



(86) Date de dépôt PCT/PCT Filing Date: 2008/12/12
(87) Date publication PCT/PCT Publication Date: 2009/06/18
(45) Date de délivrance/Issue Date: 2014/08/19
(85) Entrée phase nationale/National Entry: 2010/05/20
(86) N° demande PCT/PCT Application No.: US 2008/086698
(87) N° publication PCT/PCT Publication No.: 2009/076647
(30) Priorité/Priority: 2007/12/13 (US11/956,278)

(51) Cl.Int./Int.Cl. *H04L 1/18* (2006.01)

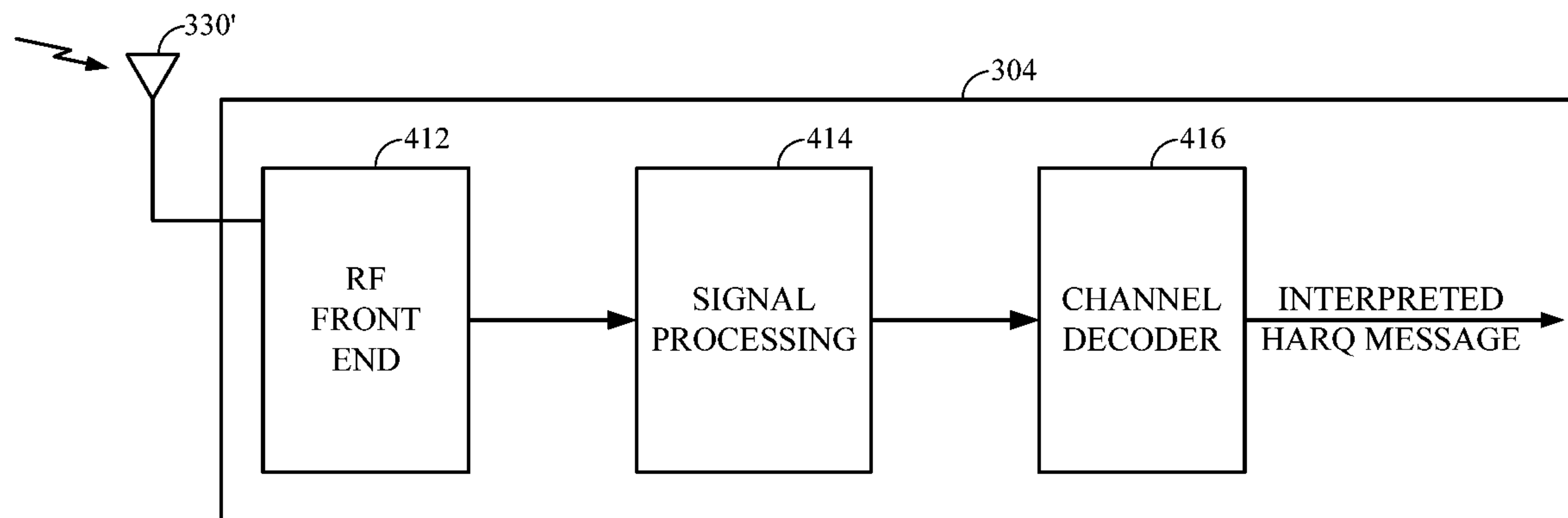
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(54) Titre : MECANISME DE COMBINAISON HARQ SELECTIVE PAR DECALAGE AVANT ET DECALAGE INVERSE
POUR DES SYSTEMES AMROF

(54) Title: FORWARD AND REVERSE SHIFTING SELECTIVE HARQ COMBINING SCHEME FOR OFDMA SYSTEMS



(57) Abrégé/Abstract:

A method and apparatus for combining retransmitted hybrid automatic repeat- request (HARQ) messages at different stages in an OFDM/OFDMA receiver are provided. A combination of different types of HARQ combiners may be designed into the receiver and selected on a per-channel basis. Proper selection of a HARQ combining scheme may reduce the required HARQ buffer size and may provide an increased combining gain when compared to conventional HARQ combining techniques. Furthermore, the HARQ combiner type may be dynamically selected through forward and reverse shifting between the different types of HARQ combining schemes in an effort to decrease the bit error ratio (BER) without saturating the HARQ buffer.

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

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
18 June 2009 (18.06.2009)

PCT

(10) International Publication Number
WO 2009/076647 A1

(51) International Patent Classification:
H04L 1/18 (2006.01)

(21) International Application Number:
PCT/US2008/086698

(22) International Filing Date:
12 December 2008 (12.12.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/956,278 13 December 2007 (13.12.2007) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(54) Title: FORWARD AND REVERSE SHIFTING SELECTIVE HARQ COMBINING SCHEME FOR OFDMA SYSTEMS

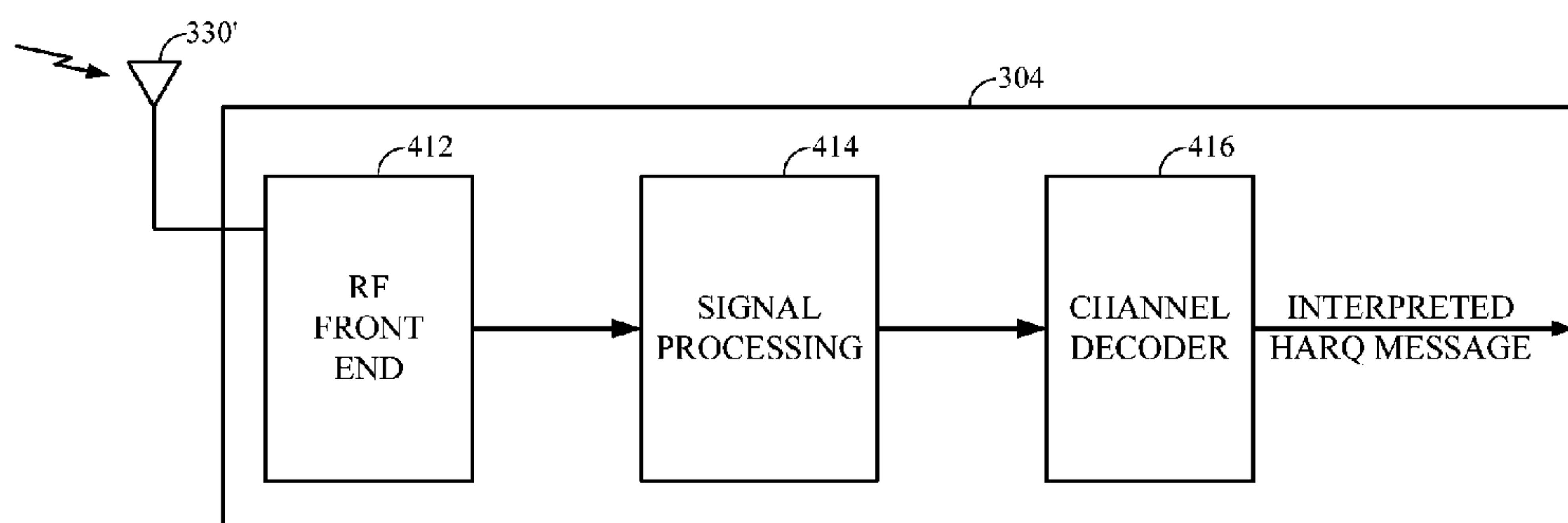


FIG. 4B

(57) Abstract: A method and apparatus for combining retransmitted hybrid automatic repeat-request (HARQ) messages at different stages in an OFDM/OFDMA receiver are provided. A combination of different types of HARQ combiners may be designed into the receiver and selected on a per-channel basis. Proper selection of a HARQ combining scheme may reduce the required HARQ buffer size and may provide an increased combining gain when compared to conventional HARQ combining techniques. Furthermore, the HARQ combiner type may be dynamically selected through forward and reverse shifting between the different types of HARQ combining schemes in an effort to decrease the bit error ratio (BER) without saturating the HARQ buffer.

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FORWARD AND REVERSE SHIFTING SELECTIVE HARQ COMBINING SCHEME FOR OFDMA SYSTEMS

TECHNICAL FIELD

[0001] Embodiments of the present disclosure generally relate to data communication
5 and, more particularly, to hybrid automatic repeat-request (HARQ) combining schemes for
wireless communication.

BACKGROUND

[0002] To improve the reliability of data transmission, some wireless systems employ
a hybrid automatic repeat-request (HARQ) scheme where error detection (ED) bits and
10 forward error correction (FEC) bits are added to transmissions. A receiver can use these ED
and FEC bits to determine whether or not a packet was decoded properly. If not, the receiver
may signal the transmitter via a negative acknowledgment (NAK), prompting the transmitter
to retransmit the packet.

[0003] In some applications, Chase combining may be employed, where incorrectly
15 received coded data blocks are stored at the receiver (in a HARQ buffer) rather than
discarded. When the retransmitted block is received, the retransmitted block is combined with
the previously received block, which can increase the probability of successful decoding.
Different types of combining techniques may have an impact on bit error rate performance
and the required buffer size, depending on transmission parameters. Unfortunately,
20 transmission parameters often change, especially between wireless channels, such that the
type of combining scheme implemented in a receiver is not always optimal.

SUMMARY

[0004] Embodiments of the present disclosure generally relate to selecting different
types of combiners for combining retransmitted hybrid automatic repeat-request (HARQ)
25 messages at different stages in a receiver for wireless communication.

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[0005] Certain embodiments of the present disclosure provide a receiver for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising: a first HARQ combiner at a first location along a reception processing path; a second HARQ combiner at a second location along the reception processing path different from the first location; control logic configured to select the first HARQ combiner to generate first HARQ combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and to select the second HARQ combiner to generate second HARQ combined signal data wherein the selection is based on signal data for a second received HARQ transmission in the channel; and at least one buffer for storing the first or the second HARQ combined signal data.

[0006] Certain embodiments of the present disclosure provide an apparatus for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising: first means for generating HARQ combined signal data at a first location along a reception processing path; second means for generating the HARQ combined signal data at a second location along the reception processing path different from the first location; means for selecting the first means for use in generating first HARQ combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and for selecting second means for use in generating second HARQ combined signal data wherein the selection is based on signal data for a second HARQ transmission in the channel; and means for storing the first or the second HARQ combined signal data.

[0007] Certain embodiments of the present disclosure provide a processor for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, the processor executing operations comprising: receiving a first HARQ transmission in a channel; selecting a first HARQ combiner for use in generating first HARQ combined signal data wherein the selection is based on signal data for the first HARQ transmission; receiving a second HARQ transmission in the channel; and selecting a second HARQ combiner for use in generating second HARQ combined signal data wherein the selection is based on signal data for the second HARQ transmission, wherein the first and second HARQ combiners are located at different locations along a reception processing path.

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[0008] Certain embodiments of the present disclosure provide a mobile device, comprising: a first HARQ combiner at a first location along a reception processing path; a second HARQ combiner at a second location along the reception processing path different from the first location; control logic configured to select the first HARQ combiner to generate
5 first hybrid automatic repeat-request (HARQ) combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and to select the second HARQ combiner to generate second HARQ combined signal data wherein the selection is based on signal data for a second received HARQ transmission in the channel; at least one buffer for storing the first or the second HARQ combined signal data; and a receiver
10 front end for receiving the first and second HARQ transmissions in the channel.

[0009] Certain embodiments of the present disclosure provide a computer-program product for processing data for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism comprising a computer readable memory having a set of instructions stored thereon, the set of instructions being executable by one or more processors
15 and the set of instructions comprising: first instructions for generating HARQ combined signal data at a first location along a reception processing path; second instructions for generating the HARQ combined signal data at a second location along the reception processing path different from the first location; instructions for selecting the first instructions for use in generating first HARQ combined signal data wherein the selection is based on
20 signal data for a first received HARQ transmission in a channel and for selecting second instructions for use in generating second HARQ combined signal data wherein the selection is based on signal data for a second HARQ transmission in the channel; and instructions for storing the first or the second HARQ combined signal data.

[0009a] Certain embodiments of the present disclosure provide a method for
25 interpreting hybrid automatic repeat-request (HARQ) transmissions in a wireless communication system, the method comprising: receiving a first HARQ transmission in a channel; selecting a first HARQ combiner for use in generating first HARQ combined signal data wherein the selection is based on signal data for the first HARQ transmission; receiving a

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second HARQ transmission in the channel; and selecting a second HARQ combiner for use in generating second HARQ combined signal data wherein the selection is based on signal data for the second HARQ transmission, wherein the first and second HARQ combiners are located at different locations along a reception processing path.

5 **[0009b]** Certain embodiments of the present disclosure provide an apparatus for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising: first means for generating HARQ combined signal data at a first location along a reception processing path; second means for generating the HARQ combined signal data at a second location along the reception processing path different from the first location, wherein
10 the first means and the second means are connected in series; means for storing HARQ combined signal data; means for determining a headroom of the means for storing; means for selecting the first means for use in generating first HARQ combined signal data based on signal data for a first received HARQ transmission in a channel, wherein the selection is based at least on the headroom of the means for storing and a modulation order of the channel; and
15 wherein the means for selecting is further configured to select the second means for use in generating second HARQ combined signal data based on signal data for a second received HARQ transmission in the channel, wherein the selection is based at least on the headroom of the means for storing and the modulation order of the channel, wherein the means for storing is configured to store the first or second HARQ combined signal data.

20 **[0009c]** Certain embodiments of the present disclosure provide a method for interpreting hybrid automatic repeat-request (HARQ) transmissions in a wireless communication system, the method comprising: receiving a first HARQ transmission in a channel; selecting a first combiner for use in generating first HARQ combined signal data based on signal data for the first HARQ transmission, wherein the selection is based at least
25 on a headroom of a buffer for storing HARQ combined signal data and the modulation order of the channel; receiving a second HARQ transmission in the channel; and selecting a second combiner for use in generating second HARQ combined signal data based on signal data for the second HARQ transmission, wherein the selection is based at least on the headroom of the buffer and a modulation order of the channel, and wherein the first and second combiners are

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connected in a series connection located at different locations along a reception processing path.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] So that the manner in which the above recited features of the present disclosure
5 can be understood in detail, a more particular description, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only certain typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the description may admit to other equally effective embodiments.

10 [0011] FIG. 1 illustrates an example wireless communication system, in accordance with certain embodiments of the present disclosure.

[0012] FIG. 2 illustrates various components that may be utilized in a wireless device in accordance with certain embodiments of the present disclosure.

[0013] FIG. 3 illustrates an example transmitter and an example receiver that may be
15 used within a wireless communication system that utilizes orthogonal frequency-division multiplexing and orthogonal frequency division multiple access (OFDM/OFDMA) technology in accordance with certain embodiments of the present disclosure.

[0014] FIG. 3A illustrates hybrid automatic repeat-request (HARQ) transmission, in accordance with certain embodiments of the present disclosure.

[0015] FIG. 4A illustrates an example transmitter for HARQ transmission, in accordance with certain embodiments of the present disclosure.

[0016] FIG. 4B illustrates an example receiver for HARQ transmission, in accordance with certain embodiments of the present disclosure.

[0017] FIG. 5 illustrates one example of the receiver of FIG. 4B, in accordance with certain embodiments of the present disclosure.

[0018] FIGs. 6A-6C illustrate the receiver of FIG. 5 with different combining schemes selected, in accordance with certain embodiments of the present disclosure.

[0019] FIG. 7 is a flow diagram of example operations for selective HARQ (S-HARQ) combining, in accordance with certain embodiments of the present disclosure.

[0020] FIG. 8 illustrates combining before signal demapping, in accordance with certain embodiments of the present disclosure.

[0021] FIG. 9 illustrates combining after signal demapping, in accordance with certain embodiments of the present disclosure.

[0022] FIG. 10 illustrates combining before channel decoding, in accordance with certain embodiments of the present disclosure.

[0023] FIG. 11 illustrates forward shifting in an S-HARQ combining scheme in the receiver of FIG. 5, in accordance with certain embodiments of the present disclosure.

[0024] FIGs. 12A-B illustrate the contents of the HARQ buffer when forward shifting from one type of HARQ combining scheme to another, in accordance with certain embodiments of the present disclosure.

[0025] FIGs. 13A-B illustrate example operations for forward shifting in an S-HARQ combining scheme, in accordance with an certain embodiments of the present disclosure.

[0026] FIG. 14 illustrates forward and reverse shifting in an S-HARQ combining scheme in the receiver of FIG. 5, in accordance with certain embodiments of the present disclosure.

[0027] FIGs. 15A-B illustrate the contents of the HARQ buffer when reverse shifting from one type of HARQ combining scheme to another, in accordance with certain embodiments of the present disclosure.

[0028] FIGs. 16A-B illustrate example operations for reverse shifting in an S-HARQ combining scheme, in accordance with certain embodiments of the present disclosure.

[0029] FIG. 17 is a flow diagram of example operations for shifting between types of HARQ combiners in an S-HARQ combining scheme, in accordance with certain embodiments of the present disclosure.

[0030] FIG. 17A is a block diagram of means corresponding to the example operations for the shifting between types of HARQ combiners in FIG. 17, in accordance with certain embodiments of the present disclosure.

DETAILED DESCRIPTION

[0031] Embodiments of the present disclosure provide techniques and systems for selecting between different types of combiners within a receiver for combining transmitted/retransmitted hybrid automatic repeat-request (HARQ) messages. For some embodiments, a combination of different types of HARQ combiners may be designed into a receiver (at different processing stages) and selected on a per-channel basis.

[0032] The type of combiner selected for use with a particular channel at any given time may depend on a number of selection criteria, such as the modulation order of the transmitted signal, the number of bits needed for the combined signals, and the amount of space remaining (headroom) in the HARQ buffer. Proper selection of a HARQ combining scheme may reduce the required HARQ buffer size and may result in an increased combining gain when compared to conventional HARQ combining techniques utilizing a single combiner.

[0033] The following description presents certain embodiments of selective HARQ (S-HARQ) combining that utilize Chase combining as a particular, but not limiting, scheme. In Chase combining, the retransmissions are copies of the original transmission. However, those skilled in the art will recognize that the concepts of selective combining described herein may be used to similar advantage with other

combining schemes, such as incremental redundancy (IR), where the retransmissions comprise new parity bits from the channel encoder.

An Exemplary Wireless Communication System

[0034] The methods and apparatus of the present disclosure may be utilized in a broadband wireless communication system. The term “broadband wireless” refers to technology that provides wireless, voice, Internet, and/or data network access over a given area.

[0035] WiMAX, which stands for the Worldwide Interoperability for Microwave Access, is a standards-based broadband wireless technology that provides high-throughput broadband connections over long distances. There are two main applications of WiMAX today: fixed WiMAX and mobile WiMAX. Fixed WiMAX applications are point-to-multipoint, enabling broadband access to homes and businesses, for example. Mobile WiMAX offers the full mobility of cellular networks at broadband speeds.

[0036] Mobile WiMAX is based on OFDM (orthogonal frequency-division multiplexing) and OFDMA (orthogonal frequency division multiple access) technology. OFDM is a digital multi-carrier modulation technique that has recently found wide adoption in a variety of high-data-rate communication systems. With OFDM, a transmit bit stream is divided into multiple lower-rate sub-streams. Each sub-stream is modulated with one of multiple orthogonal sub-carriers and sent over one of a plurality of parallel sub-channels. OFDMA is a multiple access technique in which users are assigned subcarriers in different time slots. OFDMA is a flexible multiple-access technique that can accommodate many users with widely varying applications, data rates, and quality of service requirements.

[0037] The rapid growth in wireless internets and communications has led to an increasing demand for high data rate in the field of wireless communications services. OFDM/OFDMA systems are today regarded as one of the most promising research areas and as a key technology for the next generation of wireless communications. This is due to the fact that OFDM/OFDMA modulation schemes can provide many advantages such as modulation efficiency, spectrum efficiency, flexibility, and strong multipath immunity over conventional single carrier modulation schemes.

[0038] IEEE 802.16x is an emerging standard organization to define an air interface for fixed and mobile broadband wireless access (BWA) systems. IEEE 802.16x approved “IEEE P802.16-REVd/D5-2004” in May 2004 for fixed BWA systems and published “IEEE P802.16e/D12 Oct. 2005” in October 2005 for mobile BWA systems. Those two standards defined four different physical layers (PHYs) and one media access control (MAC) layer. The OFDM and OFDMA physical layer of the four physical layers are the most popular in the fixed and mobile BWA areas respectively.

[0039] FIG. 1 illustrates an example of a wireless communication system 100. The wireless communication system 100 may be a broadband wireless communication system. The wireless communication system 100 may provide communication for a number of cells 102, each of which is serviced by a base station 104. A base station 104 may be a fixed station that communicates with user terminals 106. The base station 104 may alternatively be referred to as an access point, a Node B, or some other terminology.

[0040] FIG. 1 depicts various user terminals 106 dispersed throughout the system 100. The user terminals 106 may be fixed (*i.e.*, stationary) or mobile. The user terminals 106 may alternatively be referred to as remote stations, access terminals, terminals, subscriber units, mobile stations, stations, user equipment, etc. The user terminals 106 may be wireless devices, such as cellular phones, personal digital assistants (PDAs), handheld devices, wireless modems, laptop computers, personal computers, *etc.*

[0041] A variety of algorithms and methods may be used for transmissions in the wireless communication system 100 between the base stations 104 and the user terminals 106. For example, signals may be sent and received between the base stations 104 and the user terminals 106 in accordance with OFDM/OFDMA techniques. If this is the case, the wireless communication system 100 may be referred to as an OFDM/OFDMA system.

[0042] A communication link that facilitates transmission from a base station 104 to a user terminal 106 may be referred to as a downlink 108, and a communication link that facilitates transmission from a user terminal 106 to a base station 104 may be referred to as an uplink 110. Alternatively, a downlink 108 may be referred to as a

forward link or a forward channel, and an uplink 110 may be referred to as a reverse link or a reverse channel.

[0043] A cell 102 may be divided into multiple sectors 112. A sector 112 is a physical coverage area within a cell 102. Base stations 104 within a wireless communication system 100 may utilize antennas that concentrate the flow of power within a particular sector 112 of the cell 102. Such antennas may be referred to as directional antennas.

[0044] FIG. 2 illustrates various components that may be utilized in a wireless device 202. The wireless device 202 is an example of a device that may be configured to implement the various methods described herein. The wireless device 202 may be a base station 104 or a user terminal 106.

[0045] The wireless device 202 may include a processor 204 which controls operation of the wireless device 202. The processor 204 may also be referred to as a central processing unit (CPU). Memory 206, which may include both read-only memory (ROM) and random access memory (RAM), provides instructions and data to the processor 204. A portion of the memory 206 may also include non-volatile random access memory (NVRAM). The processor 204 typically performs logical and arithmetic operations based on program instructions stored within the memory 206. The instructions in the memory 206 may be executable to implement the methods described herein.

[0046] The wireless device 202 may also include a housing 208 that may include a transmitter 210 and a receiver 212 to allow transmission and reception of data between the wireless device 202 and a remote location. The transmitter 210 and receiver 212 may be combined into a transceiver 214. An antenna 216 may be attached to the housing 208 and electrically coupled to the transceiver 214. The wireless device 202 may also include (not shown) multiple transmitters, multiple receivers, multiple transceivers, and/or multiple antennas.

[0047] The wireless device 202 may also include a signal detector 218 that may be used in an effort to detect and quantify the level of signals received by the transceiver 214. The signal detector 218 may detect such signals as total energy, pilot energy per

pseudonoise (PN) chips, power spectral density, and other signals. The wireless device 202 may also include a digital signal processor (DSP) 220 for use in processing signals.

[0048] The various components of the wireless device 202 may be coupled together by a bus system 222, which may include a power bus, a control signal bus, and a status signal bus in addition to a data bus.

[0049] FIG. 3 illustrates an example of a transmitter 302 that may be used within a wireless communication system 100 that utilizes OFDM/OFDMA. Portions of the transmitter 302 may be implemented in the transmitter 210 of a wireless device 202. The transmitter 302 may be implemented in a base station 104 for transmitting data 306 to a user terminal 106 on a downlink 108. The transmitter 302 may also be implemented in a user terminal 106 for transmitting data 306 to a base station 104 on an uplink 110.

[0050] Data 306 to be transmitted is shown being provided as input to a serial-to-parallel (S/P) converter 308. The S/P converter 308 may split the transmission data into N parallel data streams 310.

[0051] The N parallel data streams 310 may then be provided as input to a mapper 312. The mapper 312 may map the N parallel data streams 310 onto N constellation points. The mapping may be done using some modulation constellation, such as binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), 8 phase-shift keying (8PSK), quadrature amplitude modulation (QAM), *etc.* Thus, the mapper 312 may output N parallel symbol streams 316, each symbol stream 316 corresponding to one of the N orthogonal subcarriers of the inverse fast Fourier transform (IFFT) 320. These N parallel symbol streams 316 are represented in the frequency domain and may be converted into N parallel time domain sample streams 318 by an IFFT component 320.

[0052] A brief note about terminology will now be provided. N parallel modulations in the frequency domain are equal to N modulation symbols in the frequency domain, which are equal to N mapping plus N -point IFFT in the frequency domain, which is equal to one (useful) OFDM symbol in the time domain, which is equal to N samples in the time domain. One OFDM symbol in the time domain, N_s , is equal to N_{cp} (the number of guard samples per OFDM symbol) + N (the number of useful samples per OFDM symbol).

[0053] The N parallel time domain sample streams 318 may be converted into an OFDM/OFDMA symbol stream 322 by a parallel-to-serial (P/S) converter 324. A guard insertion component 326 may insert a guard interval between successive OFDM/OFDMA symbols in the OFDM/OFDMA symbol stream 322. The output of the guard insertion component 326 may then be upconverted to a desired transmit frequency band by a radio frequency (RF) front end 328. An antenna 330 may then transmit the resulting signal 332.

[0054] FIG. 3 also illustrates an example of a receiver 304 that may be used within a wireless communication system 100 that utilizes OFDM/OFDMA. Portions of the receiver 304 may be implemented in the receiver 212 of a wireless device 202. The receiver 304 may be implemented in a user terminal 106 for receiving data 306 from a base station 104 on a downlink 108. The receiver 304 may also be implemented in a base station 104 for receiving data 306 from a user terminal 106 on an uplink 110.

[0055] The transmitted signal 332 is shown traveling over a wireless channel 334. When a signal 332' is received by an antenna 330', the received signal 332' may be downconverted to a baseband signal by an RF front end 328'. A guard removal component 326' may then remove the guard interval that was inserted between OFDM/OFDMA symbols by the guard insertion component 326.

[0056] The output of the guard removal component 326' may be provided to an S/P converter 324'. The S/P converter 324' may divide the OFDM/OFDMA symbol stream 322' into the N parallel time-domain symbol streams 318', each of which corresponds to one of the N orthogonal sub-carriers. A fast Fourier transform (FFT) component 320' may convert the N parallel time-domain symbol streams 318' into the frequency domain and output N parallel frequency-domain symbol streams 316'.

[0057] A demapper 312' may perform the inverse of the symbol mapping operation that was performed by the mapper 312, thereby outputting N parallel data streams 310'. A P/S converter 308' may combine the N parallel data streams 310' into a single data stream 306'. Ideally, this data stream 306' corresponds to the data 306 that was provided as input to the transmitter 302.

An Exemplary HARQ Transmission

[0058] To increase the reliability of communications between a base station 104 and a user terminal 106, one or more of the cells 102 of the system 100 may utilize a HARQ error control method. FIG. 3A illustrates a basic sequence of HARQ transmissions. A transmitter (TX) 302, such as the base station 104, broadcasts a first signal $s(1,t)$ containing a HARQ message via an antenna 330. An antenna 330' of a receiver (RX) 304, contained within a wireless device 202 such as a user terminal 106, receives the broadcast first signal as received signal $r(1,t)$ with a certain power $\sqrt{p(1)}$.

[0059] The first received signal $r(1,t)$ may be processed and decoded by the receiver 304. In decoding the message, error correction bits (*e.g.*, a checksum) generated for the data payload may be compared against error correction bits sent in the message. A match between the generated and transmitted error correction bits indicates the decoded message is correct, while a mismatch indicates one or more of the bits in the decoded message are not correct.

[0060] If the decoded message is not correct, the receiver 304 transmits a not-acknowledged (NAK) signal back to the transmitter 302. Assuming Chase combining, the transmitter 302, upon receiving the NAK signal, retransmits the same signal $s(q,t)$ containing the HARQ message again for the q^{th} iteration ($q=2$ in the illustrated example). This process is repeated until (at $q=N_q$) the decoded message is correct and the receiver 304 transmits an ACK signal to the transmitter 302, indicating successful reception and decoding of the correct HARQ message.

[0061] FIG. 4A illustrates an example block diagram of the transmitter 302 for some embodiments employing HARQ transmission. Assuming OFDM or OFDMA is utilized, a HARQ message may be encoded by an encoder 402, and the encoded bits may be mapped in signal mapping block 404 according to the desired digital modulation scheme by using a constellation diagram, for example.

[0062] In the subcarrier allocation block 406, the mapped signals may be allocated into assigned subcarriers according to their position on the constellation diagram. Usually, the assigned subcarriers comprise multiple subcarriers that may be distributed across several symbols along the time axis and several subcarriers across frequency axis. The subcarrier signals may be transformed into the time domain using an inverse

fast Fourier transform (IFFT) in the IFFT block 408, and the transformed signals may be transmitted into a wireless channel 334 using transmit circuitry 410 and an antenna 330.

[0063] FIG. 4B illustrates a block diagram of the receiver 304 capable of receiving the transmitted signals in certain embodiments. An antenna 330' may receive transmitted signals from the transmitter 302 and send them to an RF front end 412. The RF front end 412 may include any suitable circuits for receiving the transmitted signals and preparing them for digital signal processing, such as automatic gain control (AGC), a fast Fourier transform (FFT) block, a channel estimator, and a carrier-to-interference-and-noise ratio (CINR) estimator.

[0064] Signals from the RF front end 412 may then be sent to a signal processing block 414 for demodulating the signals and any HARQ combining that may need to be done for retransmitted messages. Thus, the signal processing block 414 may contain any suitable circuits for subcarrier deallocation, signal demapping, HARQ combining, and signal weighting. The processed signals may be sent from the signal processing block 414 to the channel decoder 416, which may decode the demapped, HARQ-combined encoded bits, output a decoded HARQ message, and check the error bits to see if the message was decoded correctly.

[0065] For some embodiments, portions of the RF front end 412, the signal processing block 414, and/or the channel decoder 416 may be implemented in a digital signal processor (DSP). The DSP may comprise logic for executing any suitable function described above, such as signal demapping, HARQ combining, and channel decoding.

An Exemplary Selective HARQ Combining Scheme

[0066] As previously described, certain embodiments of the present disclosure may select between different HARQ combiners, for example, implemented at different processing stages in the signal processing block 414 of a receiver. For example, one type of combiner may be positioned before the signal demapper and may be designated as a Type A combiner. Another type of combiner may be positioned after the signal demapper and may be considered as a Type B combiner. A third type of combiner may be positioned just before the channel decoder 416 and may be dubbed as a Type C

combiner. Depending on the particular embodiment, an OFDM/OFDMA receiver for HARQ transmission may include a combination of a Type A, Type B, and/or Type C combiner, with each type of combiner described in greater detail below.

[0067] The receiver 304 will include logic to select which type of combiner will be used, in some cases, for a given wireless channel. In such a selective HARQ (S-HARQ) combining scheme, one or more of the HARQ combiners may share a HARQ buffer or each HARQ combiner may have its own buffer. Non-selected combiners may be effectively disabled, for example, by bypassing that combiner with an alternate signal path.

[0068] Selection of the combiner for a certain HARQ channel may depend on various criteria, such as the modulation order of the transmitted signal and the headroom in the HARQ buffer(s). For example, if the HARQ transmission employs a high modulation order (e.g., 256 point quadrature amplitude modulation (256-QAM), 64-QAM, or 16-QAM), the Type A combiner may be selected. If the HARQ transmission uses a medium modulation order (e.g., 16-QAM or quadrature phase-shift keying (QPSK)), the Type B combiner may be selected. If the HARQ channel is associated with a low modulation order transmission (e.g., QPSK or binary phase-shift keying (BPSK)), the Type B or Type C combiner may be selected.

[0069] As portrayed by the provided examples, there may be some overlap between the different types of HARQ combiners for certain modulation orders. Another criterion for combiner selection may be the number of bits needed for the combined signals for each type of combiner, which affects buffer space consumption. The S-HARQ combining scheme may significantly reduce the required HARQ buffer size, when compared to conventional combining schemes, while still providing improved combining gain.

[0070] FIG. 5 is a block diagram 500 of a receiver with multiple combiners located at different processing stages capable of performing S-HARQ combining in accordance with certain embodiments of the present disclosure. Different embodiments may have different combinations of different types of combiners at different processing stages, which may share a single HARQ buffer or have multiple HARQ buffers.

[0071] In the illustrated embodiment, the receiver includes a Type A combiner 502, a Type B combiner 504, a Type C combiner 506, and a single HARQ buffer 508 common to all three combiners. In the illustrated example, the Type A combiner 502 is positioned before the signal demapper 510, while the Type B combiner 504 is positioned just after the signal demapper 510. The Type C combiner 506 may be positioned just before the channel decoder 416.

[0072] The description that follows for the S-HARQ combining scheme assumes that the receiver 304 is receiving the qth HARQ message and has already received q-1 HARQ messages before receiving the qth HARQ message. For the qth HARQ message, the transmitter 302 broadcasts a signal $s(q,t)$ for transmission across wireless channel h having properties $h(q,t)$ in the time domain. The receiver 304 receives the transmitted signal, which may have signal amplitude

$\sqrt{p(q)} r(q,t) = \sqrt{p(q)} (s(q,t) \otimes h(q,t) + n(q,t))$, where $p(q)$ is the measured power of the qth reception and $n(q,t)$ is an additive noise term.

[0073] The RF front end 412 of the receiver 304 may include an AGC 512 for the gain of the received signal such that all signals at the output of the AGC 512 may have the same amplitude. As feedback and control for the AGC 512, the RF front end 412 may contain a power measuring circuit 514 to measure $p(q)$ from the output of the AGC 512. The regulated output of the AGC 512, may be considered to be a normalized signal $r(q,t)$.

[0074] The RF front end 412 may also include an FFT block 516 for transforming the normalized received signal $r(q,t)$ from the time domain into the frequency domain.

The output of the FFT block 516 is $R_{fft}(q,i,n) = fft(r(q,i,t))$, where N_{fft} is the number of FFT points, $i = \dots, sym(i-1), sym(i), sym(i+1), \dots$; i^{th} OFDM symbol, $n = 1, 2, \dots, N_{fft}$, and $t = 1, 2, \dots, N_{fft}$. As shown in FIG. 5, the FFT block 516 may include a subcarrier

deallocation block to deallocate the subcarriers from the transformed signal to form signal $R_{sc}(q,u)$, where $u=1, 2, \dots, N_u$ and N_u is the number of all allocated subcarriers.

[0075] Furthermore, the $R_{fft}(q,i,n)$ signal or the $R_{sc}(q,u)$ signal may be sent to a channel estimator (CE) 518, which may estimate the channel for corresponding subcarriers and symbols. The output of the CE 518 may be $H_p(q,i,n)$ or, if the CE 518

includes a subcarrier deallocation block, Hsc(q,u) as shown. The Rfft(q,i,n) signal or the Rsc(q,u) signal may be sent to a Carrier to Interference-plus-Noise Ratio (CINR) estimator 520. The CINR estimator 520 may estimate the signal power (Psignal(q)), the interference power (Pinterference(q)), the noise power (Pnoise(q)), and the CINR(q) for the qth received signal. The CINR estimator 520 may also calculate a combined CINRc(q) as illustrated.

[0076] A weighting calculator 522 may calculate a weighting factor F(q) for the qth HARQ signal based on the power p(q) as measured by the power measuring circuit 514 or the CINR(q) as measured by the CINR estimator 520, for example. If a power weighting factor is to be calculated, F(q) may be a ratio of the power of the qth HARQ signal to the power of the first HARQ signal p(1) or a predetermined power p_{pd}. As a mathematical equation, the weighting factor may be expressed as

$$F(q) = \frac{p(q)}{p(1)} \quad \text{or} \quad F(q) = \frac{p(q)}{p_{pd}}$$

If a CINR weighting factor is to be calculated, F(q) may be a ratio of the CINR of the qth HARQ signal to the CINR of the first HARQ signal CINR(1) or a predetermined carrier-to-interference-and-noise ratio CINR_{pd}. As a mathematical equation, the weighting factor may be expressed as

$$F(q) = \frac{CINR(q)}{CINR(1)} \quad \text{or} \quad \frac{CINR(q)}{CINR_{pd}}$$

The purpose of the weighting factor as calculated by the weighting calculator 522 may be to equalize the power or the CINR of the qth received HARQ signal with the other previously received HARQ signals before combining. By using the weighting factor, noise or changes in the wireless channel between retransmissions that may affect the power of the received signal should not affect the HARQ combining. The use of the weighting factor is described in further detail below.

[0077] For a given receiver 304, there may be up to Nharqch HARQ channels, and each HARQ channel may be retransmitted up to Nharqrt times. If Nharqrt is large and an inappropriate type of combiner is selected, the HARQ buffer 508 may rapidly run out of space. The algorithm for selecting a combiner scheme may be designed to take this situation into consideration in an attempt to conserve buffer space.

[0078] For example, a HARQ message/channel manager 524 may determine the HARQ channel being decoded (e.g., by channel number) and the modulation order N_{mod} associated with the channel and may output these to an S-HARQ buffer controller 526 coupled to the HARQ buffer 508. The modulation order N_{mod} may equal 1 for BPSK, 2 for QPSK, 4 for 16-QAM, 6 for 64-QAM, and 8 for 256-QAM. The S-HARQ buffer controller 526 may use the channel number and the modulation order to determine the headroom in the HARQ buffer 508 and, based on these, select an appropriate type of HARQ combiner according to the description below.

[0079] The selected type of combiner may be per channel in the S-HARQ combining scheme. Thus, for any given channel, once a type of combiner has been selected, any subsequent retransmitted messages may use the same combiner type.

[0080] Selection between the different types of HARQ combiners may depend on a number of selection criteria and may involve tradeoffs between the required buffer size and performance. By considering the modulation order corresponding to each HARQ channel and the bit width of each HARQ combiner type, the required buffer size may be reduced.

[0081] In general, for lower modulation orders, such as BPSK, the required buffer size tends to increase from Type C to Type B to Type A, with Type A requiring a significantly larger buffer than Type B (i.e., $\text{ReqBufSizeType-C} < \text{ReqBufSizeType-B} \ll \text{ReqBufSizeType-A}$). For higher modulation orders, such as 256-QAM, the required buffer size generally tends to increase from Type A to Type B to Type C (i.e., $\text{ReqBufSizeType-A} < \text{ReqBufSizeType-B} < \text{ReqBufSizeType-C}$).

[0082] However, the bit error ratio (BER) performance for both lower and higher modulation orders is typically best with Type A followed by Type B and then by Type C HARQ combiners. In other words, the BER, or the likelihood of a bit misinterpretation due to electrical noise, is lowest with Type A HARQ combiners (i.e., $\text{BERType-A} < \text{BERType-B} < \text{BERType-C}$). Considering all of these tendencies, the HARQ buffer controller 526 may generally select the Type A combiner 502 for high modulation order transmissions, the Type B combiner 504 for medium modulation order transmissions, and the Type C combiner 506 for low modulation order transmissions.

[0083] Available buffer headroom may also be a factor in the selection criteria for determining which type of HARQ combiner to use according to the S-HARQ combining scheme. For example, the HARQ buffer controller 526 may consider the total number of supported HARQ channels and the amount of free space remaining in the buffer 508 to select an appropriate HARQ combiner for a given channel.

[0084] FIGs. 6A-6C illustrate the signal processing flow through the receiver 304 with the different types of combiners selected. The Type A combiner 502 is selected in FIG. 6A, the Type B combiner 504 is selected in FIG. 6B, and the Type C combiner 506 is selected in FIG. 6C. FIGs. 6A-6C also portray the relative differences among the different types of combiners in the required buffer size for storing the combined HARQ signals.

[0085] As illustrated in FIG. 6A, if the Type A combiner 502 is selected for a particular channel, HARQ combining may occur at the symbol level before demapping. For the q th received signal, $R_{sc}(q,u)$ may be combined with the deallocated subcarrier signal $RA(q-1,u)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined signal $RA(q,u)$. The output of the CE 518 $H_{sc}(q,u)$ may also be combined with the channel estimate signal $CA(q-1,u)$ from previous HARQ receptions in an effort to produce the HARQ combined channel estimate signal $CA(q,u)$. The Type A combiner 502 will be described in further detail below.

[0086] If the Type A combiner 502 is not selected for this particular channel then the outputs of the FFT block 516 and CE 518 may most likely not be combined with the signals $RA(q-1,u)$ and $CA(q-1,u)$ stored in the buffer from previous HARQ receptions for Type A HARQ combining. Instead, as illustrated in FIGs. 6B and 6C, the outputs of the FFT block 516 and CE 518 may bypass or be passed unchanged through the Type A combiner 502 such that $RA(q,u) = R_{sc}(q,u)$ and $CA(q,u) = H_{sc}(q,u)$.

[0087] The combined signals $RA(q,u)$ and $CA(q,u)$ may be saved to the HARQ buffer 508 in case the decoded HARQ message for the q th iteration is incorrect, thereby suggesting another retransmission. For some embodiments, the combined signals $RA(q,u)$ and $CA(q,u)$ may replace the previously stored signals in an effort to conserve memory space in the HARQ buffer 508. If the Type A combiner 502 is not selected for

this particular channel, the combined signals $RA(q,u)$ and $CA(q,u)$ need not be saved in the HARQ buffer 508.

[0088] The $RA(q,u)$ and $CA(q,u)$ signals may enter the demodulation/LLR (log likelihood ratio) block 528. In the signal demapper 510, the $RA(q,u)$ signal may be demapped according to a constellation diagram, for example, for the type of modulation associated with the particular channel. The output of the signal demapper 510 may be a demapped signal $Rm(q,b)$, where $b=1,2,\dots,N_b$, N_b is the number of coded bits for the HARQ message, and $N_b = N_u N_{\text{mod}}$. The channel state information (CSI) may be arranged in the CSI arranger 530 according to the corresponding signal demapping occurring in the signal demapper 510 for the particular channel. The CSI arranger 530 may accept $CA(q,u)$ as input and output an arranged CSI signal $Cm(q,b)$.

[0089] As illustrated in FIG. 6B, if the Type B combiner 504 is selected for a particular channel, HARQ combining may occur at the demodulated signal level after demapping. For the q th received signal, $Rm(q,b)$ may be combined with the demapped signal $RB(q-1,b)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined signal $RB(q,b)$. The output of the CSI arranger 530 $Cm(q,b)$ may also be combined with the CSI signal $CB(q-1,b)$ from previous HARQ receptions in an effort to produce the HARQ combined CSI signal $CB(q,b)$. The Type B combiner 504 will be described in further detail below.

[0090] If the Type B combiner 504 is not selected for this particular channel, then the outputs of the signal demapper 510 and CSI arranger 530 may most likely not be combined with the signals $RB(q-1,b)$ and $CB(q-1,b)$ stored in the buffer from previous HARQ receptions for Type B HARQ combining. Instead, as illustrated in FIGs. 6A and 6C, the outputs of the signal demapper 510 and CSI arranger 530 may bypass or be passed unchanged through the Type B combiner 504 such that $RB(q,b) = Rm(q,b)$ and $CB(q,b) = Cm(q,b)$.

[0091] The combined signals $RB(q,b)$ and $CB(q,b)$ may be saved to the HARQ buffer 508 in the event that the decoded HARQ message for the q th iteration is incorrect, thereby suggesting another retransmission. For some embodiments, the combined signals $RB(q,b)$ and $CB(q,b)$ may replace the previously stored signals in an effort to conserve memory space in the HARQ buffer 508. If the Type B combiner 504

is not selected for this particular channel, the combined signals $RB(q,b)$ and $CB(q,b)$ need not be saved in the HARQ buffer 508.

[0092] As depicted, the combined signals $RB(q,b)$ and $CB(q,b)$ signals may be input to a signal weighting block 532. In the signal weighting block 532, the demodulated received signal $RB(q,b)$ may be adjusted, or weighted, by at least the corresponding CSI signal $CB(q,b)$ to form an output weighted signal $Rw(q,b)$. For some embodiments, the adjustment may include multiplying the demodulated received signal $RB(q,b)$ and the corresponding CSI signal $CB(q,b)$. Also for some embodiments, the $CINR_c(q)$ and/or a tuning factor F_{tune} may be employed when weighting the demodulated signal $RB(q,b)$. The tuning factor may be a function of the modulation type, the bit position of modulation symmetry, and the $CINR_c$ and may have a default value of 1. Thus, the weighted signal $Rw(q,b)$ may be expressed as

$$R_w(q,b) = R_B(q,b) \times C_B(q,b) \times 2 \times CINR_c(q) \times F_{tune}.$$

[0093] As illustrated in FIG. 6C, if the Type C combiner 506 is selected for a particular channel, HARQ combining may occur at the LLR or soft-bit level just before channel decoding. For the q th received signal, $Rw(q,b)$ may be combined with the weighted signal $Rw(q-1,b)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined signal $RC(q,b)$.

[0094] By combining after signal weighting in the signal processing block 414, the weighted signal $Rw(q,b)$ may be combined with previous signals, and the CSI signals need not be processed. In this manner, the HARQ buffer 508 need not store CSI information, and the required buffer size may be reduced when Type C HARQ combining is utilized, especially for HARQ channels with low modulation order modulation schemes (e.g., BPSK). The HARQ buffer 508 may also store the weighting factor $F(q)$ for the q th HARQ signal for normalization purposes when the Type C HARQ combiner 506 is selected. The Type C combiner 506 will be described in further detail below.

[0095] If the Type C combiner 506 is not selected for this particular channel, then the output of the signal weighting block 532 may most likely not be combined with the weighted signal $RC(q-1,b)$ stored in the buffer 508 from previous HARQ receptions for Type C HARQ combining. Instead, as illustrated in FIGs. 6A and 6B, the outputs of the

signal weighting block 532 may bypass or be passed unchanged through the Type C combiner 506 such that $RC(q,b) = R_w(q,b)$.

[0096] The combined signal $RC(q,b)$ may be saved to the HARQ buffer 508 lest the decoded HARQ message for the q th iteration is incorrect, thereby suggesting another retransmission. For some embodiments, the combined signal $RC(q,b)$ may replace the previously stored signal in an effort to conserve memory space in the HARQ buffer 508. If the Type C combiner 506 is not selected for this particular channel, the combined signal $RC(q,b)$ need not be saved in the HARQ buffer 508.

[0097] The combined signal $RC(q,b)$ may be sent from the signal processing block 414 to the channel decoder 416, which may decode the demapped, HARQ-combined encoded bits and output an interpreted HARQ message for the q th iteration. Based on the correctness of the q th HARQ message, the receiver 304 may transmit an ACK or a NAK signal to the transmitter 302 as described above.

[0098] FIG. 7 illustrates a flow diagram of example operations 600 for selective hybrid automatic repeat-request (S-HARQ). The operations begin, at 602, by receiving a HARQ message through a certain wireless channel. At 604, the status of HARQ buffer 508 may be checked to determine the headroom. If there is enough headroom at 606, the type of HARQ combiner may be selected at 608 for the wireless channel. The HARQ combining type may depend on one or more of the selection criteria described above. However, if there is not enough headroom, the Type C combiner 506 may be automatically selected as shown.

[0099] Of course, if this is the first transmission of the HARQ signal ($q=1$), HARQ combination need not be performed, so selection of the HARQ combining type should not matter in this case. However, in the event that retransmission is required because the decoded message is incorrect, the first transmission of the HARQ signal may most likely follow the desired type of HARQ combiner for the particular channel in order to save the signal at the appropriate reception stage to the HARQ buffer 508 for HARQ combination in subsequent iterations.

[0100] If the Type A combiner 502 is selected at 608, then the previously combined signal that was last saved to the HARQ buffer 508 may be accessed at 610. At 612, the accessed signal may be combined with the received HARQ signal. The new combined

signal may be saved to the HARQ buffer 508 at 614 and normalized at 616. The normalized signal may be demapped according to the constellation diagram for the particular channel at 618. At 620, the demapped signal may be weighted with the CSI and sent to the channel decoder 416.

[0101] If the Type B combiner 504 is selected at 608, then the HARQ message may be equalized at 622. At 624, the equalized signal may be demapped according to the constellation diagram for the particular channel. The previously combined signal that was last saved to the HARQ buffer 508 may be accessed at 626. At 628, the accessed signal may be combined with the demapped HARQ signal. The new combined signal may be saved to the HARQ buffer 508 at 630 and normalized at 632. The normalized signal may be weighted with the CSI at 634, and the weighted signal may be sent to the channel decoder 416.

[0102] If the Type C combiner 506 is selected at 608, then the HARQ signal may be equalized at 636. At 638, the equalized signal may be demapped according to the constellation diagram for the particular channel, and the demapped signal may be weighted with the CSI at 640. The previously combined signal that was last saved to the HARQ buffer 508 may be accessed at 642. At 644, the accessed signal may be combined with the weighted HARQ signal. The new combined signal may be saved to the HARQ buffer 508 at 646 and normalized at 648. The normalized signal may be sent to the channel decoder 416.

[0103] At 650, the HARQ combined signal from the selected type of HARQ combiner may be decoded in the channel decoder 416. If the designated bits of the HARQ message—such as the error detection (ED) bits, which may include cyclic redundancy check (CRC) bits, and the forward error correction (FEC) bits—are correct, then the message may be interpreted to be successfully transmitted and received. The particular HARQ channel may be removed from the HARQ buffer 508 at 654, and the operations may repeat with the reception of a new HARQ message from a different wireless channel at 602. However, if any of the designated bits of the HARQ message are incorrect, the receiver 304 may send a request to the transmitter 302 for a retransmission of the HARQ message as described above, and the operations may repeat beginning with 602 for the same channel.

An Exemplary TYPE A Combiner

[0104] Referring now to FIG. 8, an example Type A combiner for combining multiple HARQ signals before signal demapping is illustrated. The block diagram 700 of FIG. 8 may be considered as a fixed Type A HARQ combining scheme. However, the details of the Type A HARQ combiner 702 within the dotted line of FIG. 8 may be included in the Type A combiner 502 of the S-HARQ combining scheme shown in FIG. 5 for some embodiments.

[0105] This scheme, where the combining is performed before constellation demapping, may use a maximum ratio combining (MRC) scheme in an effort to provide increased diversity combining gain. This may be done recursively by adding incoming HARQ signals with weighting factors. The weighting factors may be different for each HARQ reception and may be extracted from the CINR (or power) of the incoming HARQ signal of each reception. For the weighting factor, the CINR (or power) of the first reception or a predetermined CINR (or power) may be considered as a reference, and the CINR (or power) of each reception may be normalized by the reference. To avoid noise enhancement, all combined HARQ signals may be magnitude-equalized near the final combining stage of every reception. The resulting signal may be weighted with combined CSI and the CINR before channel decoding.

[0106] Many of the blocks in the block diagram 700 of FIG. 8 are similar to the block diagram 500 of FIG. 5 and will not be described again. Similar to FIG. 5, the description that follows for the Type A HARQ combining scheme assumes that the receiver 304 is receiving the q^{th} HARQ message and has already received $q-1$ HARQ messages before receiving the q^{th} HARQ message.

[0107] The output of the FFT block 516 $R_{fft}(q,i,n)$ may be sent to a first subcarrier deallocation block 704 in an effort to deallocate the subcarriers from the transformed signal to form signal $R_{sc}(q,u)$, where $u=1,2,\dots,N_u$ and N_u is the number of all allocated subcarriers. The subcarrier deallocation may be performed based on the same permutation used in transmitting the HARQ message. Furthermore, the $R_{fft}(q,i,n)$ signal may be sent to the channel estimator (CE) 518, which may estimate the channel for corresponding subcarriers and symbols. The output of the CE 518 $H_p(q,i,n)$ may be sent to a second subcarrier deallocation block 706 in an effort to deallocate the subcarriers from the channel estimation to form signal $H_{sc}(q,u)$ as shown.

[0108] The deallocated $R_{sc}(q,u)$ and $H_{sc}(q,u)$ signals may be sent to the Type A HARQ combiner 702. In a signal equalizer/combiner 708, the power or the CINR of $R_{sc}(q,u)$ may be equalized with that of the other previously received HARQ signals before combining based on the weighting factor as calculated by the weighting calculator 522. By using the weighting factor, noise or changes in the wireless channel between retransmissions that may affect the power of the received signal should not affect the HARQ combining. The output of signal equalizer/combiner 708 $R_{ae}(q,u)$ may be calculated as $R_{ae}(q,u) = F(q)R_{sc}(q,u)H_{sc}(q,u)^*$, where $H_{sc}(q,u)^*$ is the complex conjugate of $H_{sc}(q,u)$ and $F(q)$ is the weighting factor as described above. In a CSI estimator/combiner 710, the power or the CINR of $H_{sc}(q,u)$ may be equalized with that of the other prior channel estimations before combining based on the weighting factor as calculated by the weighting calculator 522. The output of CSI estimator/combiner 710 $C_{ae}(q,u)$ may be calculated as $C_{ae}(q,u) = F(q)|H_{sc}(q,u)|^2$.

[0109] For the q^{th} received signal, the equalized signal $R_{ae}(q,u)$ may be combined with the Type A combined signal $R_{ah}(q-1,u)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined signal $R_{ah}(q,u)$ according to the equation $R_{ah}(q,u) = R_{ae}(q,u) + R_{ah}(q-1,u)$ in a signal HARQ combiner and buffer block 712. In a CSI HARQ combiner and buffer block 714, the output of the CSI estimator/combiner 710 $C_{ae}(q,u)$ may also be combined with the combined CSI signal $C_{ah}(q-1,u)$ from previous HARQ receptions in an effort to produce the HARQ combined CSI signal $C_{ah}(q,u)$ according to the equation $C_{ah}(q,u) = C_{ae}(q,u) + C_{ah}(q-1,u)$.

[0110] The output of the signal HARQ combiner and buffer 712 $R_{ah}(q,u)$ may be normalized in a signal HARQ normalizer 716 by a suitable normalization factor to form normalized signal $R_{an}(q,u)$. For some embodiments, the normalization factor may be the combined CSI signal $C_{ah}(q,u)$ for the q^{th} iteration, such that the normalized signal may be calculated according to the equation $R_{an}(q,u) = R_{ah}(q,u)/C_{ah}(q,u)$. The output of the CSI HARQ combiner and buffer 714 $C_{ah}(q,u)$ may also be normalized in a CSI HARQ normalizer 718 by a suitable normalization factor to form normalized signal $C_{an}(q,u)$. For some embodiments, the normalization factor may be the HARQ sequence number q , such that the normalized signal may be calculated according to the equation

$C_{an}(q,u) = C_{ah}(q,u)/q$. For other embodiments, the normalization factor for combined CSI normalization may be the power $p(q)$ of the q^{th} iteration.

[0111] Therefore, to summarize the signal output of the Type A HARQ combiner 702, the normalized output signal $R_{an}(q,u)$ may be calculated from the signal input $R_{sc}(q,u)$, the channel estimation input $H_{sc}(q,u)$, and the weighting factor $F(q)$ for any q^{th} iteration according to the following equation:

$$R_{an}(q,u) = \frac{\sum_{q=1}^{N_q} (F(q) R_{sc}(q,u) H_{sc}(q,u)^*)}{\sum_{q=1}^{N_q} (F(q) |H_{sc}(q,u)|^2)}$$

In a similar manner, the CSI output of the Type A HARQ combiner 702 may be calculated from the channel estimation input $H_{sc}(q,u)$ and the weighting factor $F(q)$ for any q^{th} iteration according to the following equations for some embodiments:

$$C_{an}(q,u) = \frac{\sum_{q=1}^{N_q} (F(q) |H_{sc}(q,u)|^2)}{N_q}$$

or

$$C_{an}(q,u) = PowerNorm \left(\sum_{q=1}^{N_q} (F(q) |H_{sc}(q,u)|^2) \right)$$

[0112] The remaining blocks of the Type A HARQ combiner 702 may function similarly to corresponding blocks in the block diagram of FIG. 5, where $R_A(q,u) = R_{an}(q,u)$, $C_A(q,u) = C_{an}(q,u)$, and the other types of HARQ combiners are bypassed.

An Exemplary TYPE B Combiner

[0113] Referring now to FIG. 9, a Type B HARQ diversity combining scheme for OFDM/OFDMA systems, where the combining of multiple HARQ signals is done after signal demapping, is illustrated. The block diagram 800 of FIG. 9 may be considered as a fixed Type B HARQ combining scheme. However, the details of the Type B HARQ combiner 802 within the dotted line of FIG. 9 may be included in the Type B combiner 504 of the S-HARQ combining scheme shown in FIG. 5 for some embodiments. This scheme, where the combining is performed after constellation demapping, may use an

MRC scheme in an effort to provide increased diversity combining gain. This may be done recursively by adding incoming HARQ signals with weighting factors as described above. The weighting factors may be different for each HARQ reception and may be extracted from the CINR (or power) of the incoming HARQ signal of each reception. Incoming HARQ signals may be equalized, demapped, weighted with the weighting factor, and added recursively. The resulting signal may be normalized by the combined CSI at or near the final stage of every reception and weighted with the combined CSI and CINR before channel decoding.

[0114] Many of the blocks in the block diagram 800 of FIG. 9 are similar to the block diagrams 500 and 700 of FIGs. 5 and 8, respectively, and will not be described again below. Similar to FIG. 5, the description that follows for the Type B HARQ combining scheme assumes that the receiver 304 is receiving the q^{th} HARQ message and has already received $q-1$ HARQ messages before receiving the q^{th} HARQ message.

[0115] Of note, the output $C_{be}(q,u)$ of the CSI estimator/combiner block 710 may not depend on the weighting factor $F(q)$ and may be calculated as

$C_{be}(q,u) = |H_{sc}(q,u)|^2$. $C_{be}(q,u)$ may be used in equalizing the output $R_{sc}(q,u)$ of the first subcarrier deallocation block 704. In a signal equalizer/combiner 804, $R_{sc}(q,u)$ may be equalized by the CSI before HARQ combining. The output of the signal equalizer/combiner 804 $R_{be}(q,u)$ may be calculated as

$$R_{be}(q,u) = \frac{R_{sc}(q,u)H_{sc}(q,u)^*}{C_{be}(q,u)}$$

where $H_{sc}(q,u)^*$ is the complex conjugate of $H_{sc}(q,u)$. The output of the signal equalizer/combiner 804 may undergo signal demapping in the signal demapper 510 to form signal $R_{bm}(q,b)$, and the estimated CSI $C_{be}(q,u)$ may be processed in a similar fashion in the CSI arranger 530 to form signal $C_{bm}(q,b)$.

[0116] The demodulated outputs $R_{bm}(q,b)$ and $C_{bm}(q,b)$ signals may be sent to the Type B HARQ combiner 802. For the q^{th} received signal, the demodulated CSI signal $C_{bm}(q,b)$ may be multiplied by the weighting factor $F(q)$ and combined with the Type B combined signal $C_{bh}(q-1,b)$ from previous HARQ receptions in an effort to produce the HARQ combined CSI signal $C_{bh}(q,b)$ according to the equation

$C_{bh}(q, b) = F(q)C_{bm}(q, b) + C_{bh}(q-1, b)$ in a CSI HARQ combiner and buffer block 806.

[0117] The demodulated output $R_{bm}(q, b)$ may be multiplied with the weighting factor $F(q)$ and the demodulated CSI signal $C_{bm}(q, b)$ and combined with the combined Type B combined signal $R_{bh}(q-1, b)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined signal $R_{bh}(q, b)$ according to the equation $R_{bh}(q, b) = F(q)C_{bm}(q, b)R_{bm}(q, b) + R_{bh}(q-1, b)$. The calculation of $R_{bh}(q, b)$ may be performed in a signal HARQ combiner and buffer block 808.

[0118] The output of the CSI HARQ combiner and buffer 806 $C_{bh}(q, b)$ may be normalized in a CSI HARQ normalizer 810 by a suitable normalization factor to form normalized signal $C_{bn}(q, b)$. For some embodiments, the normalization factor may be the HARQ sequence number q , such that the normalized signal may be calculated according to the equation $C_{bn}(q, b) = C_{bh}(q, b)/q$. For other embodiments, the normalization factor for combined CSI normalization may be the power $p(q)$ of the q^{th} iteration. The output of the signal HARQ combiner and buffer 808 $R_{bh}(q, b)$ may also be normalized in a signal HARQ normalizer 812 by a suitable normalization factor to form normalized signal $R_{bn}(q, b)$. For some embodiments, the normalization factor may be the combined CSI signal $C_{bh}(q, b)$ for the q^{th} iteration, such that the normalized signal may be calculated according to the equation $R_{bn}(q, b) = R_{bh}(q, b)/C_{bh}(q, b)$.

[0119] Therefore, to summarize the recursive signal output of the Type B HARQ combiner 802 for the q^{th} iteration, the normalized output signal $R_{bn}(q, b)$ may be calculated from the demapped signal input $R_{bm}(q, b)$, the CSI signal input $C_{bm}(q, b)$, and the weighting factor $F(q)$ according to the following equation:

$$R_{bn}(q, b) = \frac{\sum_{q=1}^{N_q} \left(F(q) R_{bm}(q, b) |H_{bm}(q, b)|^2 \right)}{\sum_{q=1}^{N_q} \left(F(q) |H_{bm}(q, b)|^2 \right)}$$

In a similar manner, the recursive CSI output of the Type B HARQ combiner 802 may be calculated from the CSI signal input $C_{bm}(q, b)$ and the weighting factor $F(q)$ for any q^{th} iteration according to the following equations for some embodiments:

$$C_{bn}(q,b) = \frac{\sum_{q=1}^{N_q} \left(F(q) |C_{bm}(q,b)|^2 \right)}{N_q}$$

or

$$C_{bn}(q,b) = \text{PowerNorm} \left(\sum_{q=1}^{N_q} \left(F(q) |C_{bm}(q,b)|^2 \right) \right)$$

[0120] The remaining blocks of the Type B HARQ combiner 802 may function similarly to corresponding blocks in the block diagram of FIG. 5, where $R_B(q,b) = R_{bn}(q,b)$, $C_B(q,b) = C_{bn}(q,b)$, and the other types of HARQ combiners are bypassed.

An Exemplary TYPE C Combiner

[0121] Referring now to FIG. 10, a Type C HARQ diversity combining scheme for OFDM/OFDMA systems, where the combining of multiple HARQ signals is done before channel decoding, is illustrated. The block diagram 900 of FIG. 10 may be considered as a fixed Type C HARQ combining scheme. However, the details of the Type C HARQ combiner 902 within the dotted line of FIG. 10 may be included in the Type C combiner 506 of the S-HARQ combining scheme shown in FIG. 5 for some embodiments.

[0122] The Type C combining scheme may be done recursively by adding incoming HARQ signals with weighting factors as described above. The weighting factors may be different for each HARQ reception and may be extracted from the CINR (or the power) of the incoming HARQ signal of each reception. Incoming HARQ signals may be equalized, demapped, weighted by the CSI and CINR of each reception. The resulting signal may be adjusted by the weighting factor, added recursively, and normalized by the combined weighting factor before channel decoding.

[0123] Many of the blocks in the block diagram 900 of FIG. 10 are similar to the block diagrams 500 and 800 of FIGs. 5 and 9, respectively, and will not be described again below. Similar to FIG. 5, the description that follows for the Type C HARQ combining scheme assumes that the receiver 304 is receiving the q^{th} HARQ message and has already received $q-1$ HARQ messages before receiving the q^{th} HARQ message.

[0124] For the Type C HARQ combining scheme of FIG. 10, rather than sending the output of the signal equalizer/combiner 804 $R_{cm}(q,b) = R_{bm}(q,b)$ and the output of the

CSI arranger 530 $C_{cm}(q,b) = C_{bm}(q,b)$ to be combined, these signals may be sent to the signal weighting block 532. In the signal weighting block 532, the demodulated received signal $R_{cm}(q,b)$ may be adjusted by at least the corresponding CSI signal $C_{cm}(q,b)$ to form an output weighted signal $R_{cc}(q,b)$. For some embodiments, the adjustment may include multiplying the demodulated received signal $R_{cm}(q,b)$ with the corresponding CSI signal $C_{cm}(q,b)$, the $CINR(q)$, and a tuning factor F_{tune} according to the expression $R_{cc}(q,b) = R_{cm}(q,b) \times C_{cm}(q,b) \times 2 \times CINR(q) \times F_{tune}$.

[0125] The weighted output signal $R_{cc}(q,b)$ may be sent to the Type C HARQ combiner 902. For the q^{th} received signal, $R_{cc}(q,b)$ may be multiplied by the weighting factor $F(q)$ and combined with the Type C combined signal $R_{cc}(q-1,b)$ from previous HARQ receptions in an effort to produce the HARQ combined signal $R_{ch}(q,b)$ according to the equation $R_{ch}(q,b) = F(q)R_{cc}(q,b) + R_{ch}(q-1,b)$ in a signal HARQ combiner and buffer block 904. The weighting factor $F(q)$ may be combined with the Type C combined CSI signal $C_{ch}(q-1,b)$ from previous HARQ receptions where the decoded message was incorrect in an effort to produce the HARQ combined CSI signal $C_{ch}(q,b)$ according to the equation $C_{ch}(q,b) = F(q) + C_{ch}(q-1,b)$. The calculation of $C_{ch}(q,b)$ may be performed in a CSI HARQ combiner and buffer block 906.

[0126] The output of the signal HARQ combiner and buffer 904 $R_{ch}(q,b)$ may be normalized in a signal HARQ normalizer 908 by a suitable normalization factor to form normalized signal $R_{cn}(q,b)$. For some embodiments, the normalization factor may be the combined CSI signal $C_{ch}(q,b)$ for the q^{th} iteration, such that the normalized signal may be calculated according to the equation $R_{cn}(q,b) = R_{ch}(q,b)/C_{ch}(q,b)$.

[0127] Therefore, to summarize the recursive signal output of the Type C HARQ combiner 902 for the q^{th} iteration, the normalized output signal $R_{cn}(q,b)$ may be calculated from the weighted signal input $R_{cc}(q,b)$ and the weighting factor $F(q)$ according to the following equation:

$$R_{cn}(q,b) = \frac{\sum_{q=1}^{N_q} (F(q) R_{cc}(q,b))}{\sum_{q=1}^{N_q} F(q)}$$

[0128] The remaining blocks of the Type B HARQ combiner 902 may function similarly to corresponding blocks in the block diagram of FIG. 5, where $R_C(q,b) = R_{cn}(q,b)$.

An Exemplary Forward Shifting HARQ Combining Scheme

[0129] For the selective hybrid automatic repeat-request (S-HARQ) combining scheme described above, a different type of HARQ combiner (*e.g.*, Type A, Type B, or Type C) may be selected for each wireless channel in the HARQ buffer 508, based on the selection criteria also described above. This type of static selection, where a particular wireless channel uses the same type of HARQ combiner until it is removed from the HARQ buffer, may work satisfactorily for many embodiments, offering a reduction in the required buffer size while providing increased combining gain.

[0130] However, the number of wireless channels within the HARQ buffer 508 may vary over time, depending on such factors as the noise in the channel, which may corrupt the HARQ transmission and lead to an incorrect message after decoding. Furthermore, because the selection of a HARQ combiner may involve tradeoffs between the required buffer size and the BER performance, it may be advantageous to dynamically select the HARQ combining scheme to be used for any q^{th} iteration to increase the BER performance without saturating the HARQ buffer 508.

[0131] Therefore, as illustrated in FIG. 11, a forward shifting (FS) HARQ combining scheme for OFDMA systems may be employed. For a particular wireless channel in FS HARQ, one of three HARQ combiners (*e.g.*, Type A, Type B, or Type C combiners 502, 504, 506) may be selected and used to combine retransmitted signals of the HARQ channel depending on the condition of the HARQ buffer 1100.

[0132] For example, if the buffer 1100 has suitable headroom, all active HARQ channels should use the Type A HARQ combiner 502, thereby encouraging the highest BER performance (*i.e.*, the lowest bit error ratios) without compromising the buffer storage space. This is illustrated in FIG. 11 and FIG. 12A where the Type A HARQ combiner 502 has been selected for all five channels (Ch1-5) in the HARQ buffer 1100, no matter the modulation order.

[0133] As the number of active channels increases, the buffer 1100 may eventually become full. Once the buffer 1100 becomes full or nearly full, forward shifting of the combiner type may be performed by using the Type B HARQ combiner 504 instead of the Type A HARQ combiner 502 for one or more of the active HARQ channels in an effort to decrease the allocated buffer space, thereby providing more headroom.

[0134] FIGs. 12A-B illustrate the contents of the HARQ buffer when forward shifting from one type of HARQ combining scheme to another. As illustrated in the example of FIG. 12A, Channel 4 and Channel 5 have been forward shifted to use the Type B HARQ combiner 504 instead of the Type A HARQ combiner 502 in an effort to make room for a new channel (Channel 6) in the updated HARQ buffer 1200.

[0135] As the number of active channels continues to increase, forward shifting may have allowed these new channels to have space in the updated HARQ buffer 1200 and use the Type A HARQ combiner 502, such as Channel 7 in the HARQ buffer 1202 of FIG. 12B. As the buffer capacity is approached, however, more channels may be forward shifted to use the Type B HARQ combiner 504 and/or one or more of the channels using the Type B HARQ combiner 504 may be forward shifted to use the Type C HARQ combiner 506 in an effort to increase the buffer headroom.

[0136] This scenario is illustrated in the HARQ buffer 1204 of FIG. 12B where Channel 5 has been forward shifted from using the Type B HARQ combiner 504 to using the Type C HARQ combiner 506. Such forward shifting has allowed for new channels (*e.g.*, Channel 8 and Channel 9) to have space in the HARQ buffer 1204. For some instances where the Type A HARQ combiner 502 had been used, the channel may jump directly to using the Type C HARQ combiner 506 without going through the intermediate step of using the Type B HARQ combiner 504 for an iteration of HARQ combining.

[0137] The active channel(s) selected for forward shifting—as well as the type of HARQ combiner selected—may depend, for example, on the modulation order of the channel and/or the bit width of each HARQ combiner type. By dynamically forward shifting the HARQ combining type used for a particular channel, the BER performance and combining gain may be increased without saturating the HARQ buffer 508. For some embodiments, the selection of the HARQ channel(s) for forward shifting may depend on any combination of suitable criteria, such as the modulation order, the

channel state information (CSI), the channel quality, the number of the HARQ transmission, and the decoding results for each HARQ channel. By considering other factors in addition to the modulation order when dynamically forward shifting the HARQ combining type used for a certain channel, the BER performance may be increased still further, while the memory requirements may be further reduced.

[0138] FIGs. 13A-B illustrate a flow diagram of example operations 1300 for FS HARQ. The operations begin at 1302 by receiving a HARQ message through a certain wireless channel. Whether this is the first transmission of the HARQ signal ($q=1$) may be checked at 1304, and if this is not the first transmission, then the previous HARQ combining type (pHT) (*i.e.*, the type of HARQ combiner used for the $q-1$ iteration) may be checked at 1306. At 1308, the status of the HARQ buffer 508 may be checked to determine the headroom, and based on this information, the type of HARQ combiner for the current transmission (the current HARQ type, or cHT) may be selected at 1310 for the particular wireless channel. The cHT for forward shifting may depend primarily on the buffer headroom and secondarily on the modulation order of the channel, for example, and the bit width of the HARQ combiner type, as described above.

[0139] If the previous HARQ type was Type A (pHT = A) or the current HARQ type selected is Type A (cHT = A) at 1312, then the last saved HARQ signal may be accessed at 1314. This accessed signal may be combined with the received HARQ message at 1316. If cHT = A at 1318, then the combined signal may be saved to the HARQ buffer 508 at 1320 for Type A HARQ combining in subsequent iterations. Otherwise, if cHT $\neq$ A, the operation at 1320 may be skipped.

[0140] At 1322 of FIG. 13A, the combined signal may be normalized. Signal demapping may be performed at 1324 as described above. If cHT = B at 1326, then the demapped signal may be saved to the HARQ buffer 508 at 1328 for Type B HARQ combining in subsequent iterations. Otherwise, if cHT $\neq$ B, the operation at 1328 may be skipped.

[0141] The demapped signal may be weighted at step 1330 as described above. If cHT = C at 1332, then the weighted signal may be saved to the HARQ buffer 508 at 1334 for Type C HARQ combining in subsequent iterations. Otherwise, if cHT $\neq$ C, the operation at 1334 may be skipped.

[0142] If the previous HARQ type was Type B ($pHT = B$) or the current HARQ type selected is Type B ($cHT = B$) at 1336, then the received HARQ message may be equalized at 1338, and signal demapping may be performed at 1340 as described above. The last saved HARQ signal may be accessed at 1342. This accessed signal may be combined with the received, demapped HARQ signal at 1344. If $cHT = B$ at 1346, then the combined signal may be saved to the HARQ buffer 508 at 1348 for Type B HARQ combining in subsequent iterations. Otherwise, if $cHT \neq B$, the operation at 1348 may be skipped.

[0143] At 1350 of FIG. 13B, the combined signal may be normalized, and signal weighting may be performed at 1354 as described above. If $cHT = C$ at 1356, then the demapped signal may be saved to the HARQ buffer 508 at 1358 for Type C HARQ combining in subsequent iterations. Otherwise, if $cHT \neq C$, the operation at 1358 may be skipped.

[0144] If neither the previous nor the current HARQ type selected is Type A or B (*e.g.*, $pHT = C$ and $cHT = C$), then the received HARQ message may be equalized at 1360, signal demapping may be performed at 1362, and the demapped signal may be weighted at 1364 as described above. The last saved HARQ signal may be accessed at 1366. This accessed signal may be combined with the weighted HARQ signal at 1368. The combined signal may be saved to the HARQ buffer 508 at 1370 for Type C HARQ combining in subsequent iterations and normalized at 1372.

[0145] At 1374, the signal from one of the three paths in the forward shifting HARQ flow diagram of FIGs. 13A-B may be decoded in the channel decoder 416. If the designated bits of the HARQ message (*e.g.*, the ED bits and the FEC bits) are correct at 1376, then the message may be interpreted to be successfully transmitted and received. The particular HARQ channel may be removed from the HARQ buffer 508 at 1378. However, if any of the designated bits of the HARQ message are incorrect, the previous HARQ combining type may be made equal to the current HARQ combining type ($pHT = cHT$) at 1380.

[0146] If there is enough headroom for a new HARQ channel at 1382, the operations may repeat beginning with 1302, most likely for a different wireless channel. If there is not enough headroom for a new HARQ channel at 1382, then an offline forward shift to a different HARQ combining type with reduced buffer storage

requirements may be performed at 1384 for the particular channel being processed in an effort to increase the buffer headroom. The offline shift at 1384 may include accessing the last saved HARQ signal for the selected wireless channel from the HARQ buffer 508; converting the accessed signal from Type A to Type B or C or from Type B to Type C; and saving the converted signal to the HARQ buffer 508 for subsequent iterations using the updated type of HARQ combining scheme from the conversion. Following the offline shift at 1384, the operations may repeat beginning with the reception of a HARQ message at 1302.

An Exemplary Reverse Shifting HARQ Combining Scheme

[0147] Again, because the number of wireless channels within the HARQ buffer may vary over time and the selection of a HARQ combiner may involve tradeoffs between the required buffer size and the BER performance, it may be advantageous to dynamically select the HARQ combining scheme to be used for the q^{th} iteration to increase the BER performance without saturating the HARQ buffer 508. With forward shifting as described above, the number of HARQ channels in the buffer may be increased by dynamically selecting a type of HARQ combiner that requires less storage space for appropriate channels, generally those with lower modulation order first and those with higher modulation order later if more headroom in the buffer is desired.

[0148] However, as HARQ channels are removed from the buffer once the decoded message is correct, the headroom in the buffer should increase. In an effort to increase the BER performance (*i.e.*, lower the BER), the type of HARQ combiner selected for one or more channels may be reverted back to a type that requires more storage space, but provides a lower BER.

[0149] Therefore, as illustrated in FIG. 14, a reverse shifting (RS) HARQ combining scheme for OFDMA systems may be employed in conjunction with the FS HARQ combining scheme, leading to a forward and reverse shifting hybrid automatic repeat-request (FRS HARQ) scheme. As used herein, reverse shifting generally refers to selecting a type of HARQ combiner that appears earlier in the reception processing path. For a particular wireless channel in RS HARQ, one of three HARQ combiners (*e.g.*, Type A, Type B, or Type C combiners 502, 504, 506) may be selected and used to combine retransmitted signals of the HARQ channel depending on the condition of the

HARQ buffer 1400. In reverse shifting, channels with higher modulation orders may generally have their HARQ combiner types adjusted first, while channels with lower modulation orders may be adjusted later.

[0150] As the number of active channels decreases, the HARQ buffer may eventually have enough headroom to be able to adjust the type of HARQ combiner used for a particular channel. Reverse shifting of the combiner type may be performed by using the Type B HARQ combiner 504 instead of the Type C HARQ combiner 506 for one or more of the active HARQ channels in an effort to decrease the BER, thereby taking up more space in the buffer.

[0151] FIGs. 15A-B illustrate the contents of the HARQ buffer when reverse shifting from one type of HARQ combining scheme to another. As illustrated in the example of FIG. 15A, Channel 6 from the HARQ buffer 1500 has been reverse shifted to use the Type B HARQ combiner 504 instead of the Type C HARQ combiner 506 in an effort to lower the BER and fill more of the usable space in the HARQ buffer 1500. After reverse shifting, there may be still more headroom in the updated HARQ buffer 1400, and a new channel (*e.g.*, Channel 7 as shown) may be added in the updated HARQ buffer 1400.

[0152] This new channel may be removed once the decoded HARQ message is correct, as shown in the HARQ buffer 1502 of FIG. 15B where Channel 7 has been removed. As the number of active channels continues to decrease, more channels may be reverse shifted to use the Type B HARQ combiner 504 and/or one or more of the channels using the Type B HARQ combiner 504 may be reverse shifted to use the Type A HARQ combiner 502 in an effort to increase the BER performance.

[0153] This scenario is illustrated in the HARQ buffer 1504 of FIG. 15B where Channel 4 has been reverse shifted from using the Type B HARQ combiner 504 to using the Type A HARQ combiner 502, leading to less headroom being available in the HARQ buffer 1504. For some instances where the Type C HARQ combiner 506 had been used, the channel may jump directly to using the Type A HARQ combiner 502 without going through the intermediate step of using the Type B HARQ combiner 504 for an iteration of HARQ combining.

[0154] The active channel(s) selected for reverse shifting—as well as the type of HARQ combiner selected—may depend, for example, on the modulation order of the channel and/or the bit width of each HARQ combiner type. By dynamically forward and reverse shifting the HARQ combining type used for a particular channel, the BER performance and combining gain may be increased without saturating the HARQ buffer 508. For some embodiments, the selection of the HARQ channel(s) for reverse shifting may depend on any combination of suitable criteria, such as the modulation order, the channel state information (CSI), the channel quality, the number of the HARQ transmission, and the decoding results for each HARQ channel. By considering other factors in addition to the modulation order when dynamically reverse shifting the HARQ combining type used for a certain channel, the BER performance and combining gain may be increased still further.

[0155] FIGs. 16A-B illustrate a flow diagram of example operations 1600 for RS HARQ. The operations begin at 1602 by receiving a HARQ message through a certain wireless channel. Whether this is the first transmission of the HARQ signal ($q=1$) may be checked at 1604, and if this is not the first transmission, then the previous HARQ type (pHT) may be checked at 1606. At 1608, the status of the HARQ buffer 508 may be checked to determine the headroom, and based on this information, the current HARQ type (cHT) may be selected at 1610 for the particular wireless channel. The cHT for reverse shifting may depend primarily on the buffer headroom and secondarily on the modulation order of the channel, for example, and the bit width of the HARQ combiner type, as described above.

[0156] If the current HARQ type selected is Type A (cHT = A) at 1612 and the previous HARQ type was Type C (pHT = C) at 1614, then the last saved Type C HARQ signal may be accessed and converted to a Type A HARQ signal at 1616. If cHT = A at 1612 and pHT = B at 1618, then the last saved Type B HARQ signal may be accessed and converted to a Type A HARQ signal at 1620. The Type-C-to-Type-A or Type-B-to-Type A HARQ reverse shifting may involve signal conversion to allow stored data from one type of combining scheme to be used when combining with the current HARQ signal under a different combining scheme at an earlier stage. Such signal conversions may involve undoing at least the signal weighting and/or constellation demapping of the

reception processing path. If $cHT = A$ at 1612 and $pHT = A$ at 1621, then the last saved Type A HARQ signal may be accessed at 1622.

[0157] At 1624, the received HARQ message may be combined with the converted or accessed Type A HARQ signal, and the combined signal may be saved to the HARQ buffer 508 at 1626. The combined signal may be normalized at 1630, the normalized signal may be demapped at 1632, and the demapped signal may be weighted at 1634 as described above.

[0158] If the current HARQ type selected is Type B ($cHT = B$) at 1636, the received HARQ message may be equalized at 1638, and the equalized signal may be demapped at 1640 as previously described. If $pHT = C$ at 1642, then the last saved Type C HARQ signal may be accessed and converted to a Type B HARQ signal at 1644. The Type-C-to-Type-B HARQ signal conversion may involve undoing at least the signal weighting of the reception processing path. If $pHT = B$ at 1646, then the last saved Type B HARQ signal may be accessed at 1648.

[0159] At 1650, the equalized HARQ message may be combined with the converted or accessed Type B HARQ signal, and the combined signal may be saved to the HARQ buffer 508 at 1652. The combined signal may be normalized at 1654, and the normalized signal may be weighted at 1656 as described above.

[0160] If the current HARQ type selected is neither Type A nor Type B ($cHT \neq A$ and $cHT \neq B$) at 1612 and 1636, the received HARQ message may be equalized at 1658, the equalized signal may be demapped at 1660, and the demapped signal may be weighted at 1662 as described above. At 1666, the last saved Type C HARQ signal may be accessed. The combined signal may be saved to the HARQ buffer 508 at 1668 and normalized at 1670.

[0161] At 1672, the signal from one of the three paths in the reverse shifting HARQ flow diagram of FIGs. 16A-B may be decoded in the channel decoder 416. If the designated bits of the HARQ message (*e.g.*, the ED bits and the FEC bits) are correct at 1674, then the message may be interpreted to be successfully transmitted, received, processed, and decoded. The particular HARQ channel may be removed from the HARQ buffer 508 at 1676. However, if any of the designated bits of the HARQ message are incorrect, the previous HARQ combining type may be made equal to the

current HARQ combining type ($pHT = cHT$) at 1678. The operations may repeat beginning with the reception of a HARQ message at 1602, most likely for a different wireless channel, after either removing the particular HARQ channel from the buffer 508 at 1676 or updating the pHT at 1678.

[0162] For some embodiments, rather than converting the HARQ signal of the previous HARQ type, which is stored in the buffer 508, to the current HARQ type for reverse shifting, data stored in the buffer 508 for the particular channel may be cleared when the current HARQ combiner type does not equal the previous HARQ combiner type ($cHT \neq pHT$). Then, during the next iteration ($q + 1$) for the HARQ channels, HARQ reception may start over as if this was the first reception ($q = 1$), at least for the particular channel which just changed HARQ combiner types under reverse shifting. Clearing the buffer data for the current iteration may increase the total number of retransmissions required for a correct decoded message. However, the ability to select a HARQ combining scheme with a lower BER may be worth the potential for increased retransmissions, especially since the associated time increase may be negligible.

[0163] The control for forward and reverse shifting of selected HARQ combiner types may occur in the buffer controller 526. The buffer controller 526 may be implemented in a processor, such as a digital signal processor (DSP), or any suitable integrated circuit, such as a field programmable gate array (FPGA) or application specific integrated circuit (ASIC).

An Overview of the Forward and Reverse Shifting S-HARQ Combining Scheme

[0164] FIG. 17 illustrates a flow diagram of example operations 1700 for shifting between different HARQ combiners in selective hybrid automatic repeat-request (S-HARQ) transmission. The operations may begin, at 1702, by receiving a HARQ first message through a certain wireless channel. At 1704, a first type of HARQ combiner to be used in processing the channel may be selected, based on the selection criteria described above. Using the selected first combiner, HARQ combining may occur in an effort to generate first HARQ combined signal data based on signal data from the first HARQ transmission. The first combined HARQ signal may be decoded to determine whether the message is correct.

[0165] If the message is not correct, a second HARQ message may be received through the same wireless channel at 1706. At 1708, a second type of HARQ combiner to be used in processing the channel may be selected, different from the first type and based on the selection criteria described above. The first and second HARQ combiners may be located at different points along the reception processing path. Using the selected second combiner, HARQ combining may occur in an effort to generate second HARQ combined signal data based on signal data from the second HARQ transmission. The second combined HARQ signal may be decoded to determine whether the message is correct.

[0166] The method 1700 of FIG. 17 described above may be performed by various hardware and/or software component(s) and/or module(s) (e.g., code, instructions, etc.) corresponding to the means-plus-function blocks 1700A illustrated in FIG. 17A. In other words, blocks 1702 through 1708 illustrated in FIG. 17 correspond to means-plus-function blocks 1702A through 1708A illustrated in FIG. 17A.

[0167] As used herein, the term “determining” encompasses a wide variety of actions. For example, “determining” may 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” may include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Also, “determining” may include resolving, selecting, choosing, establishing and the like.

[0168] Information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals and the like that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles or any combination thereof.

[0169] The various illustrative logical blocks, modules and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be

any commercially available processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing 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.

[0170] The steps of a method or algorithm described in connection with the present disclosure may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module (i.e., the code, instructions, etc.) may reside in any form of storage medium that is known in the art. Some examples of storage media that may be used include random access memory (RAM), read only memory (ROM), flash memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM and so forth. A software module may comprise a single instruction or code, or many instructions or strings/sets of code, and may be distributed over several different code segments or instruction sets, among different programs, and across multiple storage media. A storage medium may be coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

[0171] 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 specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

[0172] The functions described 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. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical

disc, digital versatile disc (DVD), floppy disk, and Blu-ray[®] disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

[0173] Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

[0174] Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein, such as those illustrated by FIGs. 7, 13A-B, 16A-B and 17(A), can be downloaded and/or otherwise obtained by a user terminal and/or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via a storage means (*e.g.*, RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, *etc.*), such that a user terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

[0175] It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the methods and apparatus described above without departing from the scope of the claims.

What is claimed is:

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CLAIMS:

1. A receiver for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising:
 - a first HARQ combiner at a first location along a reception processing path;
 - 5 a second HARQ combiner at a second location along the reception processing path different from the first location;
 - control logic configured to select the first HARQ combiner to generate first HARQ combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and to select the second HARQ combiner to generate second
10 HARQ combined signal data wherein the selection is based on signal data for a second received HARQ transmission in the channel; and
 - at least one buffer for storing the first or the second HARQ combined signal data.
2. The receiver of claim 1, wherein the control logic is configured to combine the
15 first HARQ combined signal data with the signal data for the second HARQ transmission to generate the second HARQ combined signal data.
3. The receiver of claim 1, wherein the control logic is configured to transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for
20 the second HARQ transmission.
4. The receiver of claim 1, wherein the first combiner is located downstream of the second combiner.
5. The receiver of claim 1, wherein at least one of the first and second combiners is located in the reception processing path after demodulation logic.

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6. An apparatus for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising:

first means for generating HARQ combined signal data at a first location along a reception processing path;

5 second means for generating the HARQ combined signal data at a second location along the reception processing path different from the first location;

means for selecting the first means for use in generating first HARQ combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and for selecting second means for use in generating second HARQ
10 combined signal data wherein the selection is based on signal data for a second HARQ transmission in the channel; and

means for storing the first or the second HARQ combined signal data.

7. The apparatus of claim 6, wherein the means for selecting is configured to combine the first HARQ combined signal data with the signal data for the second HARQ
15 transmission to generate the second HARQ combined signal data.

8. The apparatus of claim 7, wherein the means for selecting is configured to transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

20 9. A processor for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, the processor executing operations comprising:

receiving a first HARQ transmission in a channel;

selecting a first HARQ combiner for use in generating first HARQ combined signal data wherein the selection is based on signal data for the first HARQ transmission;

25 receiving a second HARQ transmission in the channel; and

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selecting a second HARQ combiner for use in generating second HARQ combined signal data wherein the selection is based on signal data for the second HARQ transmission, wherein the first and second HARQ combiners are located at different locations along a reception processing path.

5 10. A mobile device, comprising:

a first HARQ combiner at a first location along a reception processing path;

a second HARQ combiner at a second location along the reception processing path different from the first location;

10 control logic configured to select the first HARQ combiner to generate first hybrid automatic repeat-request (HARQ) combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and to select the second HARQ combiner to generate second HARQ combined signal data wherein the selection is based on signal data for a second received HARQ transmission in the channel;

15 at least one buffer for storing the first or the second HARQ combined signal data; and

a receiver front end for receiving the first and second HARQ transmissions in the channel.

11. The mobile device of claim 10, wherein the first combiner is located downstream of the second combiner.

20 12. The mobile device of claim 10, wherein the control logic is configured to combine the first HARQ combined signal data with the signal data for the second HARQ transmission to generate the second HARQ combined signal data.

13. The mobile device of claim 12, wherein the control logic is configured to transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

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14. A computer-program product for processing data for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism comprising a computer readable memory having a set of instructions stored thereon, the set of instructions being executable by one or more processors and the set of instructions comprising:

5 first instructions for generating HARQ combined signal data at a first location along a reception processing path;

second instructions for generating the HARQ combined signal data at a second location along the reception processing path different from the first location;

10 instructions for selecting the first instructions for use in generating first HARQ combined signal data wherein the selection is based on signal data for a first received HARQ transmission in a channel and for selecting second instructions for use in generating second HARQ combined signal data wherein the selection is based on signal data for a second HARQ transmission in the channel; and

instructions for storing the first or the second HARQ combined signal data.

15 15. The computer-program product of claim 14, wherein the instructions for selecting is configured to combine the first HARQ combined signal data with the signal data for the second HARQ transmission to generate the second HARQ combined signal data.

16. The computer-program product of claim 15, wherein the instructions for selecting is configured to transform at least one of the first HARQ combined signal data and
20 the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

17. A method for interpreting hybrid automatic repeat-request (HARQ) transmissions in a wireless communication system, the method comprising:

receiving a first HARQ transmission in a channel;

25 selecting a first HARQ combiner for use in generating first HARQ combined signal data wherein the selection is based on signal data for the first HARQ transmission;

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receiving a second HARQ transmission in the channel; and

selecting a second HARQ combiner for use in generating second HARQ combined signal data wherein the selection is based on signal data for the second HARQ transmission, wherein the first and second HARQ combiners are located at different locations
5 along a reception processing path.

18. The method of claim 17, further comprising:

combining the first HARQ combined signal data with the signal data for the second HARQ transmission to generate the second HARQ combined signal data.

19. The method of claim 18, further comprising:

10 transforming at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

20. The method of claim 17, wherein the first combiner is located downstream of the second combiner.

15 21. The method of claim 17, wherein selecting the second combiner comprises considering the modulation order of the channel, the channel state information (CSI), the channel quality, the number of HARQ transmissions for the channel, or any combination thereof.

22. The method of claim 21, wherein at least one of the first and second combiners
20 is located in the reception processing path after demodulation logic.

23. The method of claim 17, wherein the first and second combiners are configured to generate the HARQ combined signal data using Chase combining.

24. An apparatus for wireless communication with a hybrid automatic repeat-request (HARQ) mechanism, comprising:

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first means for generating HARQ combined signal data at a first location along a reception processing path;

second means for generating the HARQ combined signal data at a second location along the reception processing path different from the first location, wherein the first
5 means and the second means are connected in series;

means for storing HARQ combined signal data;

means for determining a headroom of the means for storing;

means for selecting the first means for use in generating first HARQ combined signal data based on signal data for a first received HARQ transmission in a channel, wherein
10 the selection is based at least on the headroom of the means for storing and a modulation order of the channel; and

wherein the means for selecting is further configured to select the second means for use in generating second HARQ combined signal data based on signal data for a second received HARQ transmission in the channel, wherein the selection is based at least on
15 the headroom of the means for storing and the modulation order of the channel,

wherein the means for storing is configured to store the first or second HARQ combined signal data.

25. The apparatus of claim 24, wherein the means for selecting is configured to combine the first HARQ combined signal data with the signal data for the second HARQ
20 transmission to generate the second HARQ combined signal data.

26. The apparatus of claim 25, wherein the means for selecting is configured to transform as an FFT transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

25 27. The apparatus of claim 24, wherein the apparatus is a mobile device, wherein the first means is

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a first combiner, the second means is a second combiner, and wherein the means for selecting is a control logic configured to select the first combiner to generate first hybrid automatic repeat-request (HARQ) combined signal data based on signal data for a first received HARQ transmission in a channel and to select the second combiner to generate
 5 second HARQ combined signal data based on signal data for a second received HARQ transmission in the channel;

wherein the means for storing is at least one buffer; and wherein the apparatus further comprises:

10 a receiver front end for receiving the first and second HARQ transmissions in the channel.

28. The mobile device of claim 27, wherein the first combiner is located downstream of the second combiner.

29. The mobile device of claim 27, wherein the control logic is configured to combine the first HARQ combined signal data with the signal data for the second HARQ
 15 transmission to generate the second HARQ combined signal data.

30. The mobile device of claim 29, wherein the control logic is configured to transform as an FFT transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

20 31. A method for interpreting hybrid automatic repeat-request (HARQ) transmissions in a wireless communication system, the method comprising:

receiving a first HARQ transmission in a channel;

selecting a first combiner for use in generating first HARQ combined signal data based on signal data for the first HARQ transmission, wherein the selection is based at
 25 least on a headroom of a buffer for storing HARQ combined signal data and the modulation order of the channel;

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receiving a second HARQ transmission in the channel; and

selecting a second combiner for use in generating second HARQ combined signal data based on signal data for the second HARQ transmission, wherein the selection is based at least on the headroom of the buffer and a modulation order of the channel, and
5 wherein the first and second combiners are connected in a series connection located at different locations along a reception processing path.

32. The method of claim 31, further comprising:

combining the first HARQ combined signal data with the signal data for the second HARQ transmission to generate the second HARQ combined signal data.

10 33. The method of claim 32, further comprising:

transforming as an FFT transform at least one of the first HARQ combined signal data and the signal data for the second HARQ transmission prior to combining the first HARQ combined signal data with the signal data for the second HARQ transmission.

15 34. The method of claim 31, wherein the first combiner is located downstream of the second combiner.

35. The method of claim 31, wherein selecting the second combiner comprises considering the modulation order of the channel, the channel state information (CSI), the channel quality, the number of HARQ transmissions for the channel, or any combination thereof.

20 36. The method of claim 35, wherein at least one of the first and second combiners is located in the reception processing path after demodulation logic.

37. The method of claim 31, wherein the first and second combiners are configured to generate the HARQ combined signal data using Chase combining.

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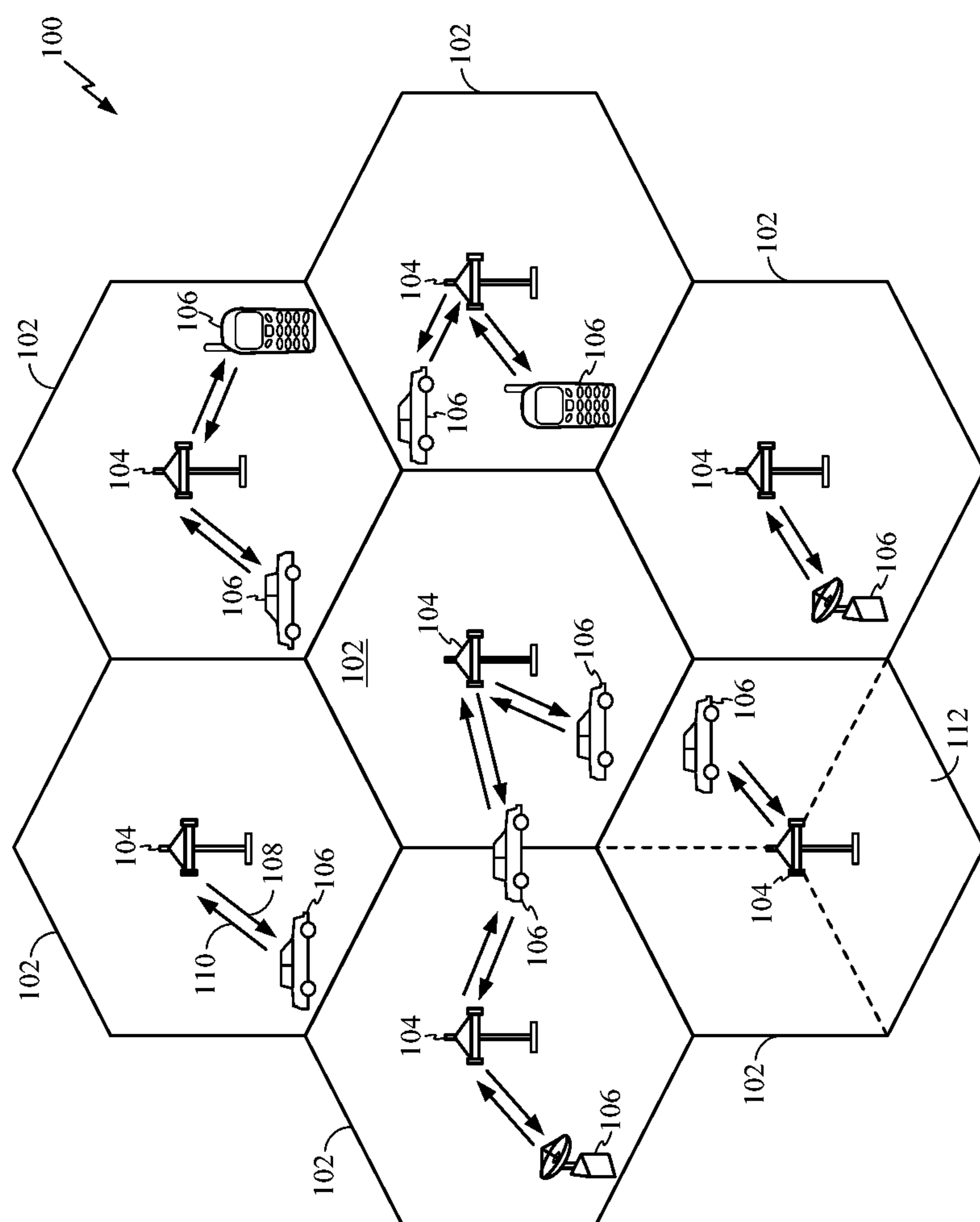


FIG. 1

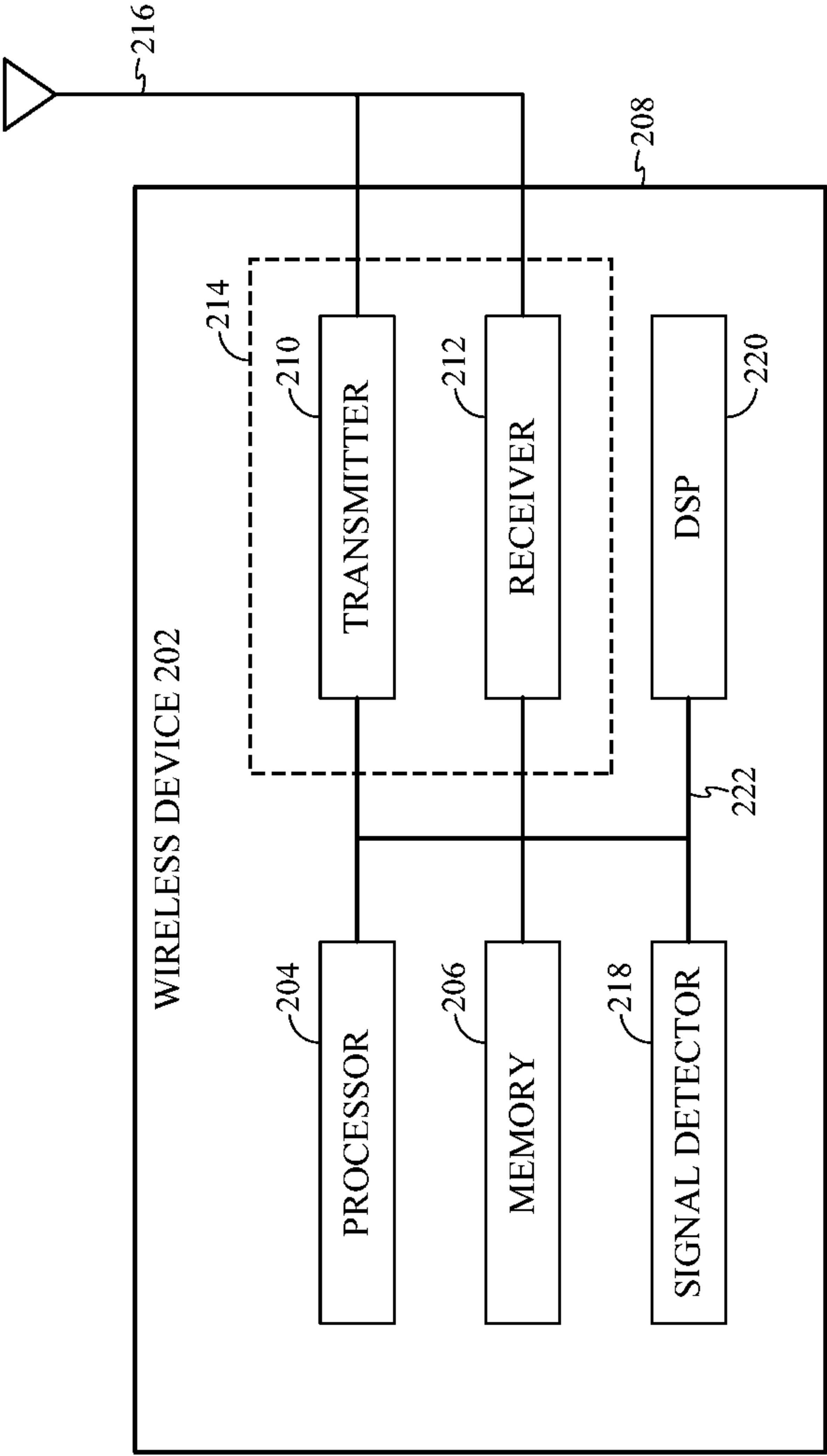


FIG. 2

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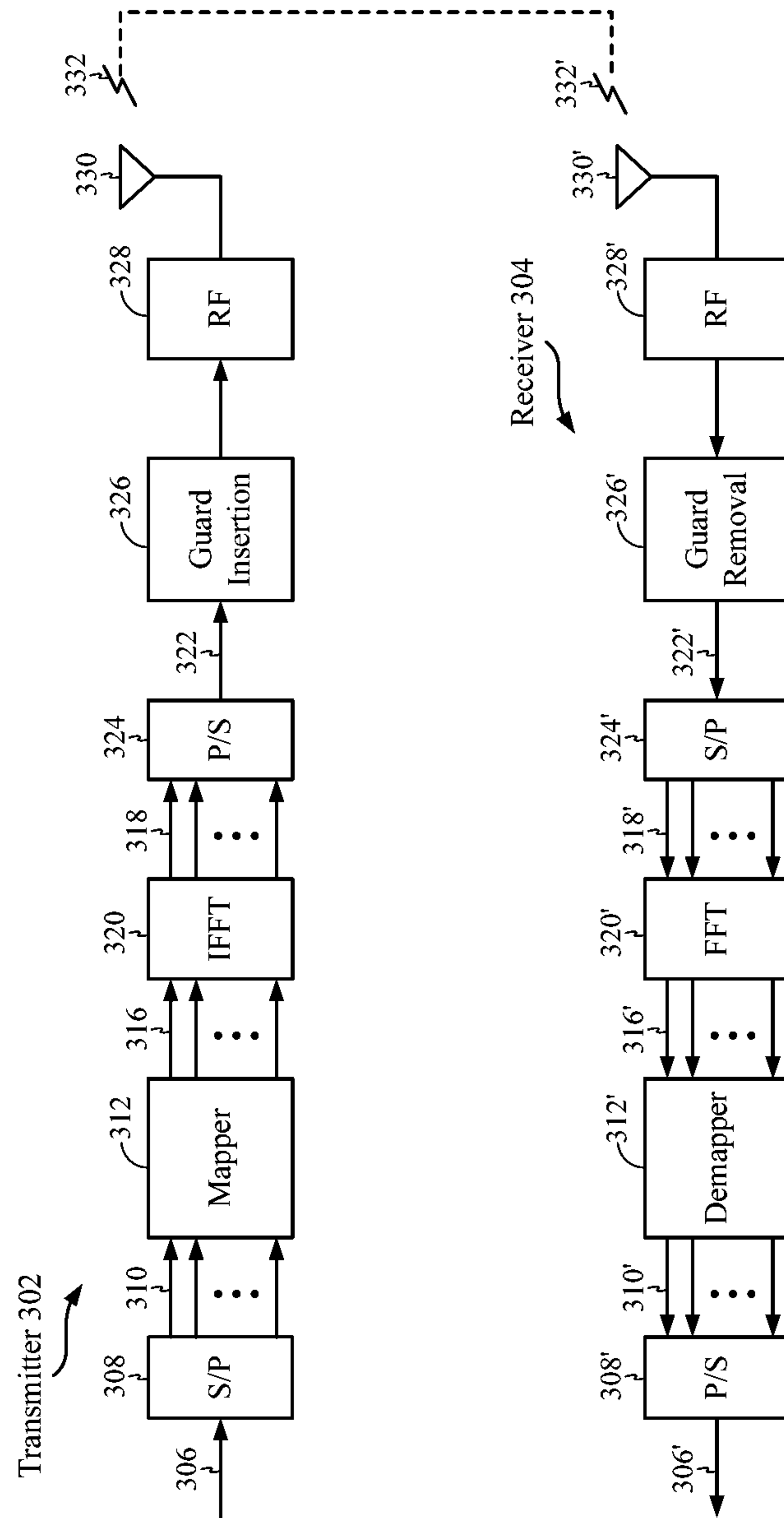


FIG. 3

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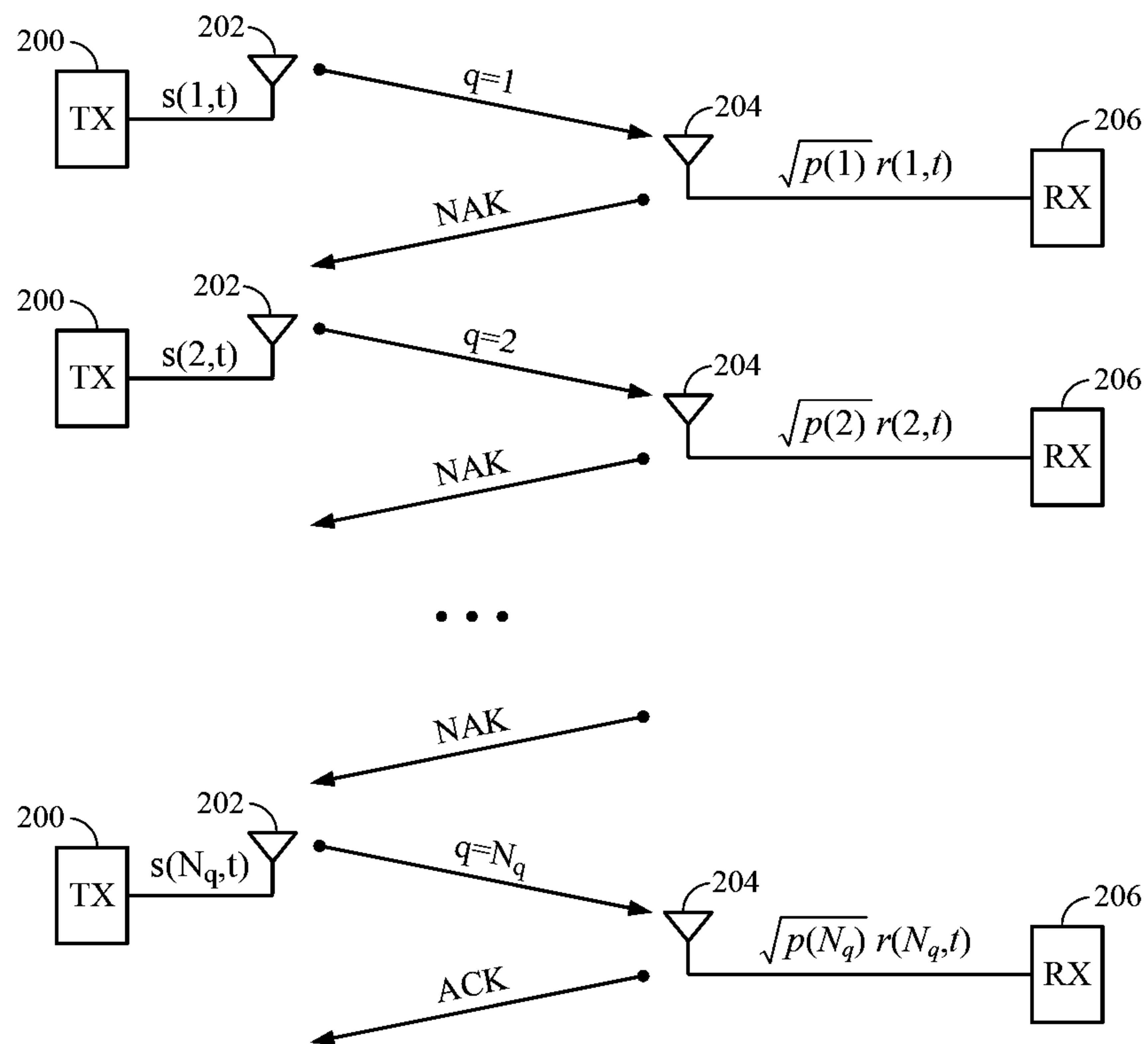


FIG. 3A

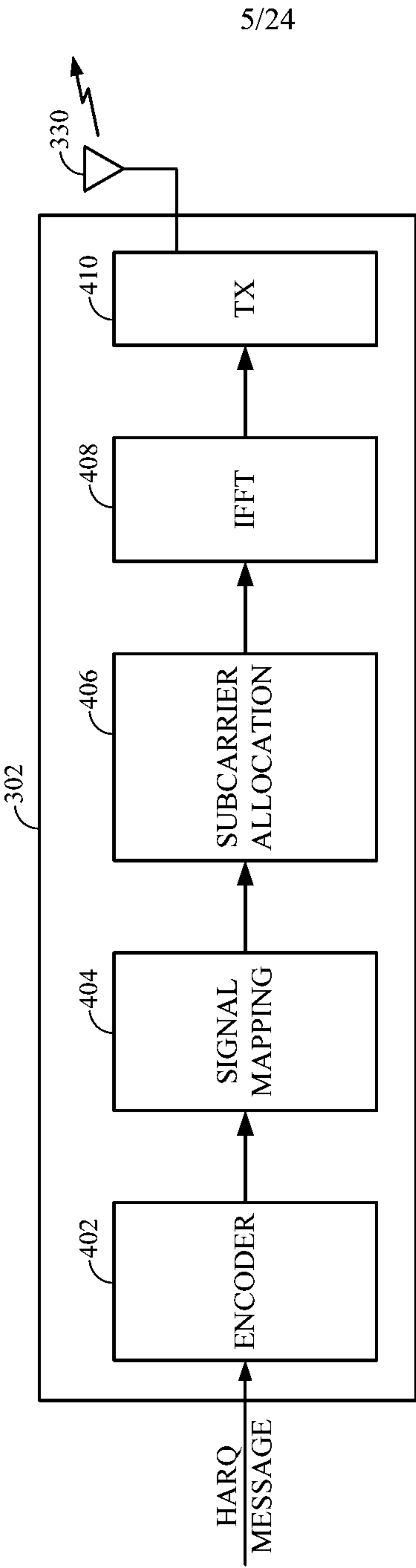


FIG. 4A

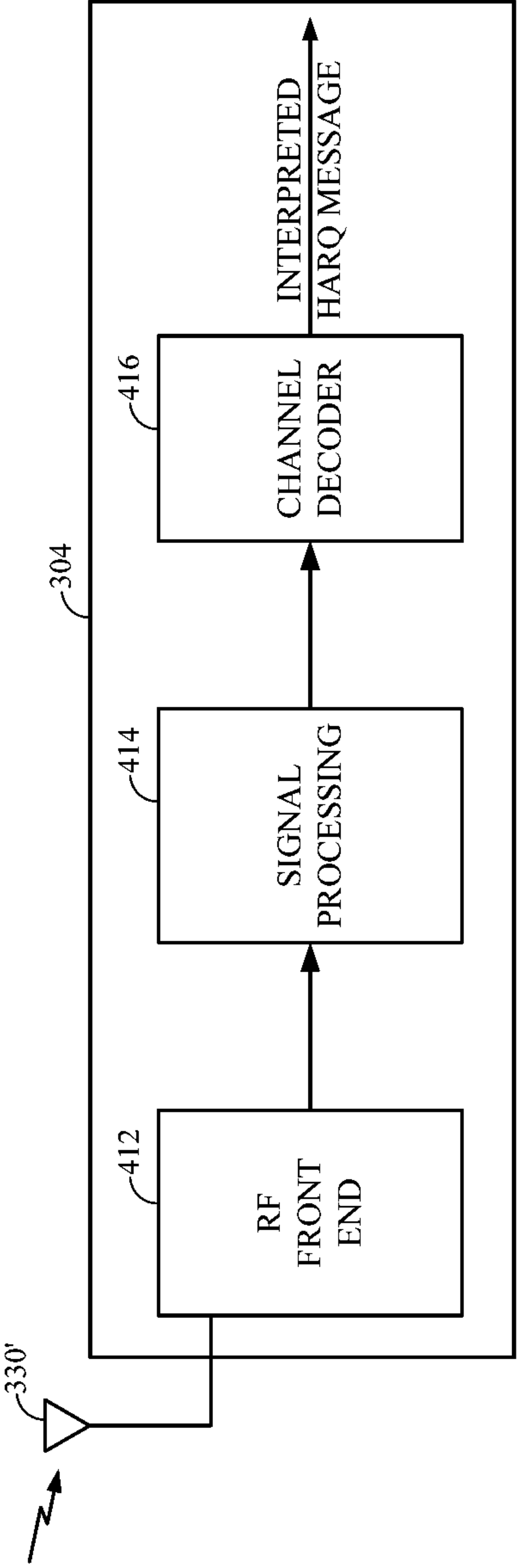


FIG. 4B

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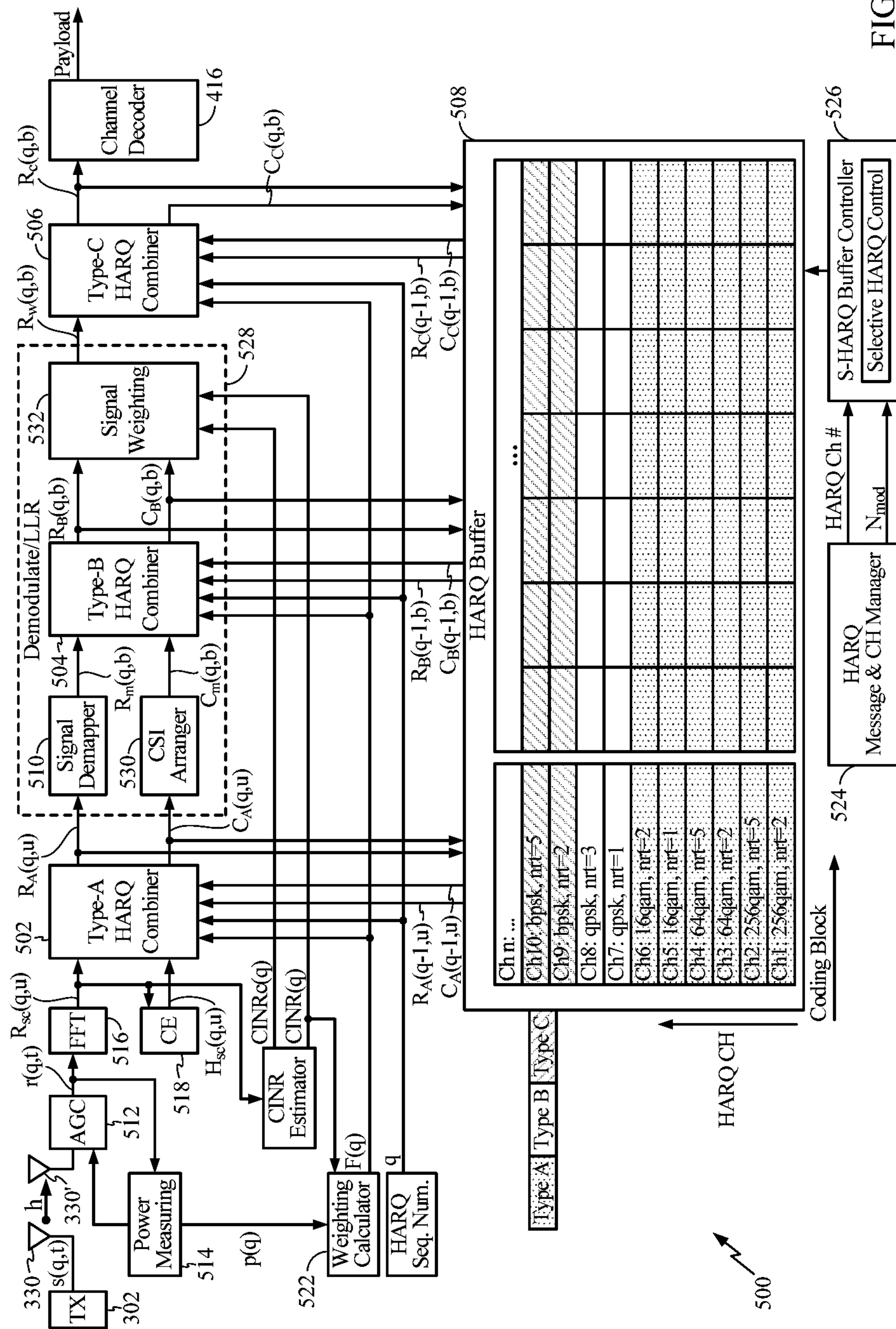


FIG. 5

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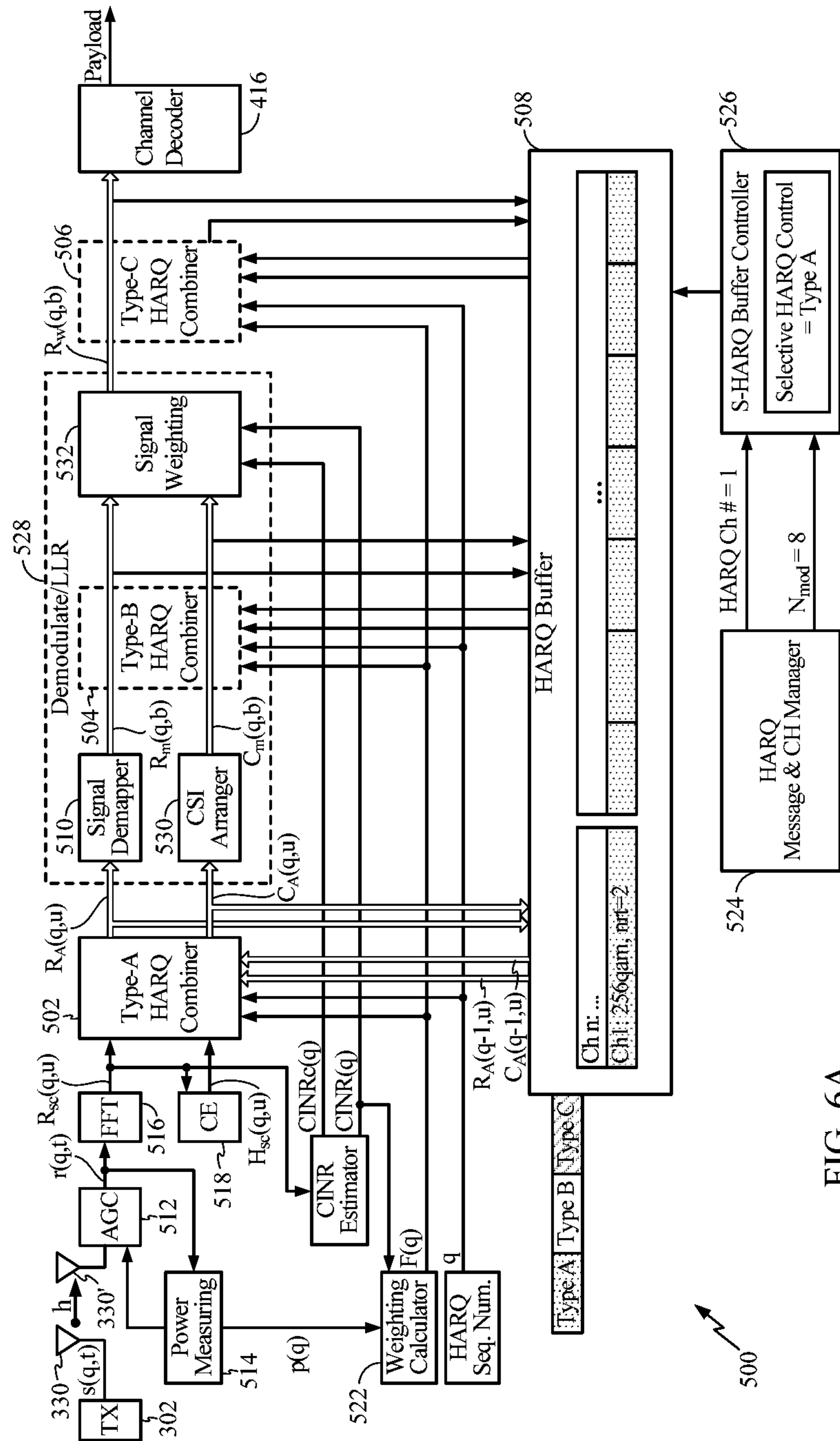


FIG. 6A

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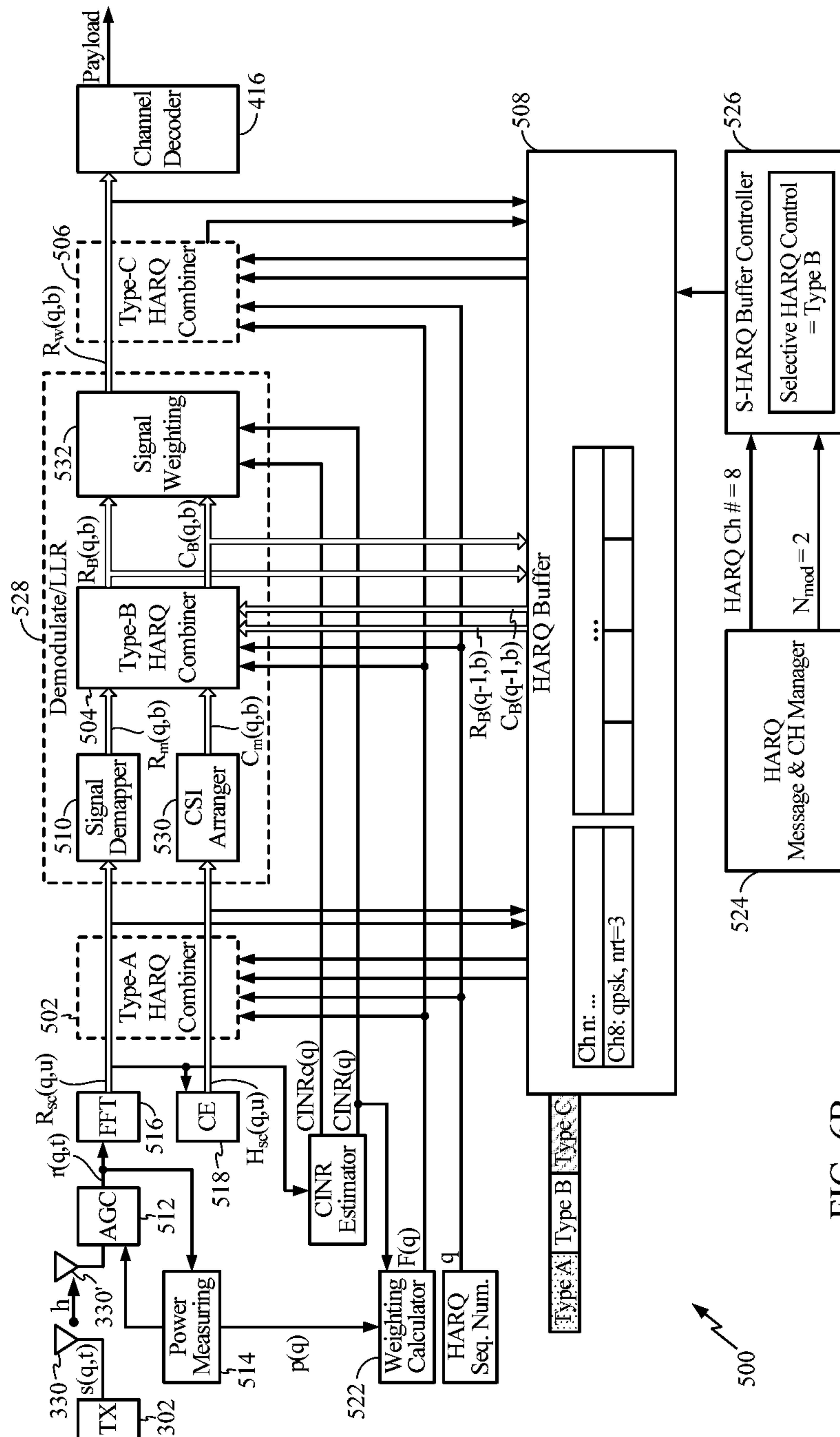


FIG. 6B

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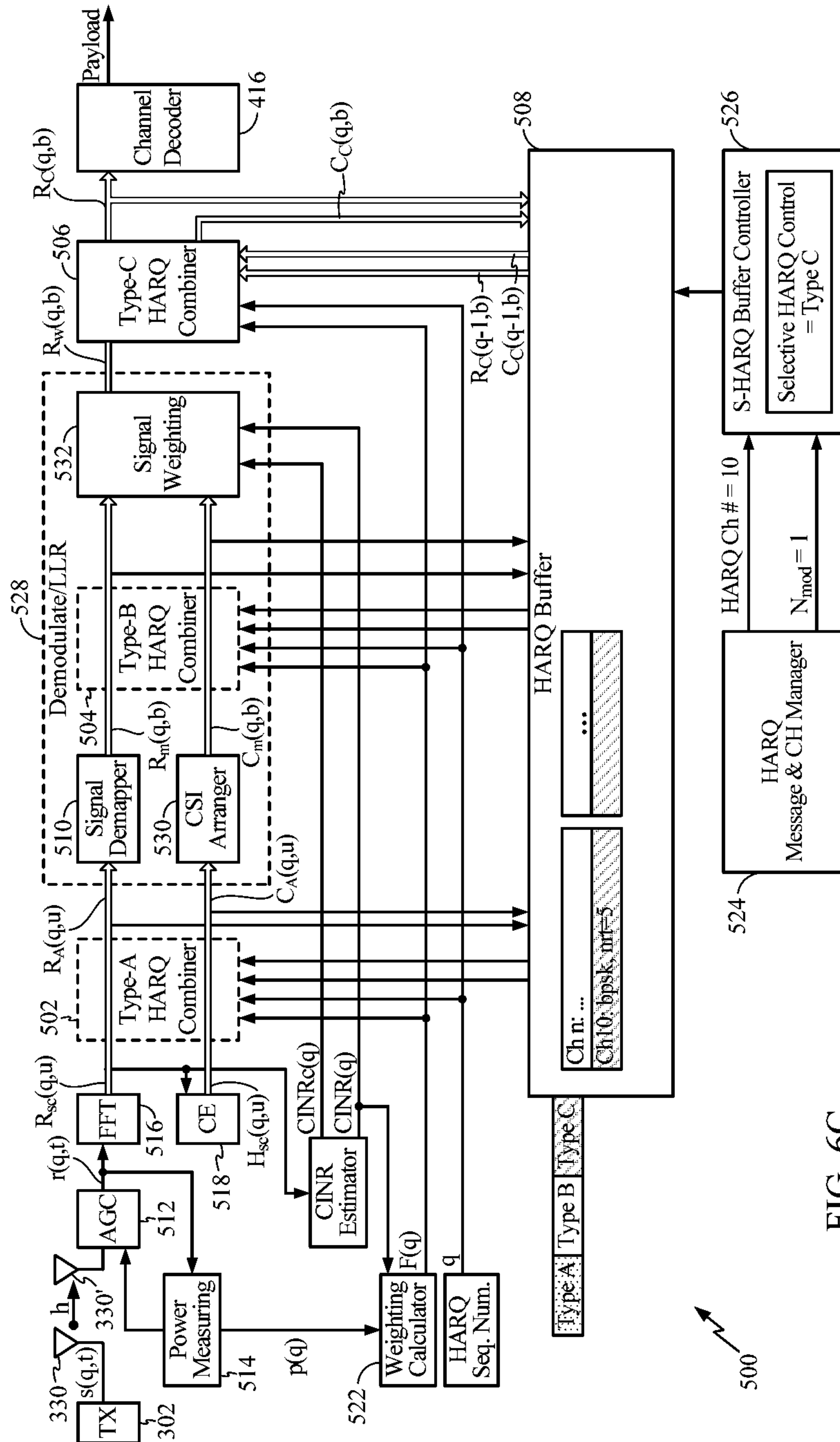
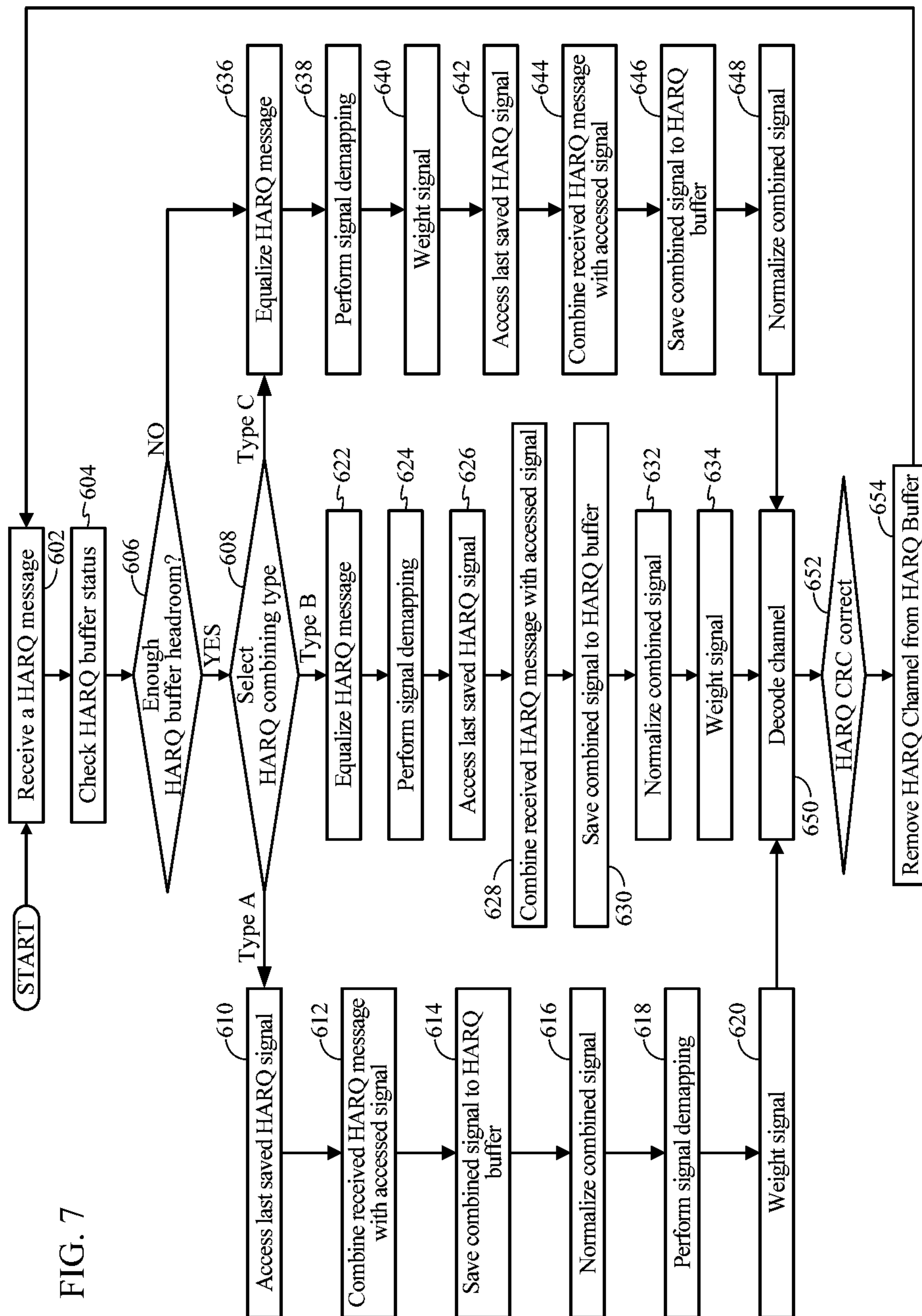
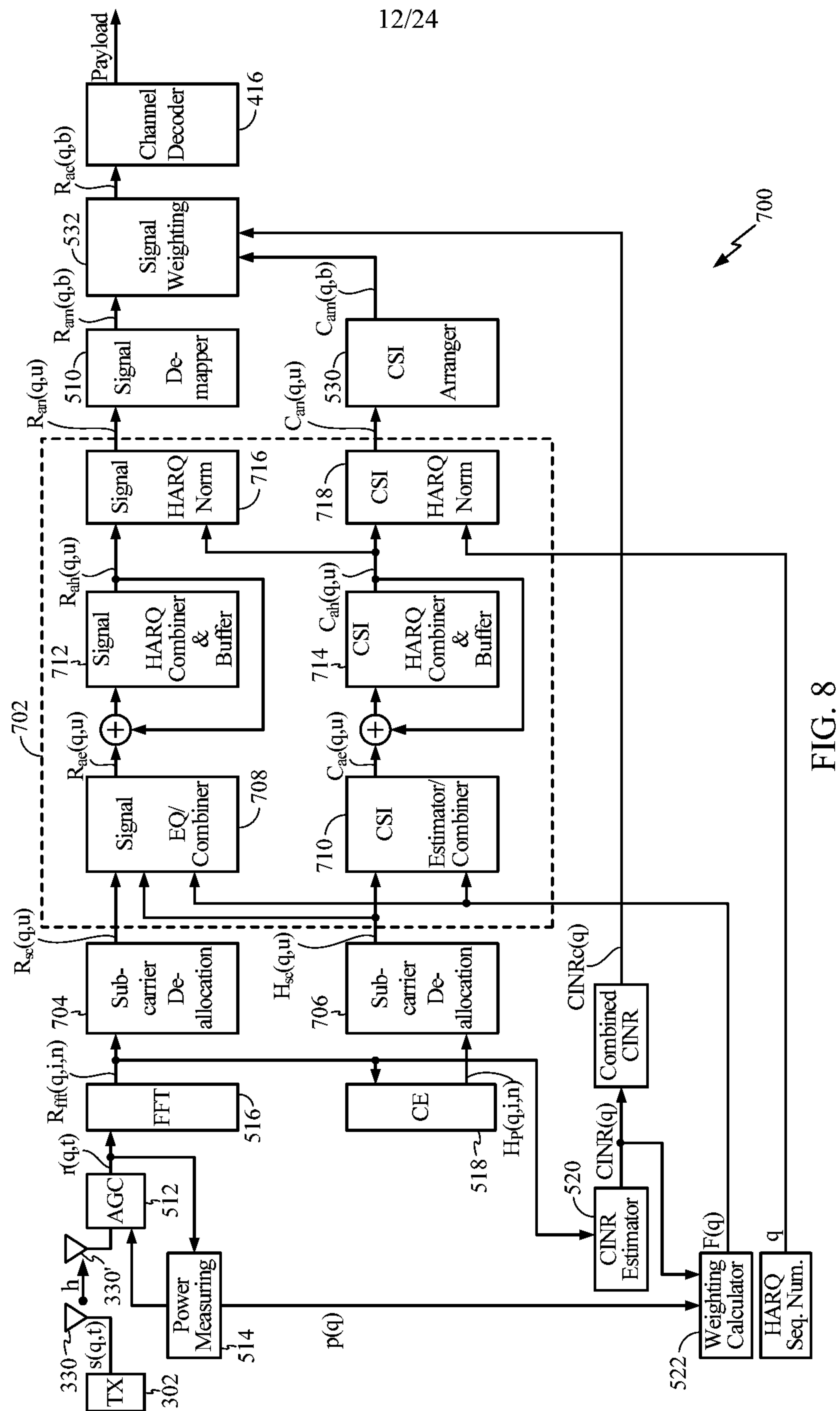


FIG. 6C

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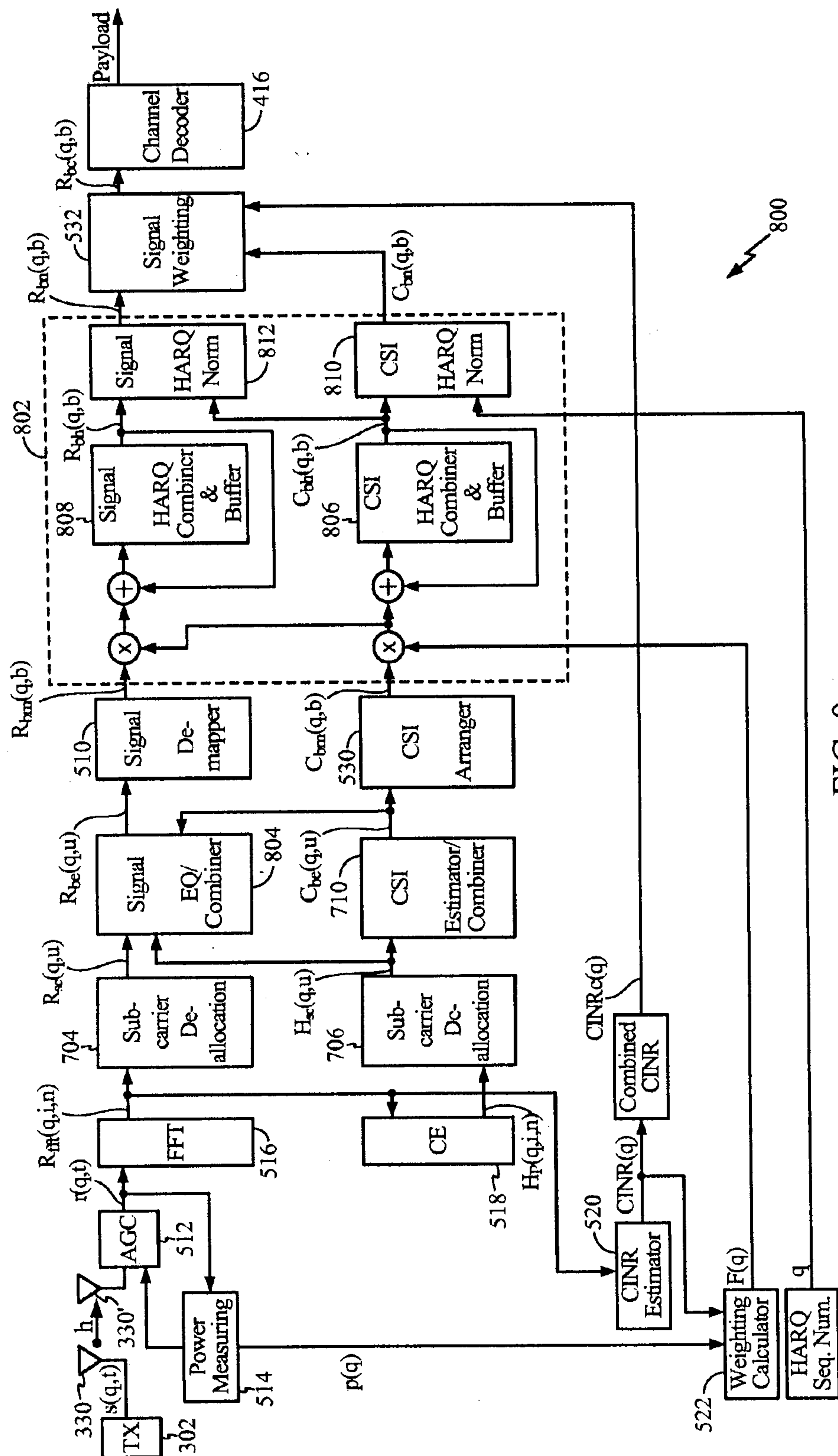


FIG. 9

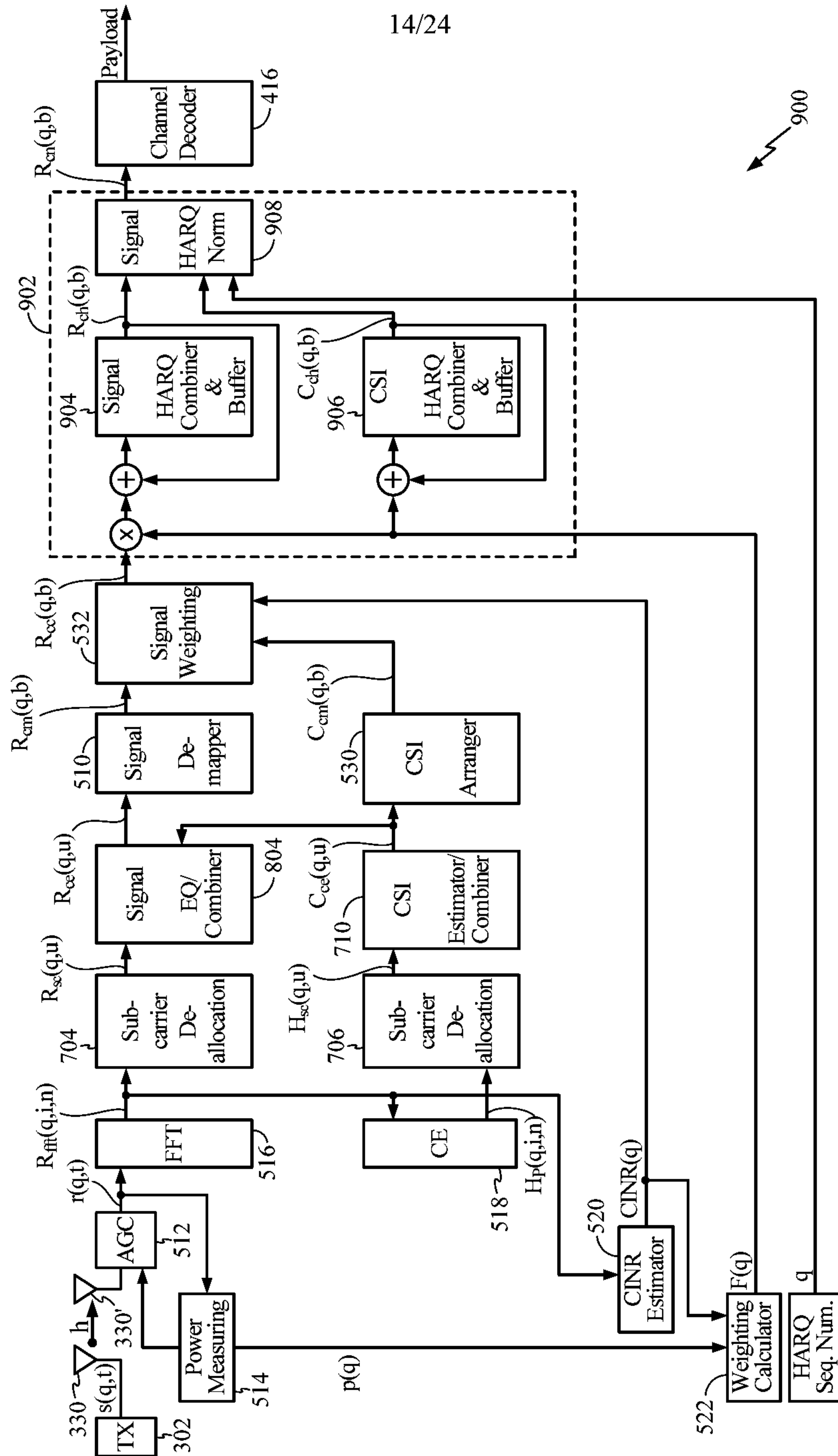


FIG. 10

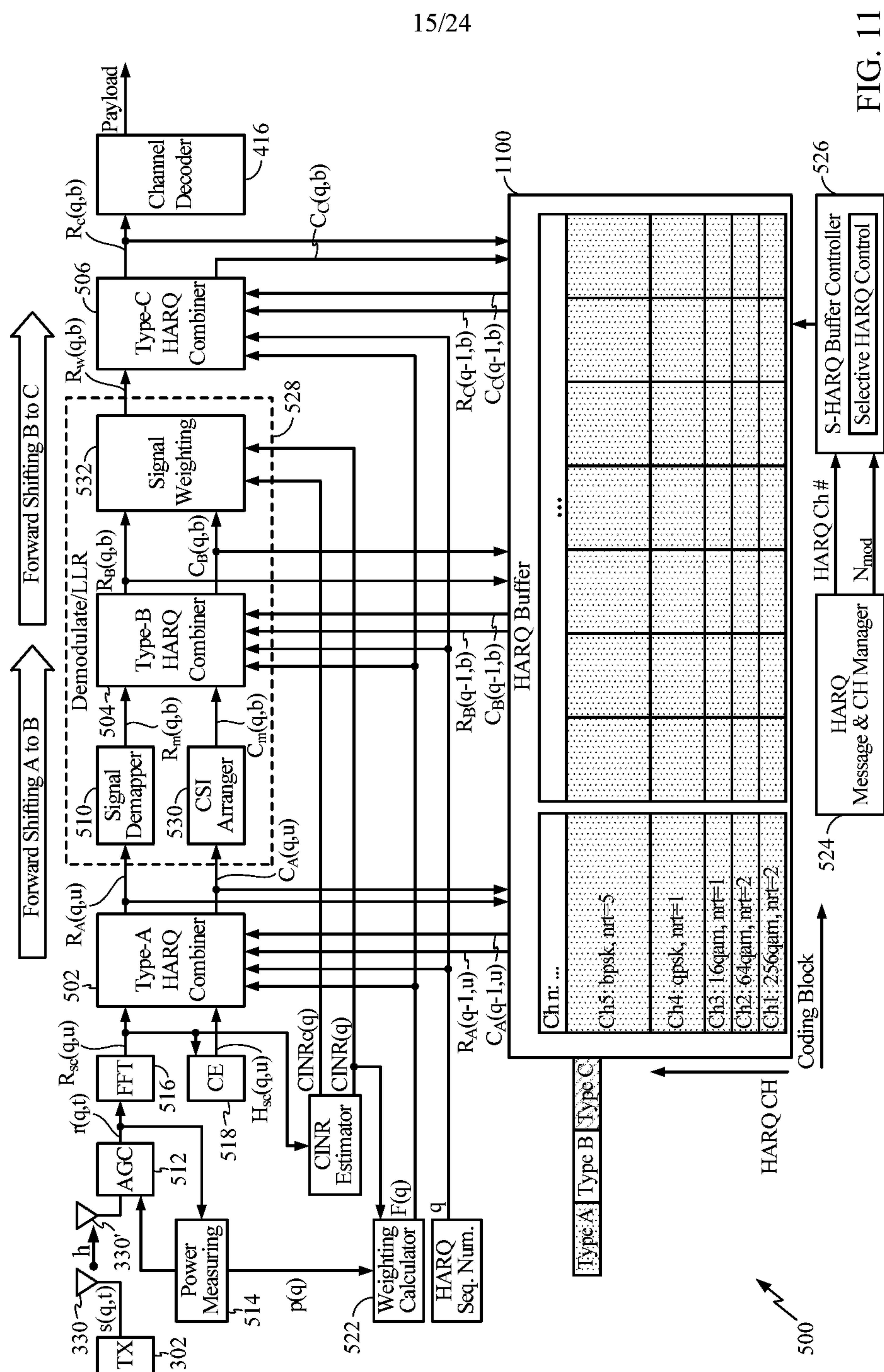


FIG. 11

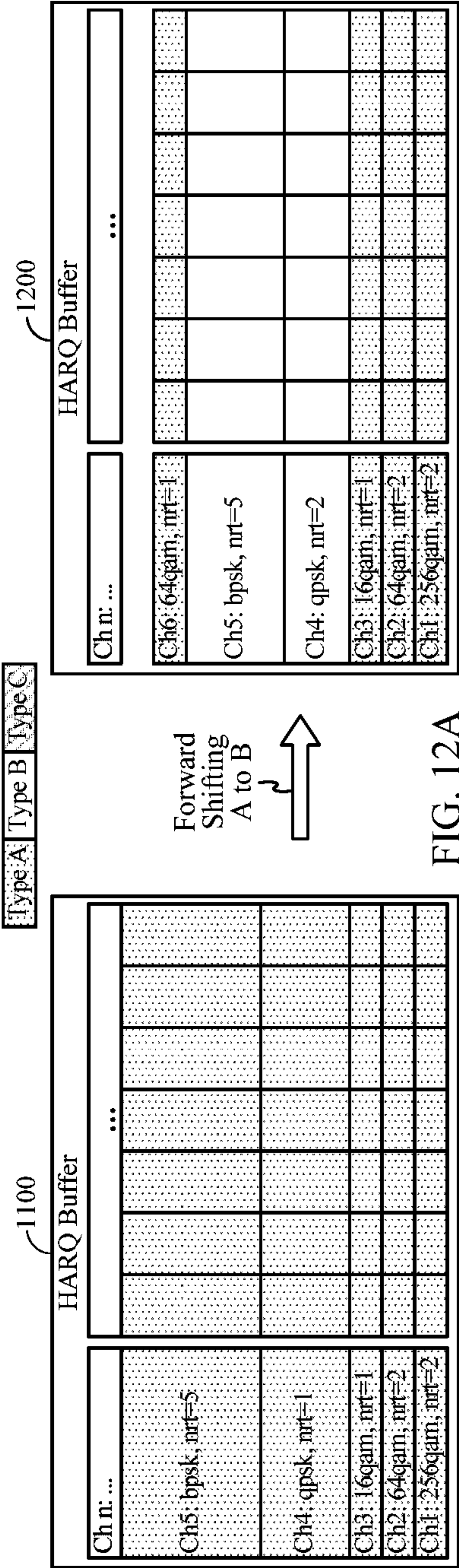


FIG. 12A

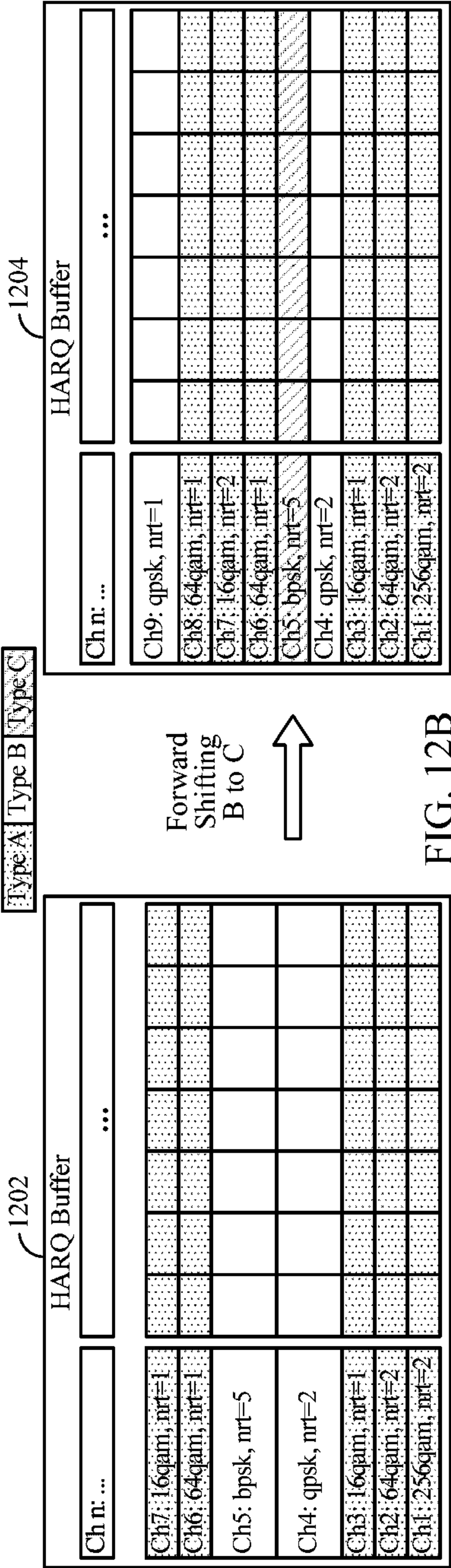


FIG. 12B

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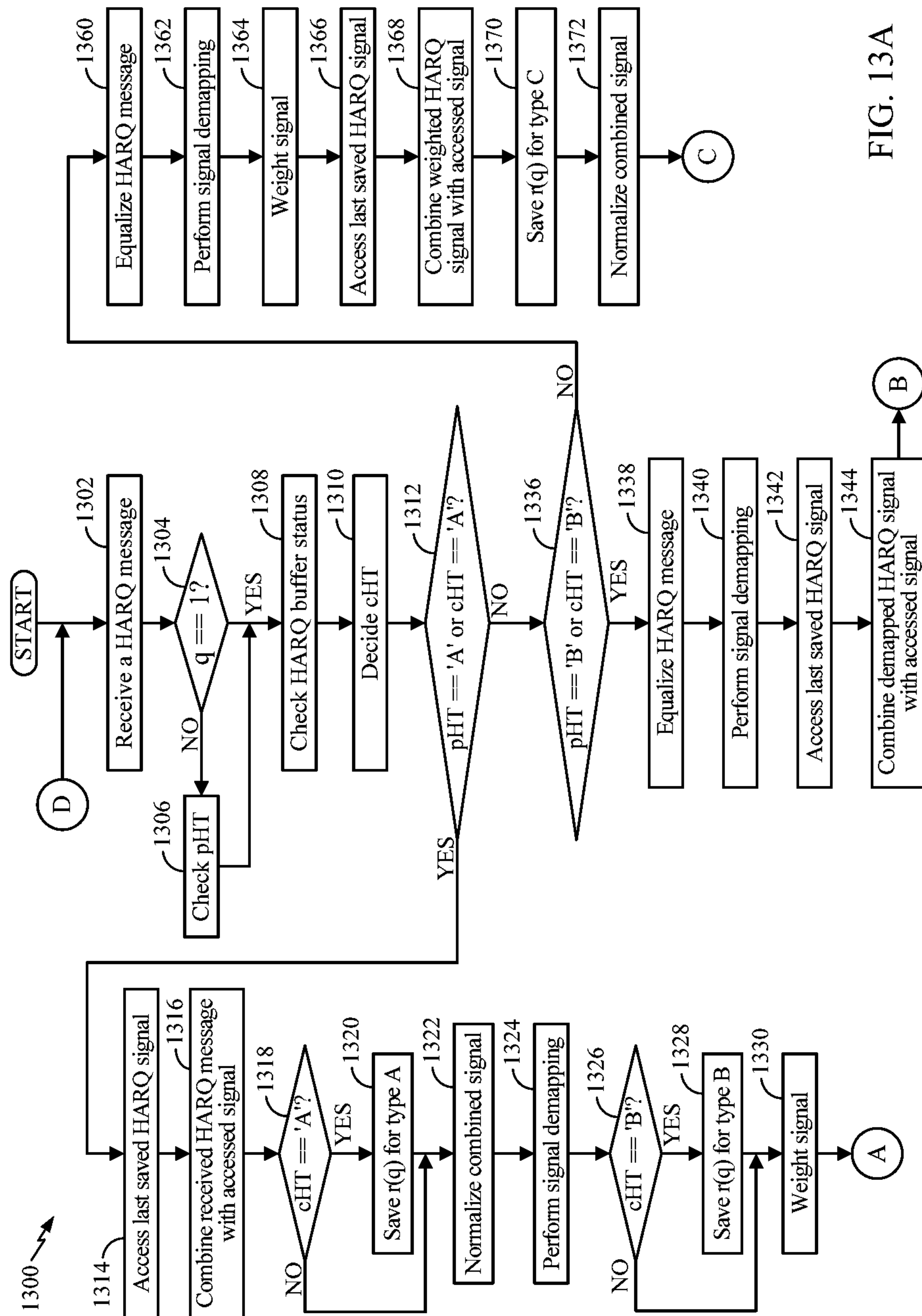


FIG. 13A

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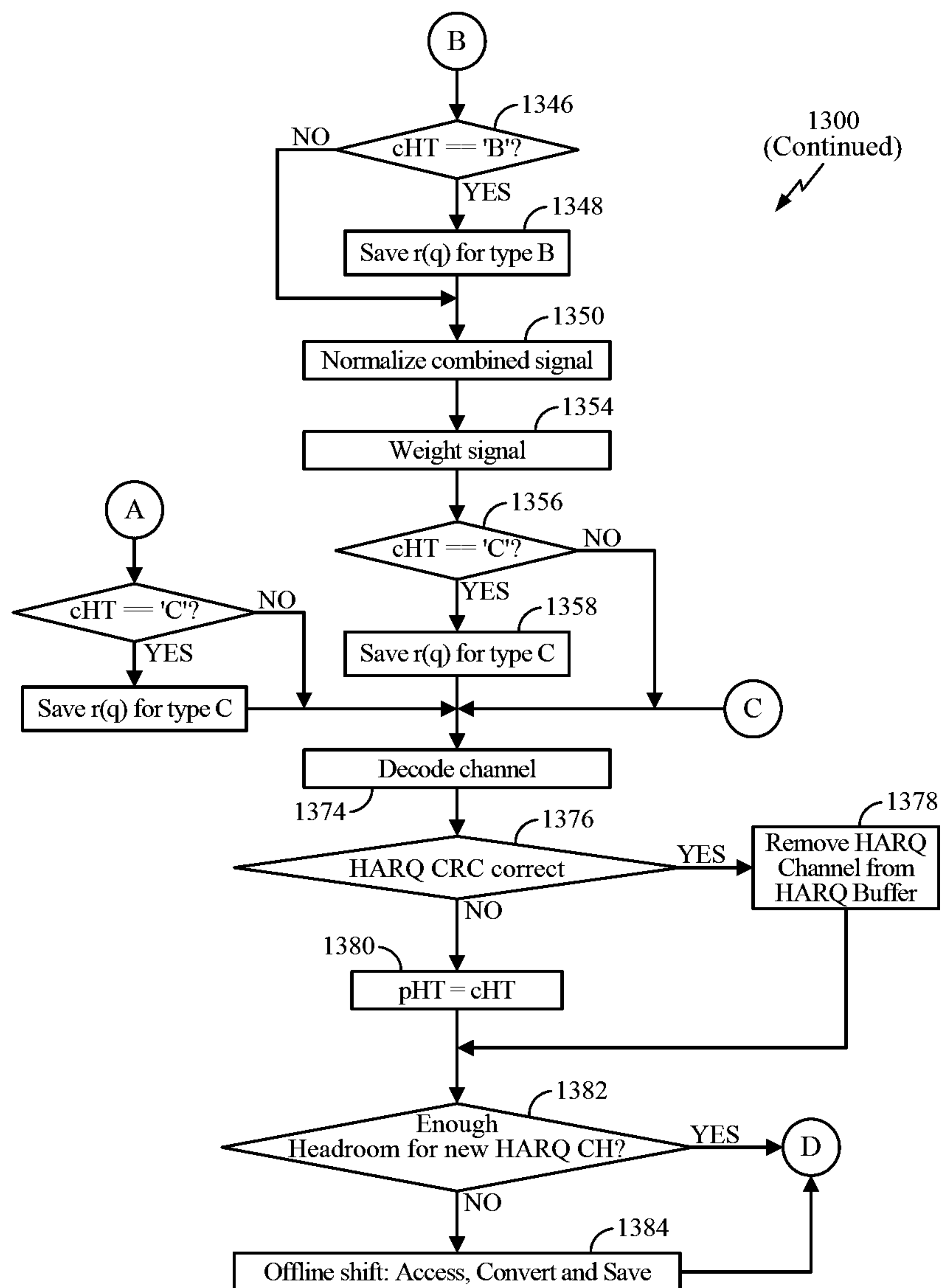


FIG. 13B

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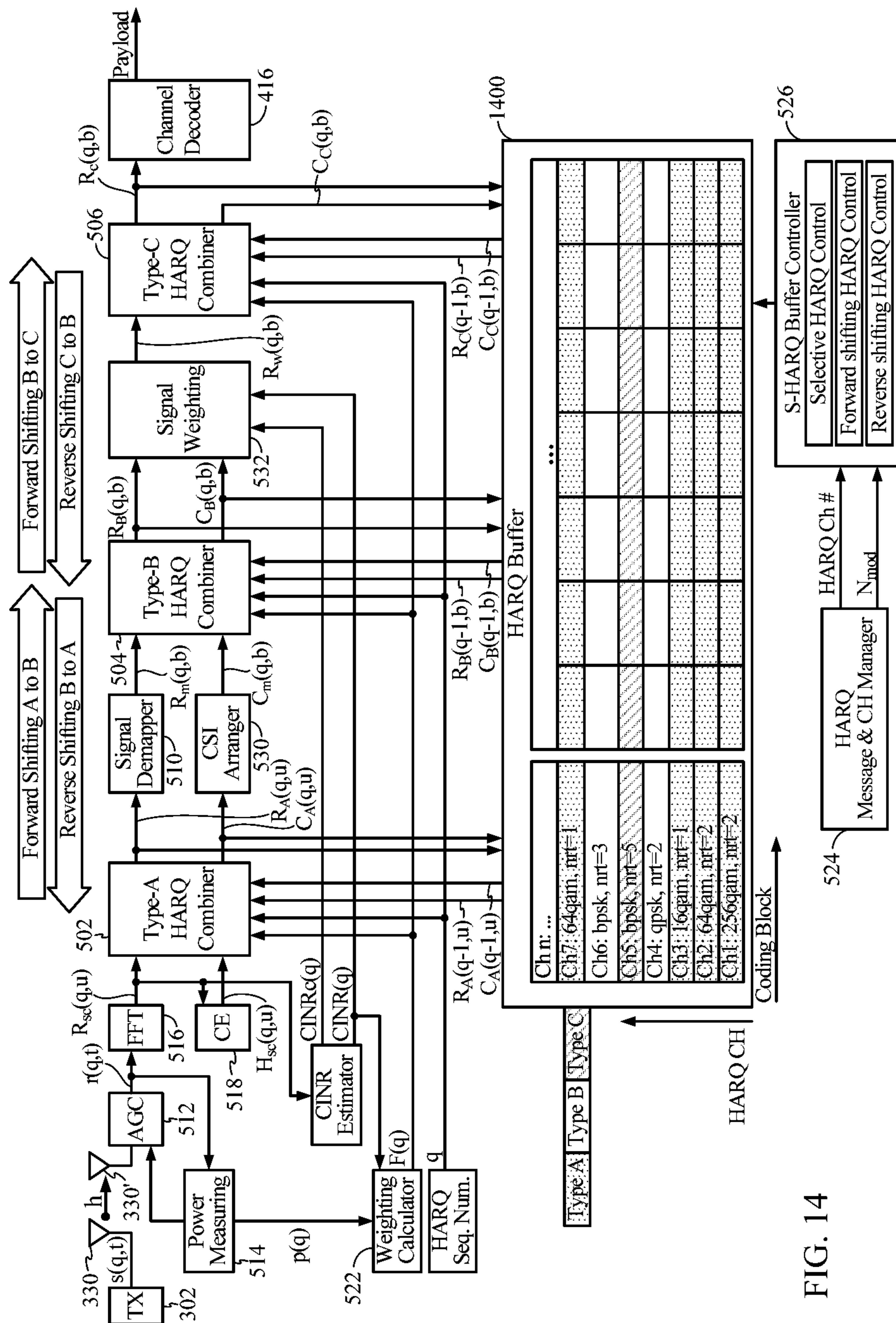


FIG. 14

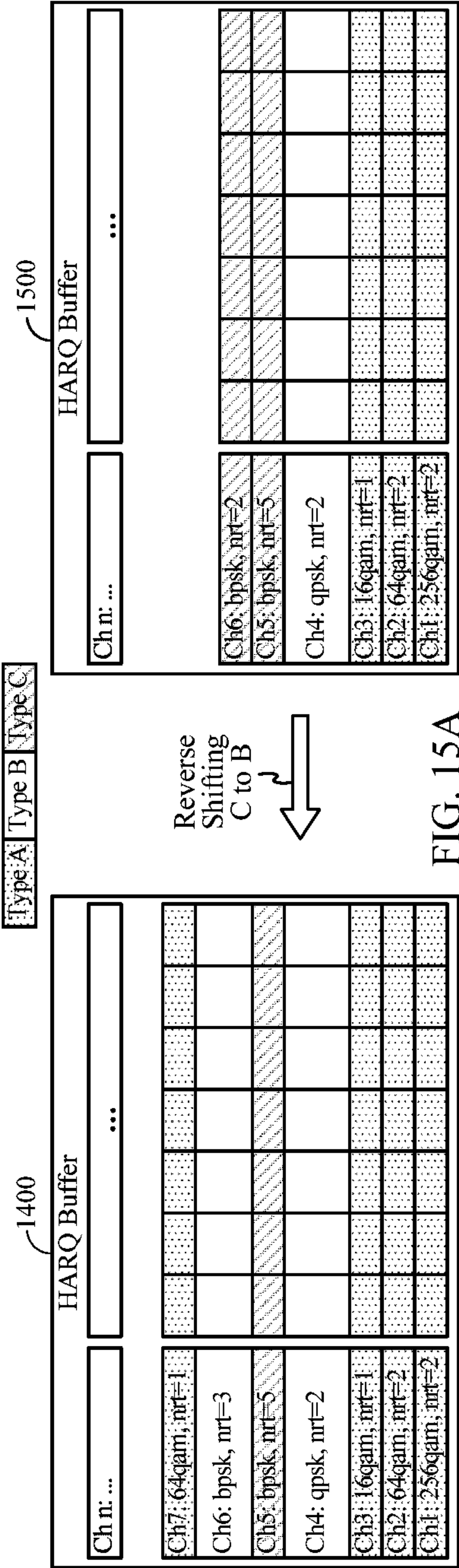


FIG. 15A

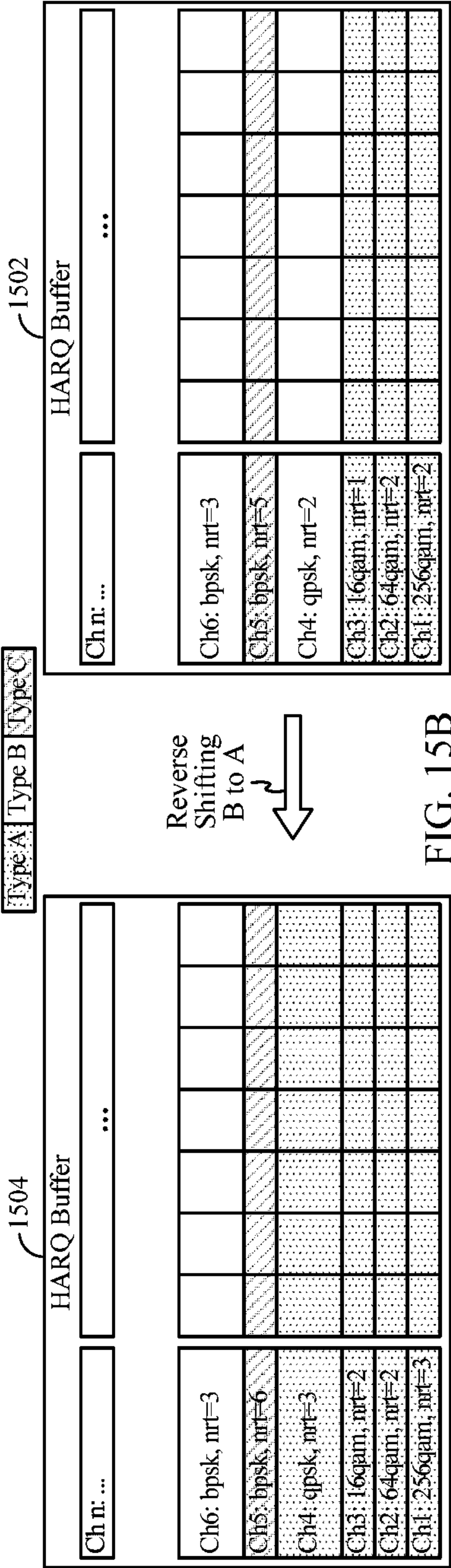


FIG. 15B

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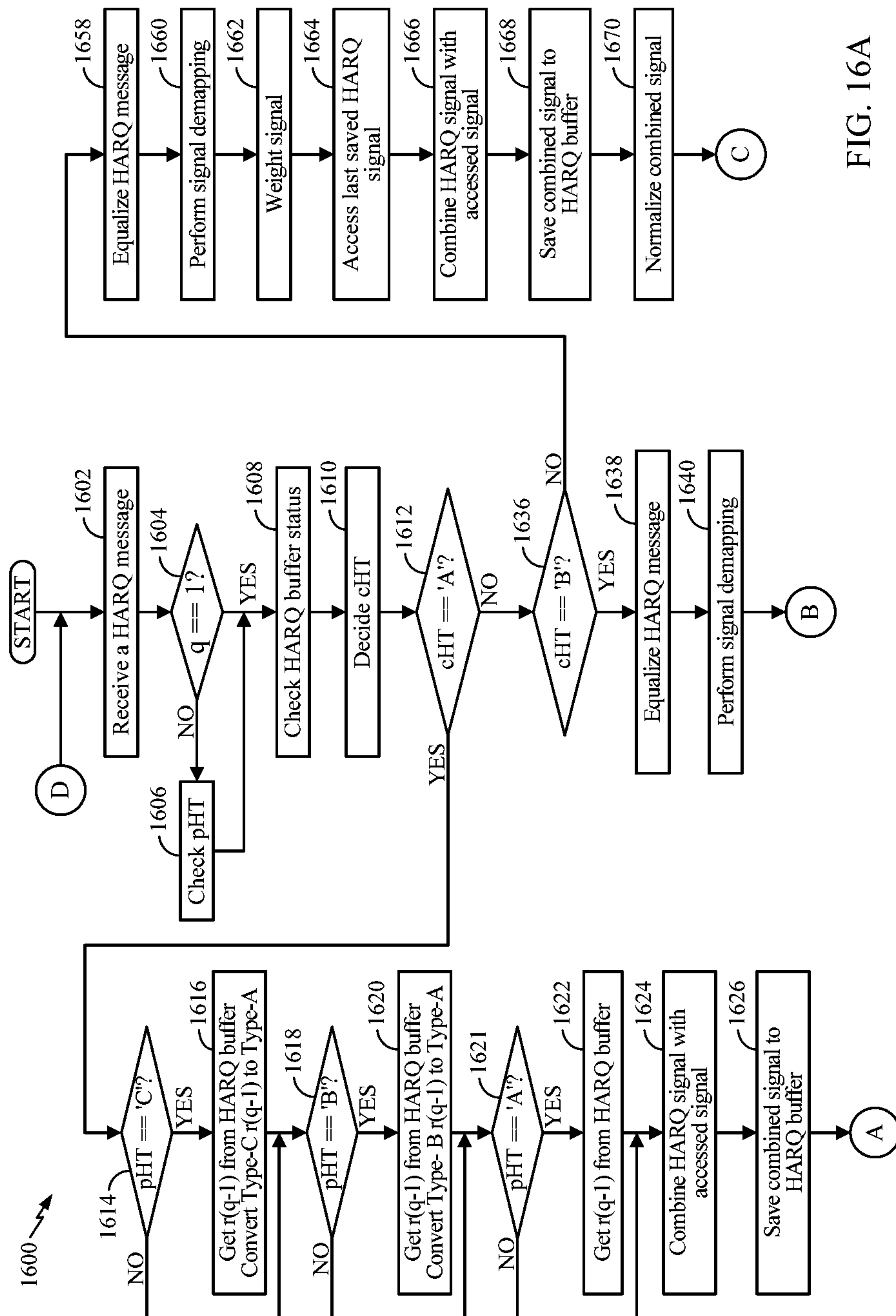
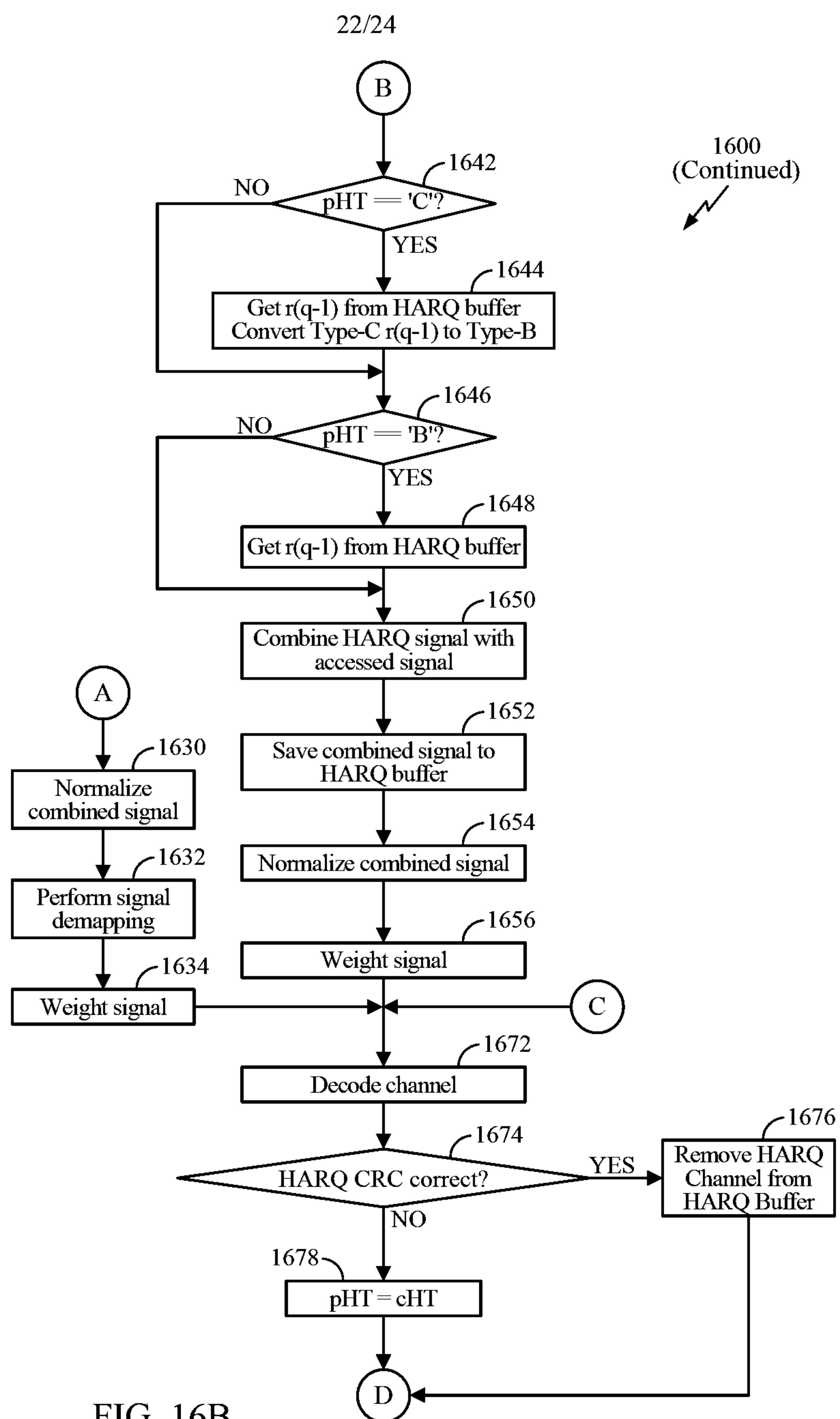


FIG. 16A



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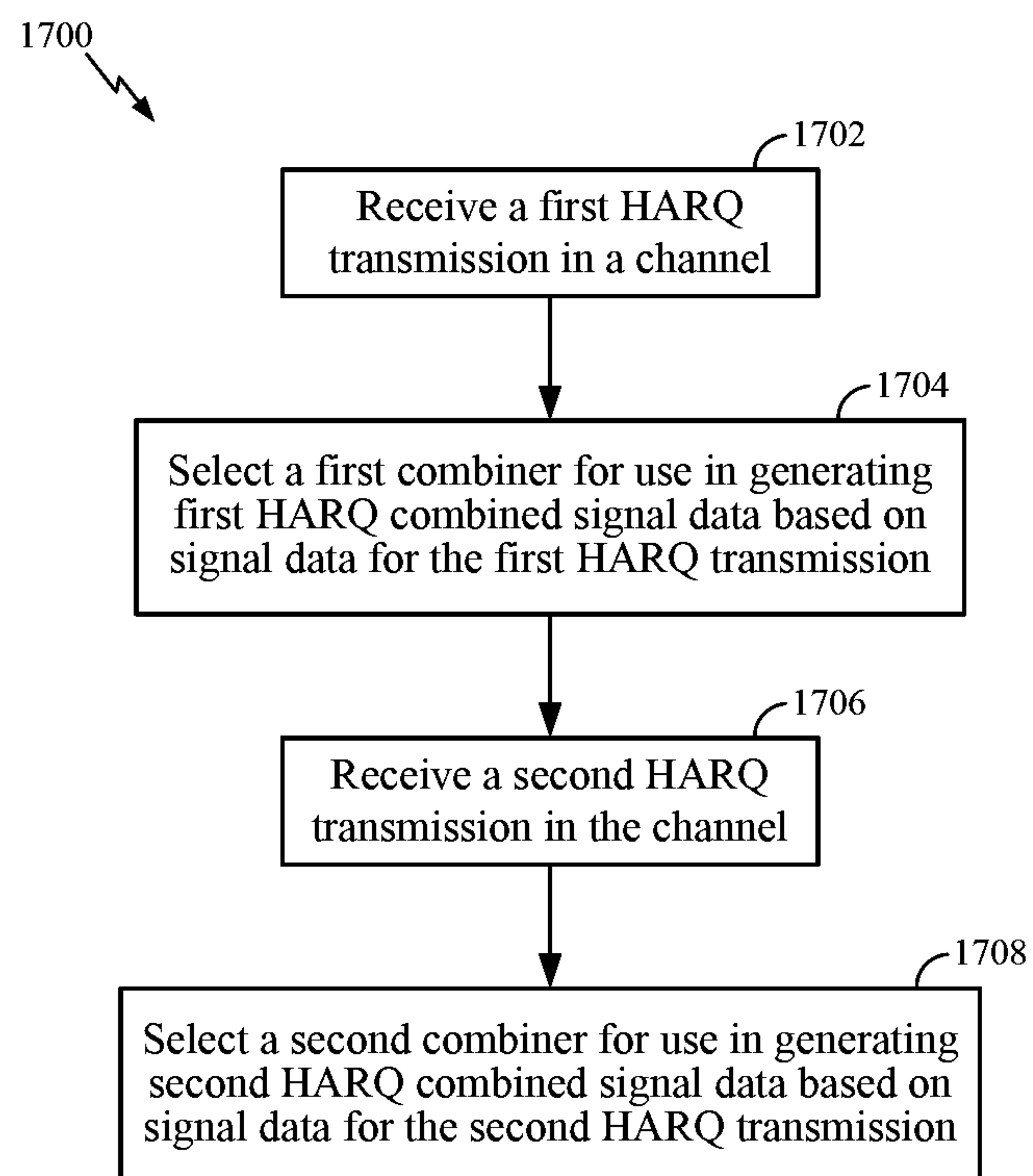


FIG. 17

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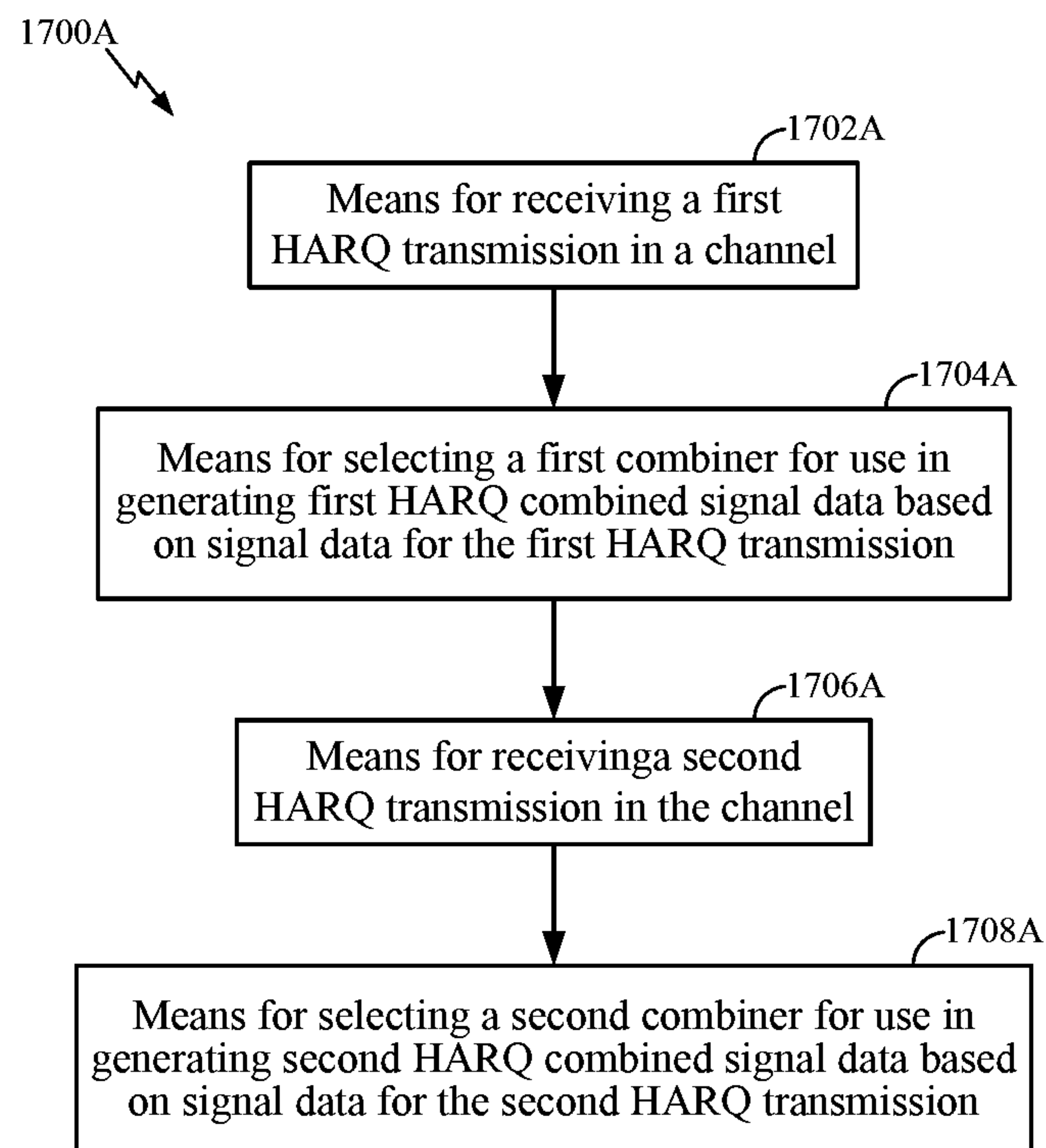


FIG. 17A

