbols from the second set of symbols by removing the phase shift based on the third ACK/NACK estimate.

10) Get the sixth set of symbols by combining the first set of symbols and the fifth set of symbols.

11) Decode the sixth set of symbols to get a second UCI (CQI/PMI/RI and ACK/NACK).

12) Compare the selected ACK/NACK estimate (in this step the third ACK/NACK estimate) with the fourth ACK/NACK estimate, i.e. the ACK/NACK in the second UCI. If they are the same (differ by less than a threshold), done. The second UCI gives the CQI/PMI/RI and A/N.

13) If they are different, get the fifth ACK/NACK estimate, i.e. the second most likely ACK/NACK based on the first ACK/NACK estimate.

14) Get the seventh set of symbols from the second set of symbols by removing the phase shift based on the fifth ACK/NACK estimate.

15) Get the eighth set of symbols by combining the first

set of symbols and the seventh set of symbols.

16) Decode the eighth set of symbols to get a third UCI (CQI/PMI/RI and ACK/NACK), which includes the sixth ACK/NACK estimate.

5 17) Compare the selected ACK/NACK estimate (in this step the fifth ACK/NACK estimate) with the sixth ACK/NACK estimate, i.e. the ACK/NACK in the third UCI. If they are the same (differ by less than a threshold), done. The third UCI gives the CQI/PMI/RI and A/N.

10 18) If they are still different, arbitrarily decide the ACK/NACK. If the CQI/PMI payload is big, the ACK/NACK from phase shift may be more reliable. If the CQI/PMI payload is small, the joint coding output may be more reliable.

15 a Joint likelihood estimation methods can be applied here to find the most likely CQI and ACK/NACK combination.

Figure 11 is a block diagram illustrating data flows for receiving uplink control information (UCI) 222 using a format 2a/2b PUCCH transmit diversity scheme. A base station 1102 may include an uplink transmit (Tx) diversity receiving module 1106. The uplink transmit (Tx) diversity receiving module 1106 of Figure 11 may be one configuration of the uplink transmit (Tx) diversity receiving module 106 of Figure 1. The base station 1102 may also include a signal receiver

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for the first PUCCH transmission 1114a and a signal receiver for the second PUCCH transmission 1114b. The signal receiver for the first PUCCH transmission 1114a may receive a first set of symbols 1162a. The signal receiver for the second PUCCH transmission 1114b may receive a second set of symbols 1162b. The first set of symbols 1162a and the second set of symbols 1162b may be received via the PUCCH.

The uplink transmit (Tx) diversity receiving module 1106 may include a differential phase shift computer 1164. The differential phase shift computer 1164 may receive the first set of symbols 1162a and the second set of symbols 1162b. The differential phase shift computer 1164 may then compute the differential phase shift 1166 between the first set of symbols 1162a and the second set of symbols 1162b. The uplink transmit (Tx) diversity receiving module 1106 may also include an ACK/NACK estimation module 1168. The ACK/NACK estimation module 1168 may also be referred to as a phase shift estimation module. The ACK/NACK estimation module 1168 may receive the differential phase shift 1166. The ACK/NACK estimation module 1168 may then estimate a first ACK/NACK estimate 1170 based on the differential phase shift 1166.

If a 2-bit ACK/NACK feedback is assumed, the format 2b may be equivalent to a 2x differential QPSK (DQPSK) repetition on each antenna. Thus, the format 2b may be

equivalent to an approximately 4x DQPSK repetition with two antennas. The phase shift estimation is essentially also a DQPSK demodulation. Thus, the ACK/NACK estimate from the phase shift detection is approximately equivalent to a 10x QPSK repetition code. Combined with the format 2b transmission on two antennas results in ~14x DQPSK repetition. Thus, up to 5.4 dB ($10 \cdot \log_{10}(14/4)$) gain over the simple repetition transmit diversity method. For other information bits, when the ACK/NACK is received correctly, full transmit diversity gain is maintained and there is no diversity gain when the ACK/NACK is in error.

The uplink transmit (Tx) diversity receiving module 1106 may include an ACK/NACK extraction module 1137. The ACK/NACK extraction module 1137 may receive the first set of symbols 1162a and the second set of symbols 1162b. The ACK/NACK extraction module 1137 may then extract the ACK/NACK from the reference symbols of the first set of symbols and the second set of symbols. The extracted ACK/NACK may be referred to as the second ACK/NACK estimate 1133.

The uplink transmit (Tx) diversity receiving module 1106 may include a second soft combiner 1176a. The second soft combiner 1176a may combine the first ACK/NACK estimate 1170 and the second ACK/NACK estimate 1133 to obtain a third ACK/NACK estimate 1135. The third ACK/NACK

estimate 1135 may be a more accurate estimate of the ACK/NACK and may be used as the ACK/NACK decision. The uplink transmit (Tx) diversity receiving module 1106 may include a phase shift removal module 1188. Based on the third ACK/NACK estimate 1135, the phase shift removal module 1188 may remove a phase shift from the second set of symbols 1162b. The phase shift removal module 1188 may then output the second set of symbols (phase shift removed) (third set of symbols) 1190.

The uplink transmit (Tx) diversity receiving module 1106 may include a first soft combiner 1176b. The first soft combiner 1176b may combine the first set of symbols 1162a and the second set of symbols (phase shift removed) 1190. The combined symbols (fourth set of symbols) 1192 may then be decoded by a decoder 1172. The decoder 1172 may be a Reed-Muller decoder 1172. The decoder 1172 may output the channel quality indicator (CQI)/precoding matrix index (PMI) 1194.

Figure 12A is a flow diagram of a method 1200 for receiving uplink control information (UCI) 222 using a format 2a/2b PUCCH transmit diversity scheme. The method 1200 may be performed by a base station 1102. The base station 1102 may receive 1202 a first set of symbols 1162a by a signal receiver for the first PUCCH transmission 1114a. The base station 1102 may receive 1204 a second set of symbols

1162b by a signal receiver for the second PUCCH transmission 1114b. The base station 1102 may then compute 1206 a differential phase shift 1166 between the first set of symbols 1162a and the second set of symbols 1162b.

5 Using the differential phase shift 1166, the base station 1102 may estimate 1208 a first ACK/NACK estimate 1170. The base station 1102 may also extract 1210 a second ACK/NACK estimate 1133 from the reference symbols 648 of the first set of symbols 1162a and the second set of symbols
10 1162b. The base station 1102 may combine 1212 the first ACK/NACK estimate 1170 and the second ACK/NACK estimate 1133 to obtain a third ACK/NACK estimate 1135. The third ACK/NACK estimate 1135 may be a more accurate estimate of the ACK/NACK and may be used as the ACK/NACK decision.

15 Using the third ACK/NACK estimate 1135, the base station 1102 may remove 1214 a phase shift from the second set of symbols 1162b. The base station 1102 may next combine 1216 the first set of symbols 1162a with the second set of symbols (phase shift removed) 1190. The base station
20 1102 may then decode 1218 the combined symbols 1192 to obtain the channel quality indicator (CQI)/precoding matrix index (PMI) 1194. The base station 1102 may decode 1218 the combined symbols 1192 using a Reed-Muller decoder 1172.

25 Figure 12B is a flow diagram of a method 1240 for

enhanced joint soft ACK/NACK 228 decoding. The method 1240 may be performed by a base station 102. The base station 102 may use 1242 all reference symbols and symbols with specified 0 or π phase shift as virtual reference symbols to obtain a better estimation of a differential decoding reference. Step 1242 may be performed by the ACK/NACK estimation module 1168. A better estimation of the differential decoding reference may reduce the effect of reference symbol miss-detection.

In the phase shift sequence pattern sets illustrated above in Table 3 and Table 4, there may be a conflict between a phase shifted sequence and another sequence. In the phase shift sequence pattern sets illustrated above in Table 5, Table 6 and Table 7, it may be possible to determine 1244 the maximum likelihood sequence (e.g., by choosing the sequence with the minimum mean squared distance to the detected symbols). Furthermore, because there is no conflict between a phase shifted sequence and another sequence, determining 1244 the maximum likelihood sequence may be optimized (convex optimization) by deliberately modifying the phase shift in order to offset the possible demodulation symbol error. Step 1244 may be performed by the ACK/NACK estimation module 1168. A vertex optimization can be employed to find the phase offset value that minimizes the sum of distances for all reference symbols and virtual reference symbols prior to

performing sequence likelihood detection.

The base station 102 may apply 1246 appropriate weights to the two ACK/NACK estimates 1170, 1133 using the first soft combiner 1176b. The base station 102 may then use 1248 joint decoding with the weighted ACK/NACK 228 detections to soft combine the two ACK/NACK estimates 1170, 1133 using the first soft combiner 1176b.

Figure 13 illustrates various components that may be utilized in a wireless communication device 1302. The wireless communication device 1302 includes a processor 1303 that controls operation of the wireless communication device 1302. The processor 1303 may also be referred to as a CPU. Memory 1305, which may include both read-only memory (ROM), random access memory (RAM) or any type of device that may store information, provides instructions 1307a and data 1309a to the processor 1303. A portion of the memory 1305 may also include non-volatile random access memory (NVRAM). Instructions 1307b and data 1309b may also reside in the processor 1303. Instructions 1307b loaded into the processor 1303 may also include instructions 1307a from memory 1305 that were loaded for execution by the processor 1303. The instructions 1307b may be executed by the processor 1303 to implement the methods disclosed herein.

The wireless communication device 1302 may also

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include a housing that contains a transmitter 1311 and a receiver 1313 to allow transmission and reception of data. The transmitter 1311 and receiver 1313 may be combined into a transceiver 1315. A first antenna 1317a and a second antenna 1317b are attached to the housing and electrically coupled to the transceiver 1315. Additional antennas may also be used.

The various components of the wireless communication device 1302 are coupled together by a bus system 1319 which may include a power bus, a control signal bus, and a status signal bus, in addition to a data bus. However, for the sake of clarity, the various buses are illustrated in Figure 13 as the bus system 1319. The wireless communication device 1302 may also include a digital signal processor (DSP) 1321 for use in processing signals. The wireless communication device 1302 may also include a communications interface 1323 that provides user access to the functions of the communication device 1302. The wireless communication device 1302 illustrated in Figure 13 is a functional block diagram rather than a listing of specific components.

Figure 14 illustrates various components that may be utilized in a base station 1404. The base station 1404 may include components that are similar to the components discussed above in relation to the wireless communication device 1302, including a processor 1403, memory 1405 that

provides instructions 1407a and data 1409a to the processor 1403, instructions 1407b and data 1409b that may reside in the processor 1403, a housing that contains a transmitter 1411 and a receiver 1413 (which may be combined into a transceiver 1415), a first antenna 1417a and a second antenna 1417b electrically coupled to the transceiver 1415, a bus system 1419, a DSP 1421 for use in processing signals, a communications interface 1423, and so forth.

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

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

The term “processor” should be interpreted broadly to encompass a general purpose processor, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a controller, a microcontroller, a state machine, and so forth.

Under some circumstances, a "processor" may refer to an application specific integrated circuit (ASIC), a programmable logic device (PLD), a field programmable gate array (FPGA), etc. The term "processor" may refer to a combination of processing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

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

The terms "instructions" and "code" should be interpreted broadly to include any type of computer-readable statement(s). For example, the terms "instructions" and

“code” may refer to one or more programs, routines, sub-routines, functions, procedures, etc. “Instructions” and “code” may comprise a single computer-readable statement or many computer-readable statements.

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

 Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital
25 subscriber line (DSL), or wireless technologies such as

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infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

5 The methods disclosed herein comprise one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is
10 required for proper operation of the method that is being described, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

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

CLAIMS

1. A method for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme, comprising:

coding UCI with a Forward Error Correction code to obtain a coded UCI;

mapping coded UCI to quadrature phase shift keying (QPSK) symbols to obtain a mapped coded UCI;

selecting a phase shift pattern;

applying a phase shift from the phase shift pattern to the mapped coded UCI based on an acknowledge/negative-acknowledge (ACK/NACK) to obtain a phase shifted mapped coded UCI;

sending the mapped coded UCI using a PUCCH resource on a first antenna; and

sending the phase shifted mapped coded UCI using a PUCCH resource on a second antenna.

2. The method of claim 1, wherein the phase shift is selected such that a phase shifted version of the mapped coded UCI will not collide with other sequences.

3. The method of claim 1, wherein selecting a phase shift comprises evenly dividing a number of reference symbols

and a number of ACK/NACK coded symbols to increase a reference reliability.

4. The method of claim 1, wherein selecting a phase shift comprises maximizing a sequence distance.

5. The method of claim 1, wherein the phase shift pattern comprises a bipolar coding that adds a simplex coding of ACK/NACK bits on the phase shifted mapped coded UCI.

6. The method of claim 1, wherein the phase shift pattern comprises an orthogonal design that allows reference symbol noise to be removed using pair symbol estimation.

7. The method of claim 1, wherein the UCI comprises a channel quality indicator (CQI), a precoding matrix index (PMI) and the ACK/NACK, and further comprising concatenating the CQI, PMI and ACK/NACK to obtain a concatenated UCI.

8. The method of claim 7, wherein coding the UCI with a FEC code comprises joint coding the concatenated UCI using a Reed-Muller code.

9. The method of claim 1, wherein the UCI comprises

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a channel quality indicator (CQI) and a precoding matrix index (PMI), and further comprising coding the ACK/NACK on reference symbols of the PUCCH resource of the first antenna to obtain a first set of ACK/NACK coded reference symbols, and combining the first set of ACK/NACK coded reference symbols with the mapped coded UCI prior to sending the mapped coded UCI.

10. The method of claim 9, further comprising coding the ACK/NACK on reference symbols of the PUCCH resource of the second antenna to obtain a second set of ACK/NACK coded reference symbols, and combining the second set of ACK/NACK coded reference symbols with the phase shifted mapped coded UCI prior to sending the phase shifted mapped coded UCI.

11. The method of claim 1, wherein the coded UCI is twenty bits.

12. The method of claim 1, wherein the coded UCI is mapped to ten QPSK symbols.

13. The method of claim 1, wherein the method is performed by a wireless communication device.

14. The method of claim 1, wherein the UCI is transmitted using PUCCH format 2.

15. The method of claim 1, wherein the UCI is transmitted using PUCCH format 2a/2b.

16. The method of claim 13, wherein the wireless communication device uses a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

17. A method for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme, comprising:

receiving a first set of symbols by a first signal receiver for a first PUCCH transmission;

receiving a second set of symbols by a second signal receiver for a second PUCCH transmission;

computing a differential phase shift between the first set of symbols and the second set of symbols;

estimating a first acknowledge/negative-acknowledge (ACK/NACK) estimate, wherein the first ACK/NACK estimate is based on the differential phase shift;

extracting a second ACK/NACK estimate from one or more reference symbols in the first set of symbols and the

second set of symbols;

using joint coding to combine the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate;

5 removing a phase shift from the second set of symbols based on the third ACK/NACK estimate to obtain a third set of symbols;

combining the first set of symbols with the third set of symbols to obtain a fourth set of symbols; and

10 decoding the fourth set of symbols to obtain the UCI.

18. The method of claim 17, further comprising using symbols with 0 or π as virtual reference symbols.

15 19. The method of claim 17, further comprising determining a maximum likelihood sequence using convex optimization.

20 20. The method of claim 17, wherein the method is performed by a base station configured to operate using a single or multiple antennas.

25 21. The method of claim 17, wherein decoding is performed using a Reed-Muller decoder if the UCI was encoded using a Reed-Muller coder.

22. The method of claim 17, wherein the UCI is sent using PUCCH format 2a/2b.

5 23. The method of claim 20, wherein the base station uses a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

10 24. A method for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme, comprising:

 receiving a first set of symbols by a first signal receiver for a first PUCCH transmission;

15 receiving a second set of symbols by a second signal receiver for a second PUCCH transmission;

 computing a differential phase shift between the first set of symbols and the second set of symbols using symbols with 0 or π as virtual reference symbols;

20 estimating a first acknowledge/negative-acknowledge (ACK/NACK) estimate based on the differential phase shift;

 removing a phase shift from the second set of symbols based on the first ACK/NACK estimate to obtain a third set of symbols;

25 combining the first set of symbols with the third set of symbols to obtain a fourth set of symbols; and

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decoding the fourth set of symbols to obtain a first UCI,
wherein the first UCI comprises a joint decoded ACK/NACK
estimate.

5 25. The method of claim 24, further comprising
determining a maximum likelihood sequence using convex
optimization.

10 26. The method of claim 25, further comprising
determining whether the first ACK/NACK estimate and the
joint decoded ACK/NACK estimate differ by less than a
threshold, and selecting the joint decoded ACK/NACK
estimate as the ACK/NACK if the first ACK/NACK estimate
and the joint decoded ACK/NACK estimate differ by less than
15 a threshold.

20 27. The method of claim 25, further comprising
determining whether the first ACK/NACK estimate and the
joint decoded ACK/NACK estimate differ by less than a
threshold, and decoding the first set of symbols to obtain a
second ACK/NACK estimate if the first ACK/NACK estimate
and the joint decoded ACK/NACK estimate differ by more than
a threshold.

25 28. The method of claim 27, further comprising:

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combining the first ACK/NACK estimate and the second ACK/NACK estimate using joint coding to obtain a third ACK/NACK estimate;

removing a phase shift from the second set of symbols based on the third ACK/NACK estimate to obtain a fifth set of symbols;

combining the fifth set of symbols with the first set of symbols to obtain a sixth set of symbols;

decoding the sixth set of symbols to obtain a second UCI, wherein the second UCI comprises a joint decoded fourth ACK/NACK estimate.

29. The method of claim 28, further comprising determining whether the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by less than a threshold, and selecting the joint decoded ACK/NACK estimate as the ACK/NACK if the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by less than a threshold.

30. The method of claim 28, further comprising determining whether the third ACK/NACK estimate and the joint decoded fourth ACK/NACK estimate differ by less than a threshold, and determining a fifth ACK/NACK estimate based on the first ACK/NACK estimate if the third ACK/NACK

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estimate and the joint decoded fourth ACK/NACK estimate differ by more than a threshold.

31. The method of claim 30, further comprising:

5 removing a phase shift from the second set of symbols based on the fifth ACK/NACK estimate to obtain a seventh set of symbols;

combining the seventh set of symbols with the first set of symbols to obtain an eighth set of symbols;

10 decoding the eighth set of symbols to obtain a third UCI, wherein the third UCI comprises a joint decoded sixth ACK/NACK estimate.

32. The method of claim 31, further comprising
15 determining whether the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by less than a threshold, and selecting the joint decoded sixth ACK/NACK estimate as the ACK/NACK if the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by less
20 than a threshold.

33. The method of claim 31, further comprising
determining whether the fifth ACK/NACK estimate and the
joint decoded sixth ACK/NACK estimate differ by less than a
25 threshold, and determining the ACK/NACK based on the

number of bits in the third UCI if the fifth ACK/NACK estimate and the joint decoded sixth ACK/NACK estimate differ by more than a threshold.

5 34. The method of claim 24, wherein the method is performed by a base station configured to operate using a single or multiple antennas.

10 35. The method of claim 24, wherein decoding is performed using a Reed-Muller decoder if the UCI was encoded using a Reed-Muller coder.

15 36. The method of claim 24, wherein the UCI was sent using PUCCH format 2.

 37. The method of claim 34, wherein the base station uses a Space Orthogonal Resource Transmit Diversity (SORTD) scheme when no ACK/NACK is transmitted.

20 38. A wireless communication device configured for transmitting uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme, the wireless communication device comprising:

 a Forward Error Correction (FEC) coder;

25 a quadrature phase shift keying (QPSK) symbol mapper;

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a phase shifter, wherein the phase shifter applies a phase shift from a selected phase shift pattern based on the ACK/NACK;

a first antenna; and

5 a second antenna.

39. The wireless communication device of claim 38, wherein the FEC coder is a Reed-Muller encoder, and wherein the Reed-Muller encoder joint codes a channel quality indicator (CQI)/precoding matrix index (PMI) and an
10 acknowledge/negative-acknowledge (ACK/NACK).

40. The wireless communication device of claim 38, further comprising a first ACK/NACK reference symbol coder and a second ACK/NACK reference symbol coder, wherein an
15 ACK/NACK reference symbol coder codes an ACK/NACK onto one or more reference symbols of a slot.

41. The wireless communication device of claim 38, wherein the wireless communication device is configured to
20 operate using single or multiple antennas.

42. The wireless communication device of claim 38, wherein the UCI is transmitted using PUCCH format 2.

43. The wireless communication device of claim 38, wherein the UCI is transmitted using PUCCH format 2a/2b.

44. A base station configured for receiving uplink control information (UCI) using a physical uplink control channel (PUCCH) transmit diversity scheme, the base station comprising:

a first signal receiver for a first PUCCH transmission, wherein the first signal receiver receives a first set of symbols;

a second signal receiver for a second PUCCH transmission, wherein the second signal receiver receives a second set of symbols;

a differential phase shift computer, wherein the differential phase shift computer computes the differential phase shift between the first set of symbols and the second set of symbols using symbols with 0 or π as virtual reference symbols;

a phase shift estimation module, wherein the phase shift estimation module estimates a first acknowledge/negative-acknowledge (ACK/NACK) estimate based on the differential phase shift;

a phase shift removal module, wherein the phase shift removal module removes a phase shift from the second set of symbols to obtain a third set of symbols;

a first combiner; wherein the first combiner combines the first set of symbols and the third set of symbols to obtain a fourth set of symbols; and

5 a first decoder, wherein the first decoder decodes the fourth set of symbols to obtain the UCI.

45. The base station of claim 44, further comprising:

an ACK/NACK extraction module, wherein the ACK/NACK extraction module extracts a second ACK/NACK estimate from one or more reference symbols of the first set of symbols and the second set of symbols; and

10 a second combiner; wherein the second combiner combines the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate, wherein the second combiner uses joint coding, and wherein the phase shift removed from the second set of symbols is based on the third ACK/NACK estimate.

46. The base station of claim 44, further comprising:

20 a second decoder, wherein the second decoder decodes a second ACK/NACK estimate from the first set of symbols;

a second combiner, wherein the second combiner combines the first ACK/NACK estimate and the second ACK/NACK estimate to obtain a third ACK/NACK estimate, and wherein the UCI output by the first decoder comprises a

25

channel quality indicator (CQI), a precoding matrix index (PMI) and a fourth ACK/NACK estimate; and

a validation module, wherein the validation module determines the validity of the fourth ACK/NACK estimate.

FIG. 1

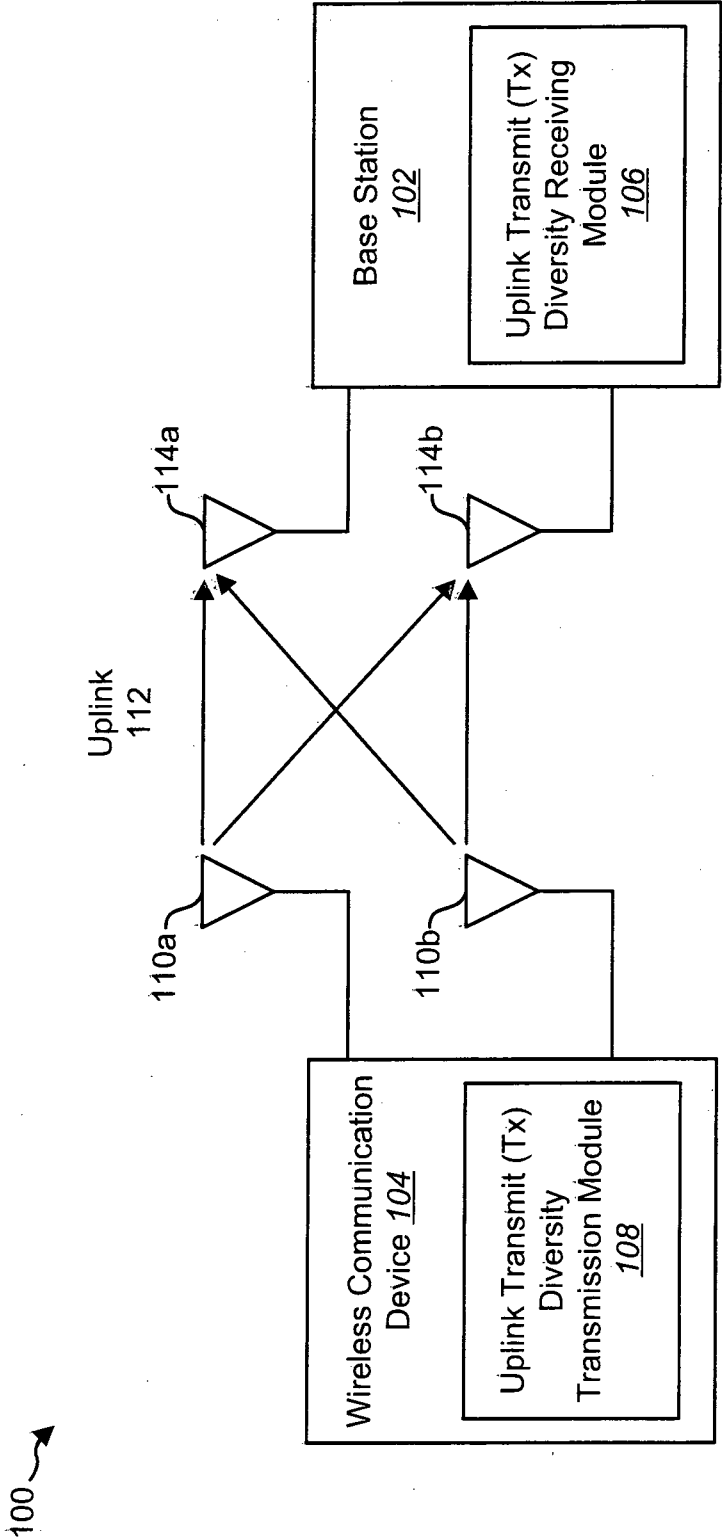
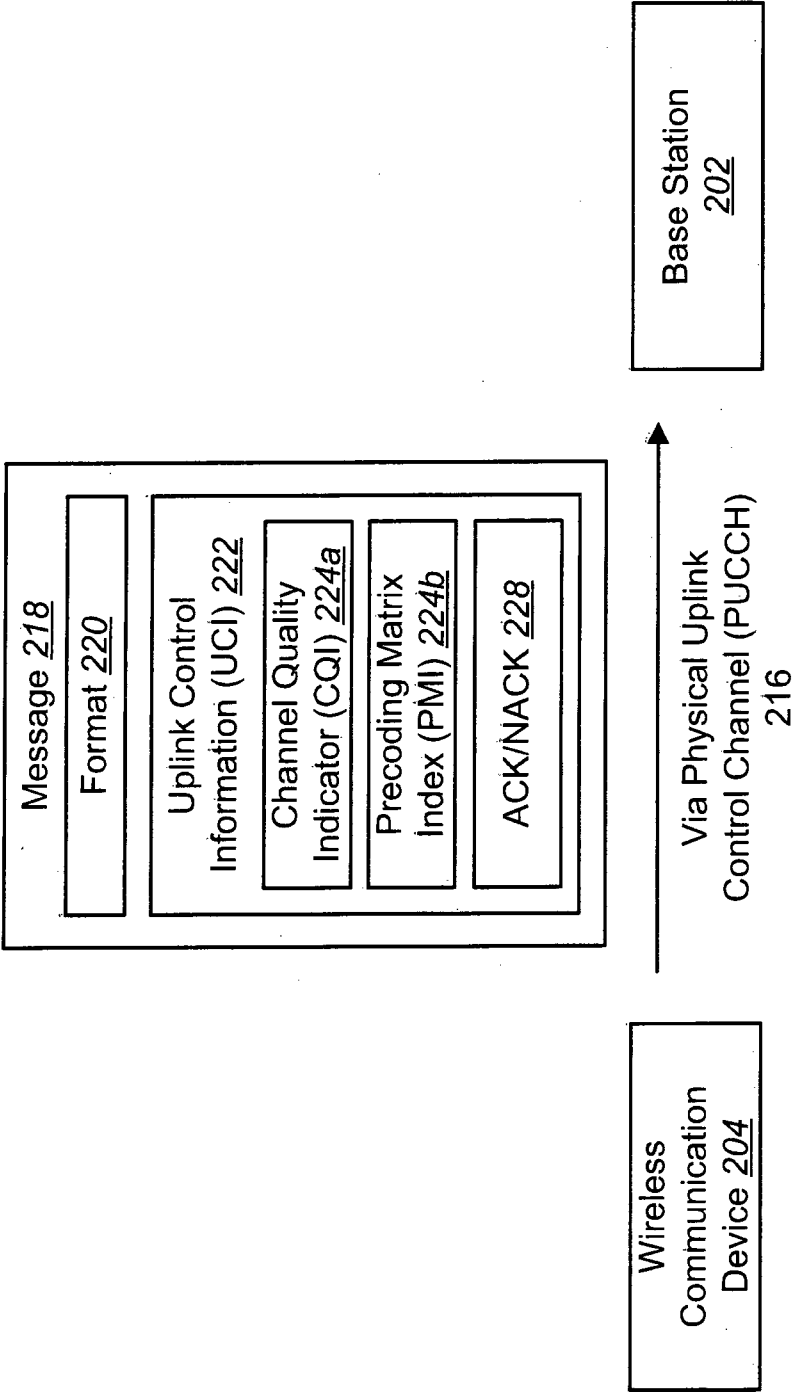
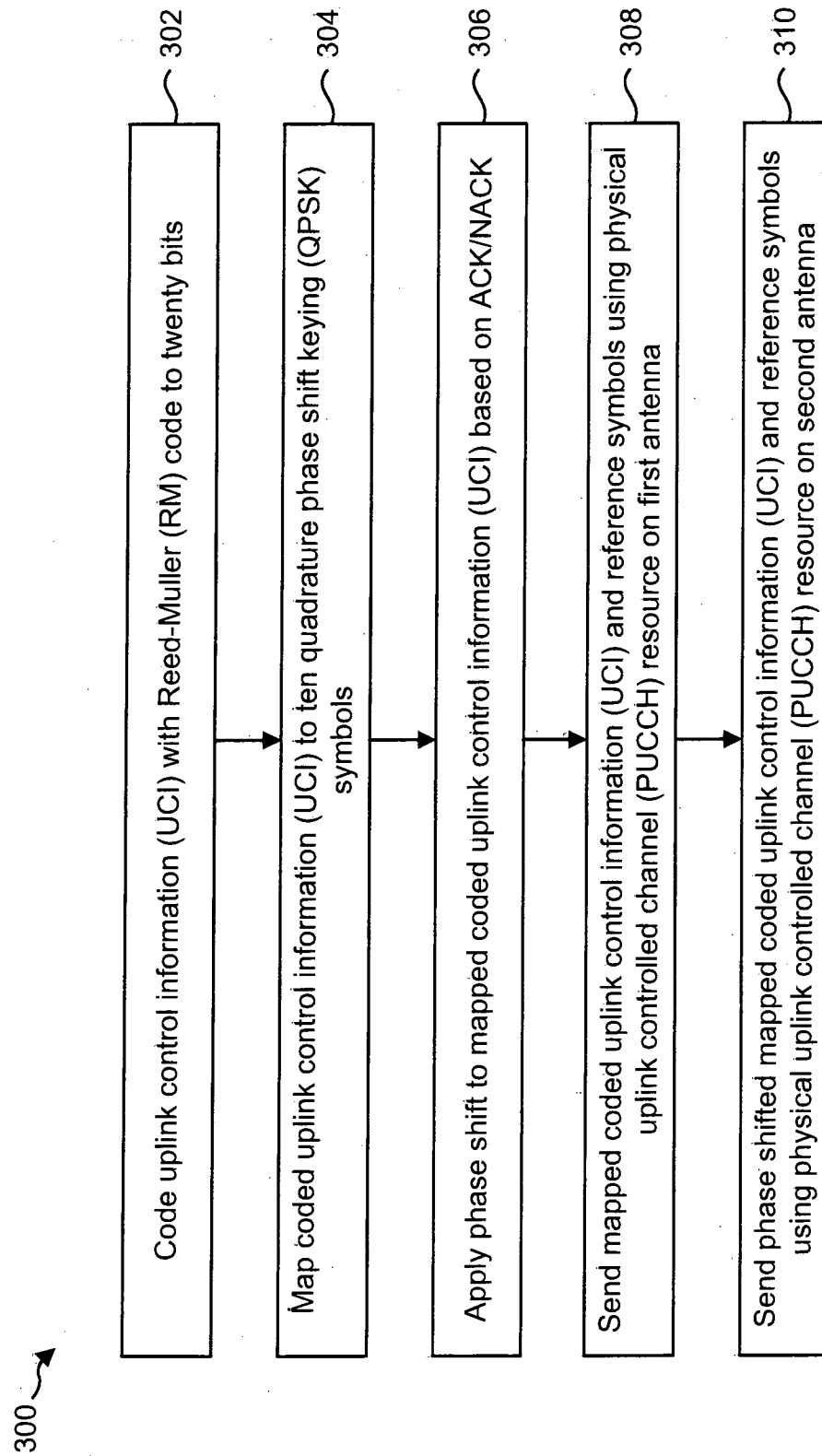


FIG. 2



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FIG. 3A



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FIG. 3B

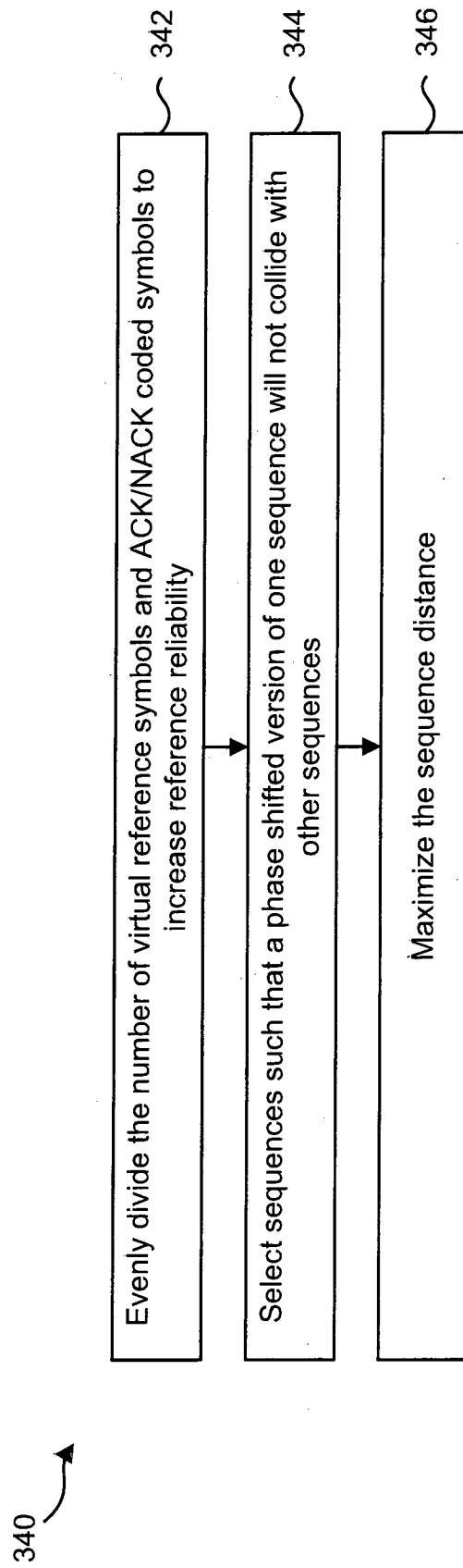
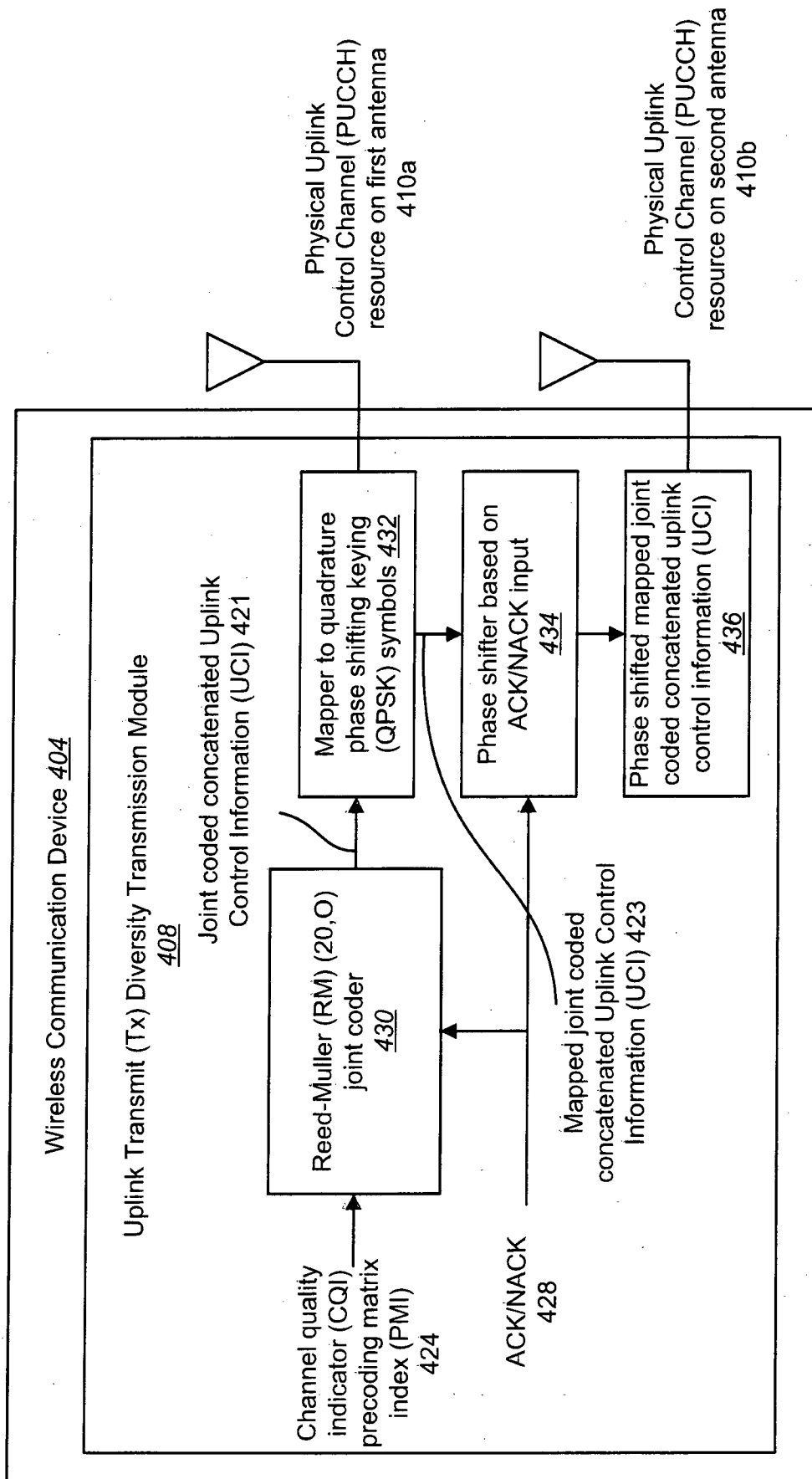


FIG. 4



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FIG. 5

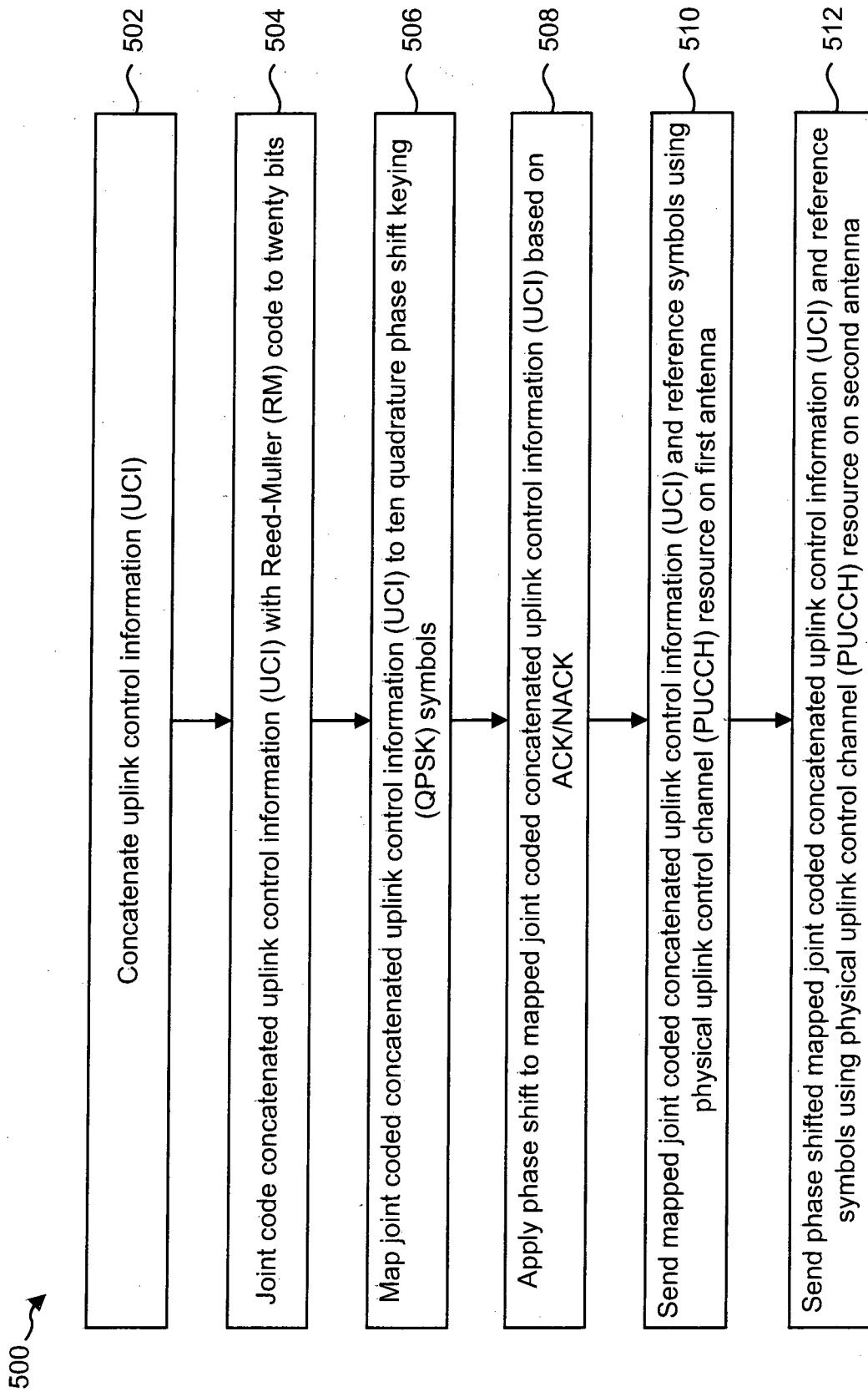
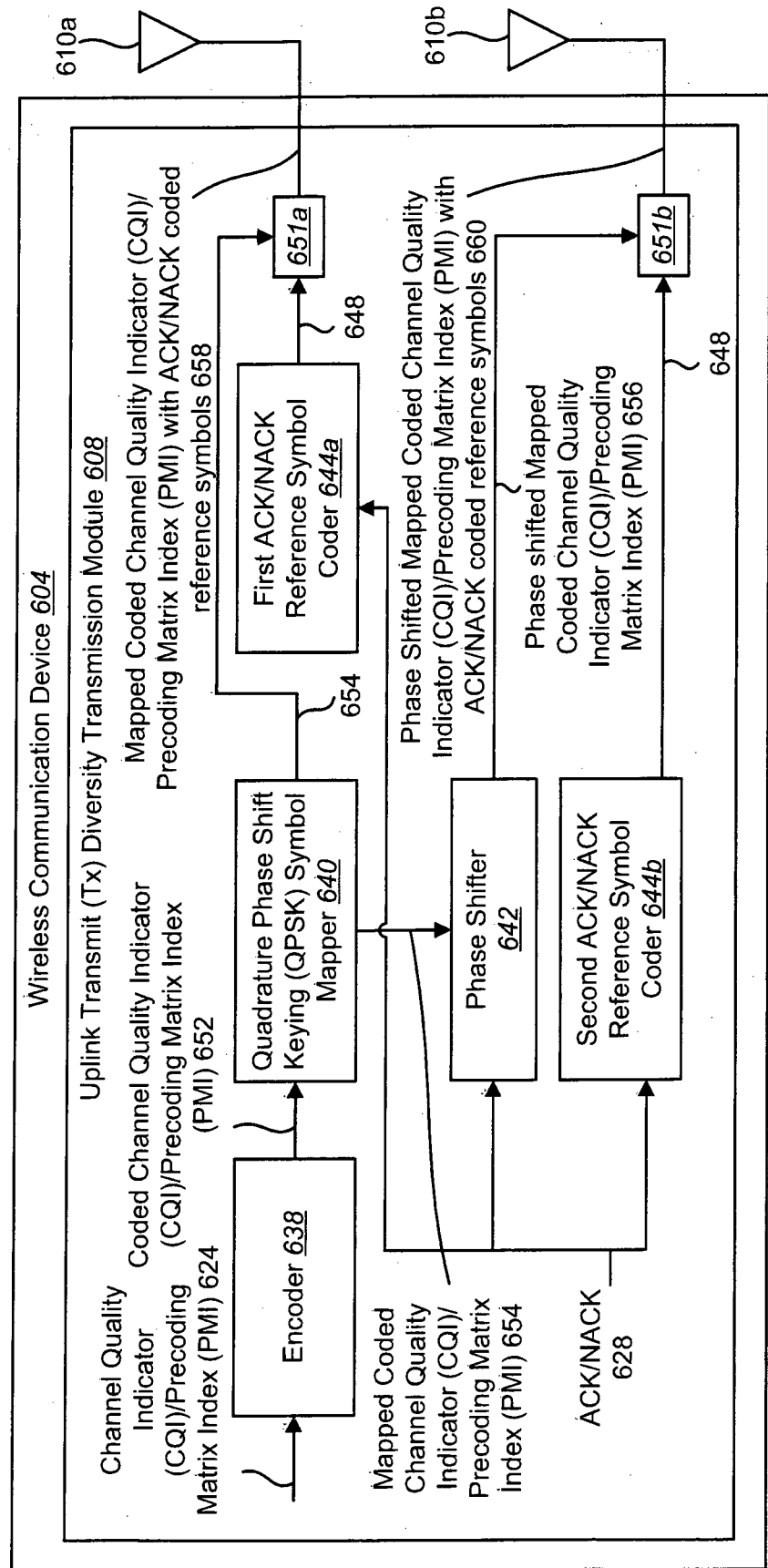
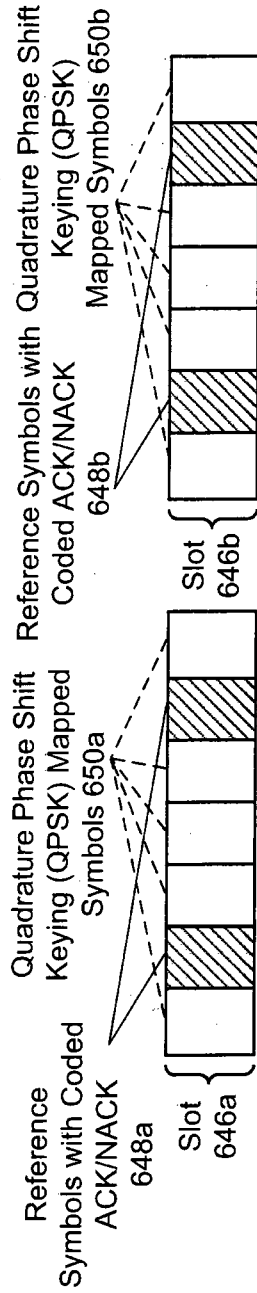
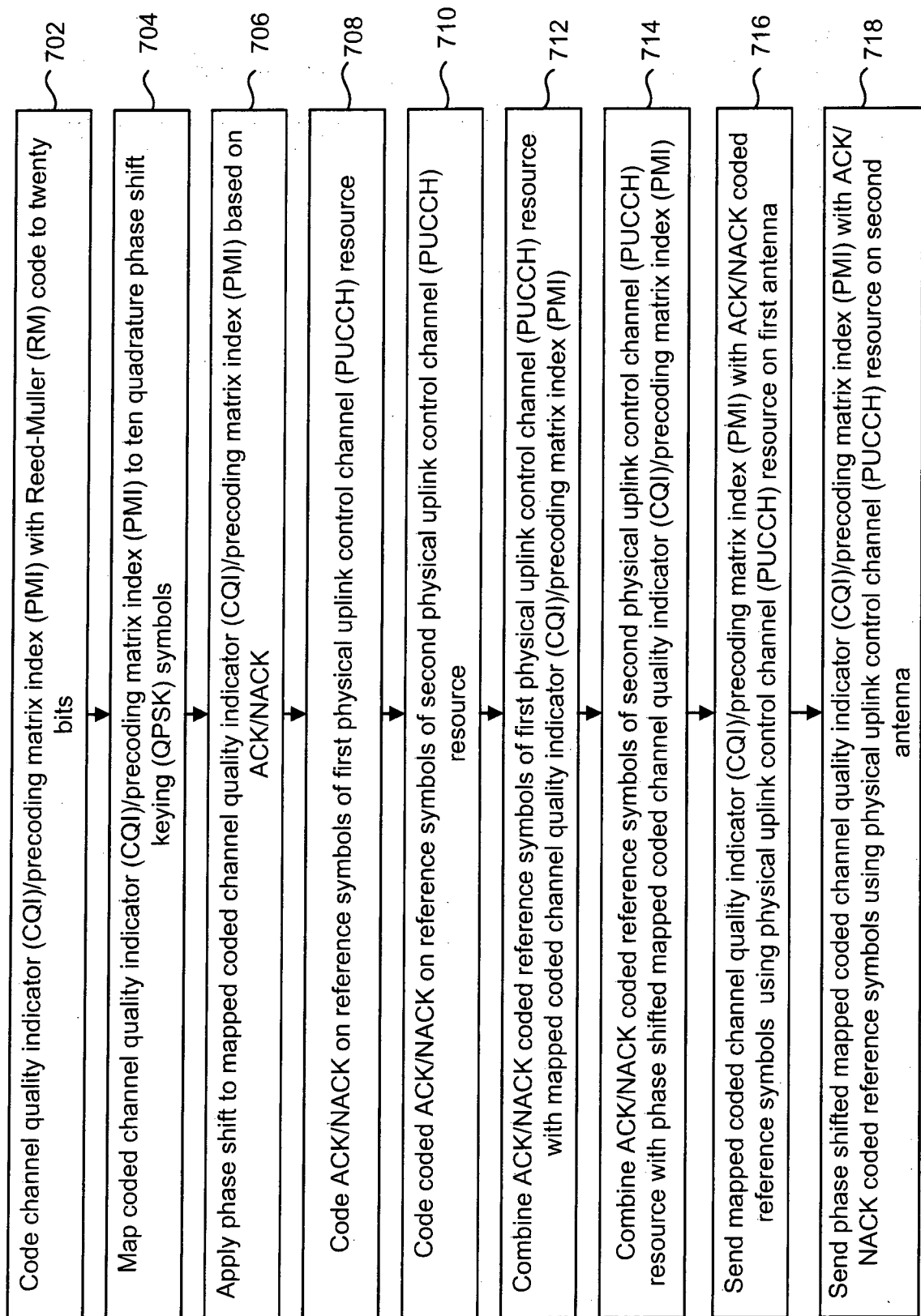


FIG. 6



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FIG. 7



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FIG. 8

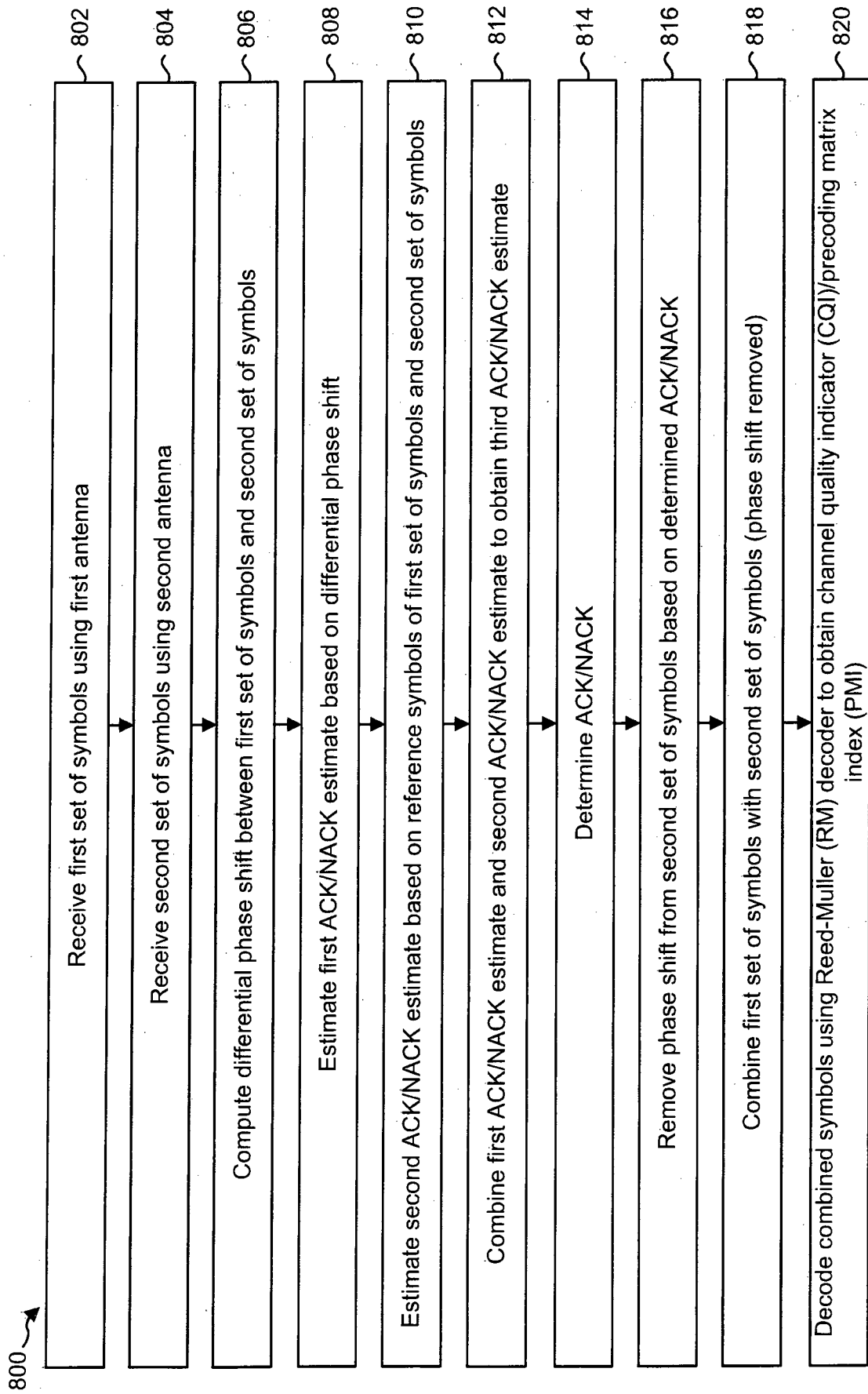


FIG. 9

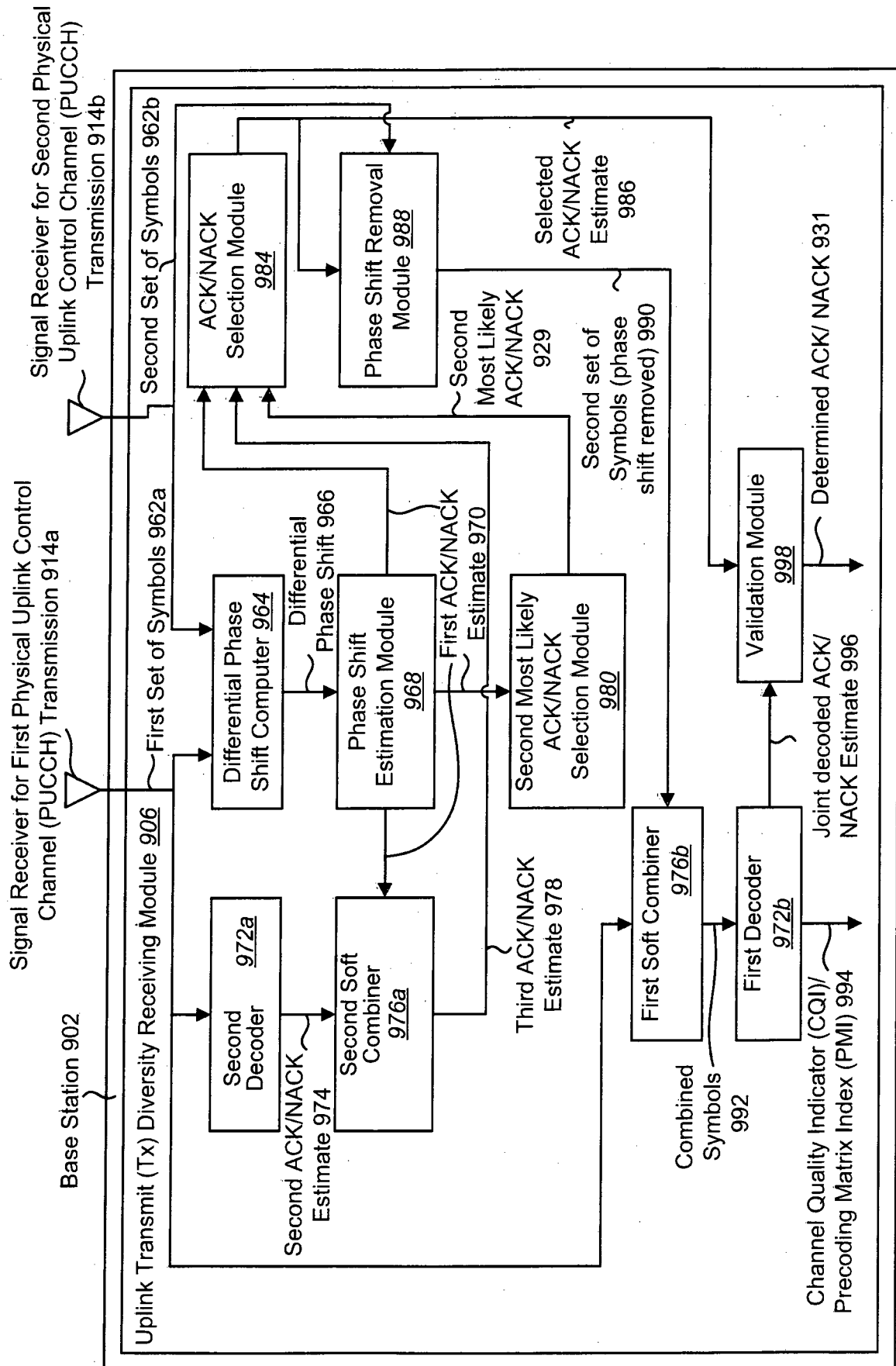


FIG. 10

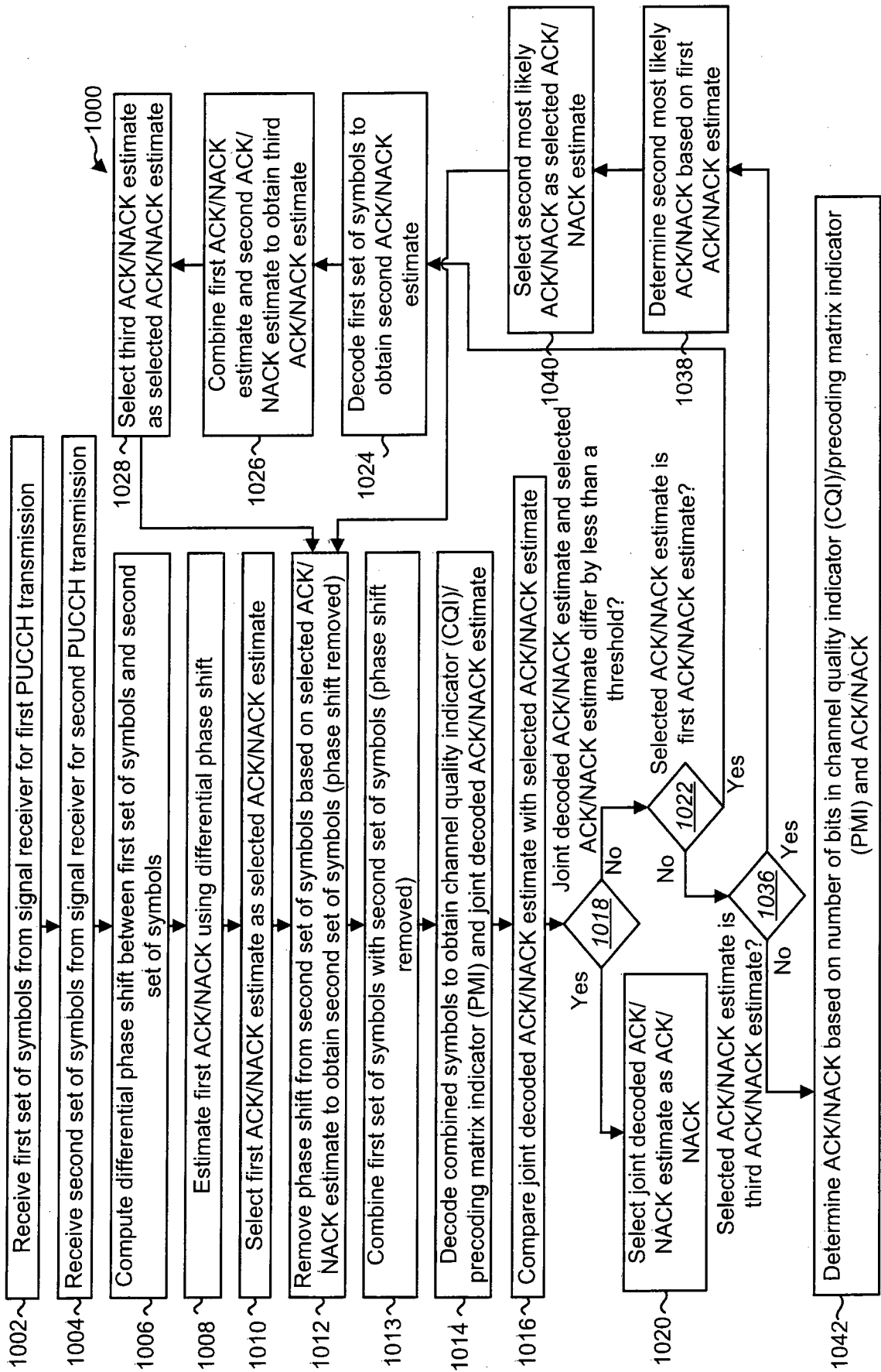


FIG. 11

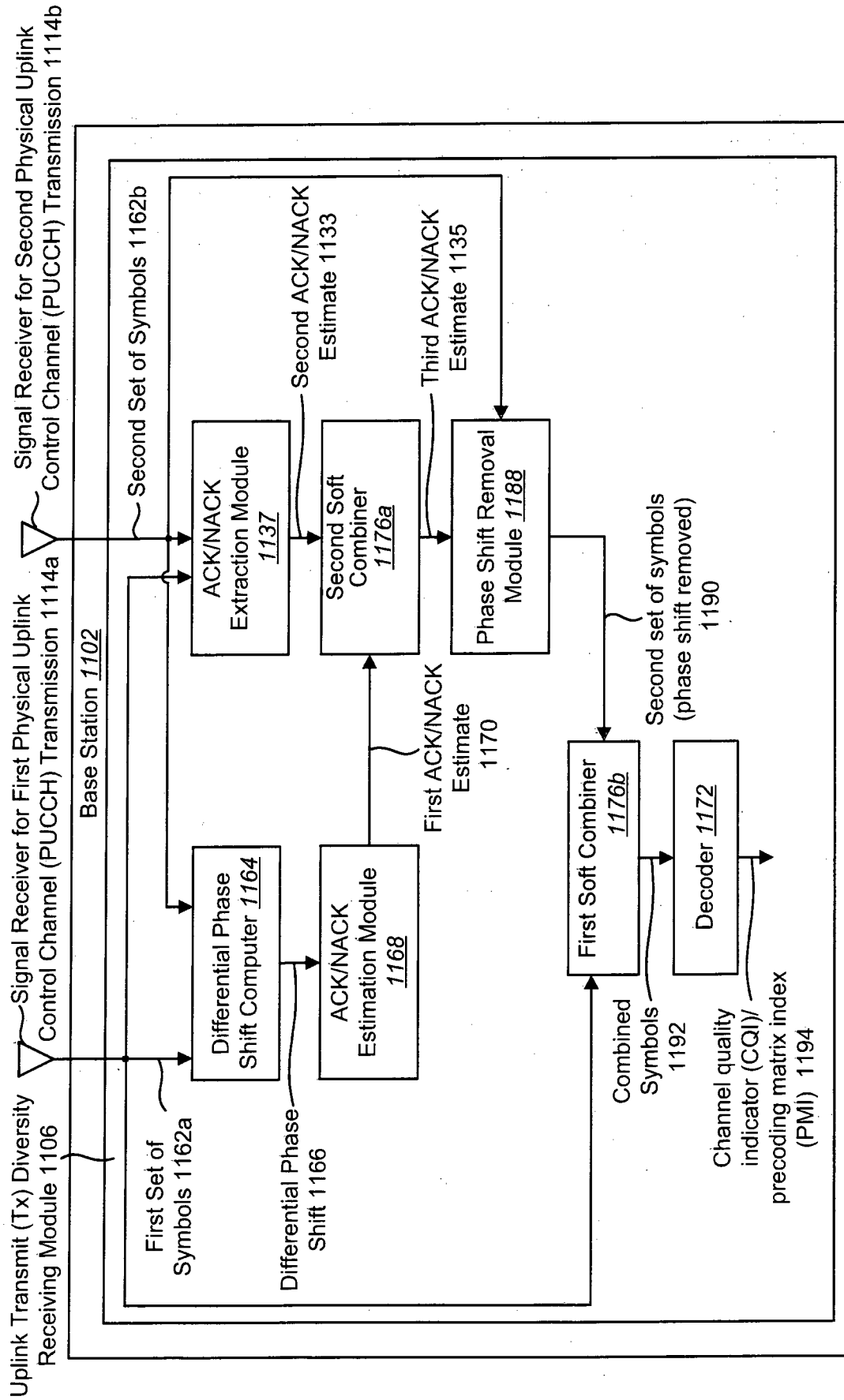
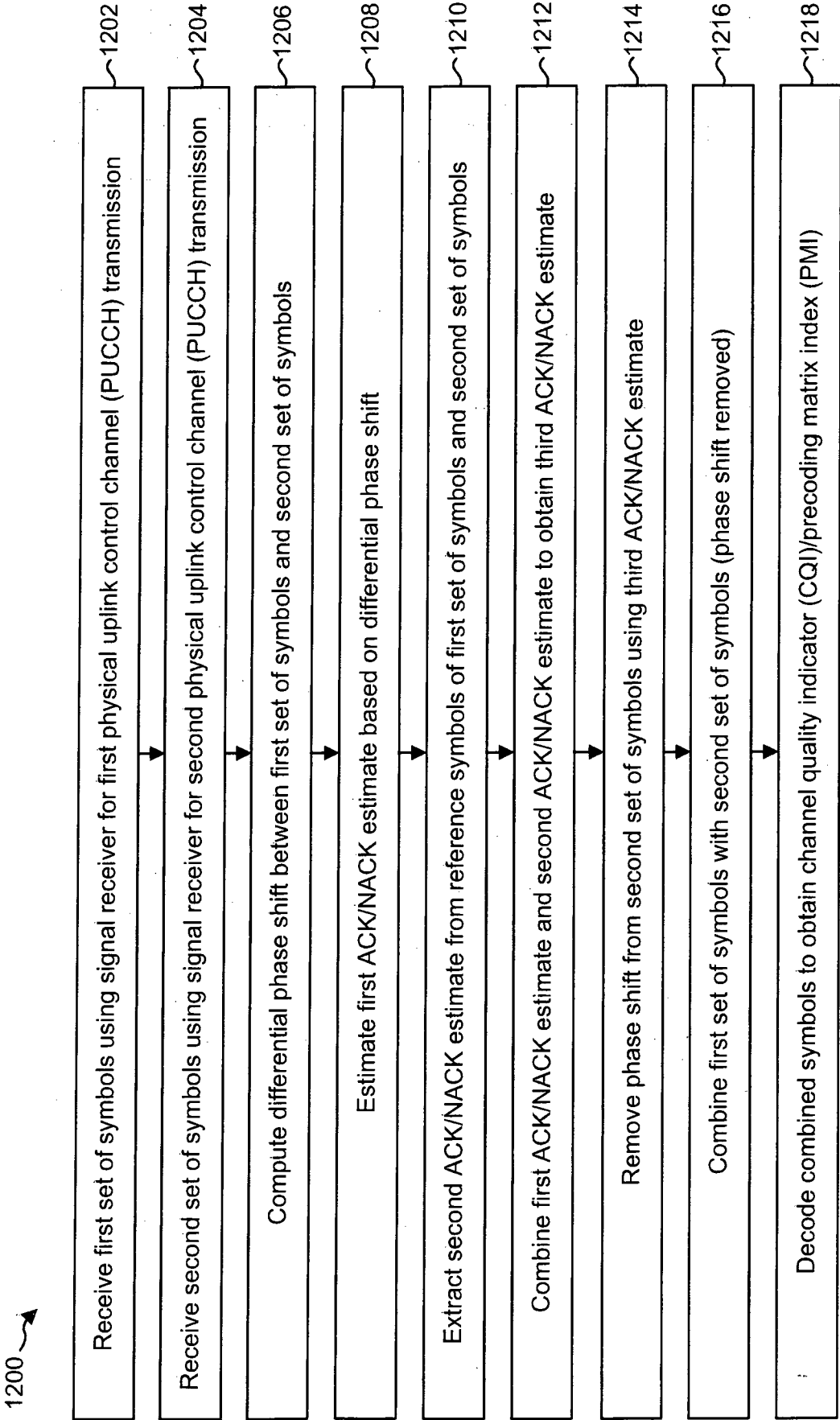


FIG. 12A



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FIG. 12B

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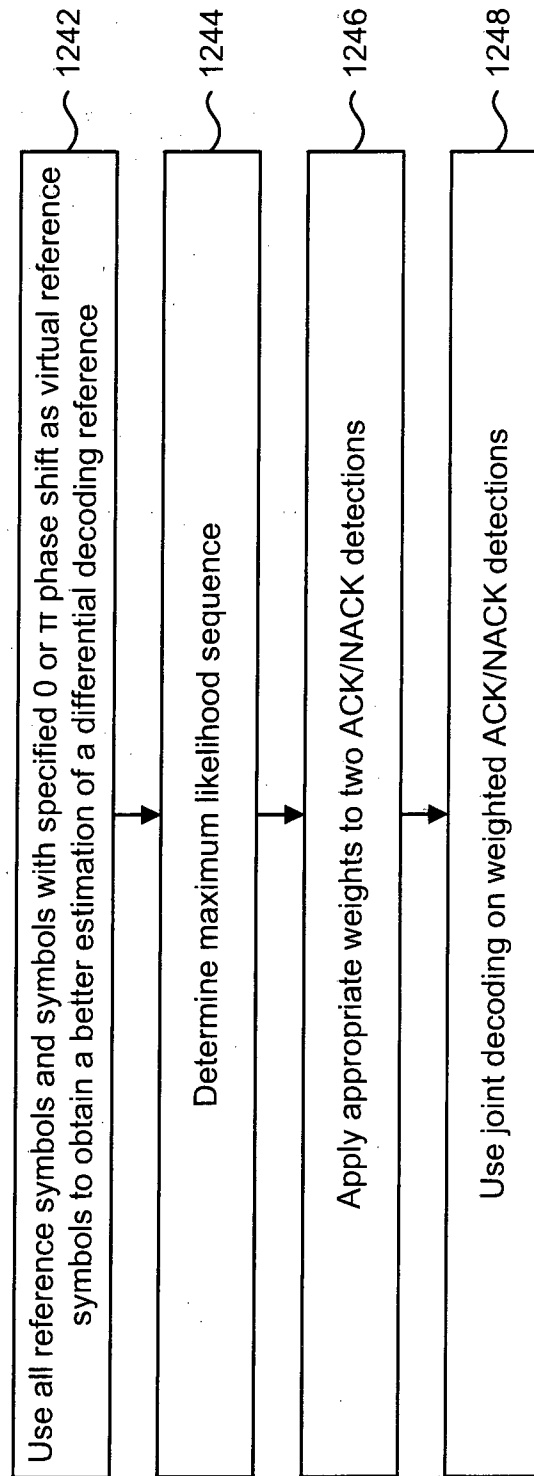
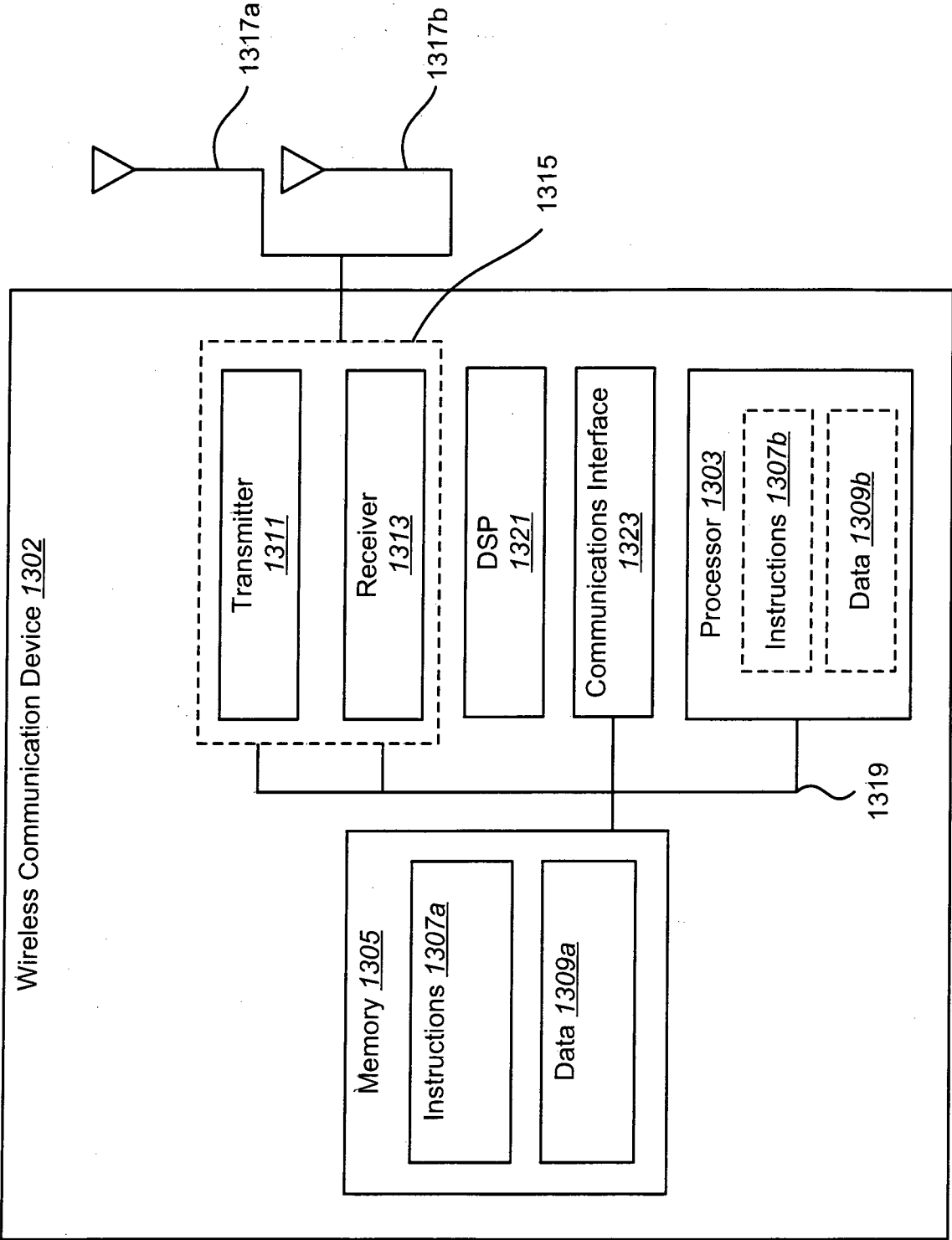
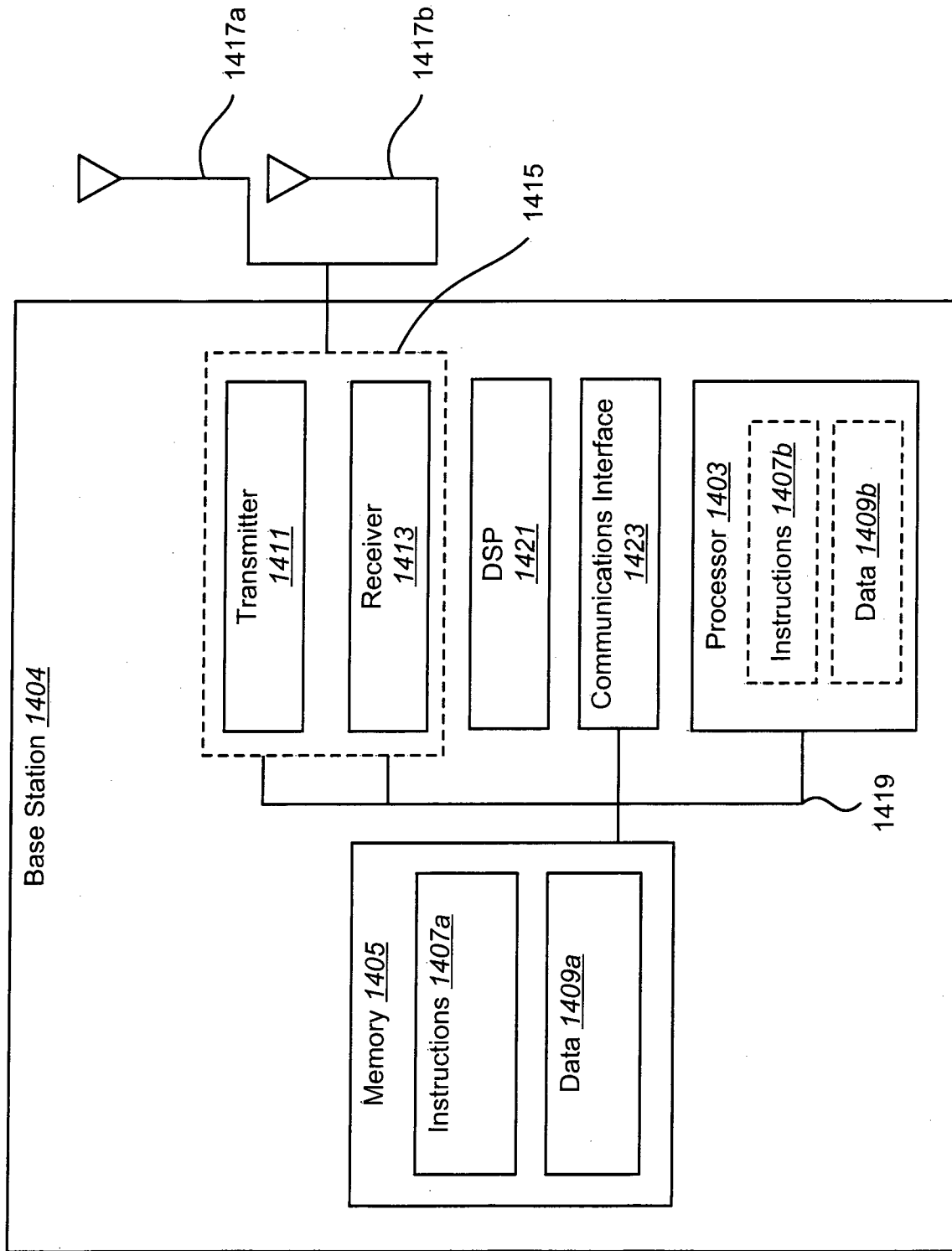


FIG. 13



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FIG. 14



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/052968

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H04W16/28 (2009.01) i, H04W28/04 (2009.01) i, H04W88/02 (2009.01) i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H04B7/24-7/26, H04W4/00-99/00

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

Published examined utility model applications of Japan 1922-1996
 Published unexamined utility model applications of Japan 1971-2011
 Registered utility model specifications of Japan 1996-2011
 Published registered utility model applications of Japan 1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	AKIMOTO Yosuke, ENOMOTO Masayuki, KATSURAGAWA Hiroshi, OH Wahoh, Transmit Diversity scheme applied to the uplink ACK/NACK transmission of Advanced E-UTRA, IEICE Technical Report RCS2008-249(2009-03), 2009.02.25, 108(445), p.219-224	1-46
Y	Sharp, LTE-A transmit diversity schemes for PUCCH format 1/1a/1b, R1-092340, 3GPP, 2009.07.03, paragraph 6.2.7	1-46



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"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

07.03.2011

Date of mailing of the international search report

22.03.2011

Name and mailing address of the ISA/JP

Japan Patent Office

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/052968

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Sharp, Views on PUCCH TxD for LTE-A, R1-092343, 3GPP, 2009.07.03, paragraph 2,3	1-46
Y	Panasonic, NTT DoCoMo, Necessity of the scrambling for ACK/NACK on PUCCH, R1-082403, 3GPP, 2008.07.04, paragraph 3	1-46
Y	NAKAO Seigo, TAKATA Tomohumi, IMAMURA Daichi, HIRAMATSU Katsuhiko, Performance improvement of Evolved UTRA uplink control channel for fast fading environments, IEICE Technical Report RCS2008-61(2008-8), 2008.08.20, 108(188), p.49-54	1-46
Y	NAKAO Seigo, TAKATA Tomohumi, IMAMURA Daichi, HIRAMATSU Katsuhiko, Considerations on the Discontinuous Transmission detection performance of the ACK/NACK signals for E-UTRA uplink control channel, IEICE Technical Report SIP2008-128, RCS2008-176(2009-01), 2009.01.15, 108(390), p.23-28	1-46