



Office de la Propriété

Intellectuelle  
du Canada

Un organisme  
d'Industrie Canada

Canadian  
Intellectual Property  
Office

An agency of  
Industry Canada

CA 2692719 C 2017/06/20

(11)(21) **2 692 719**

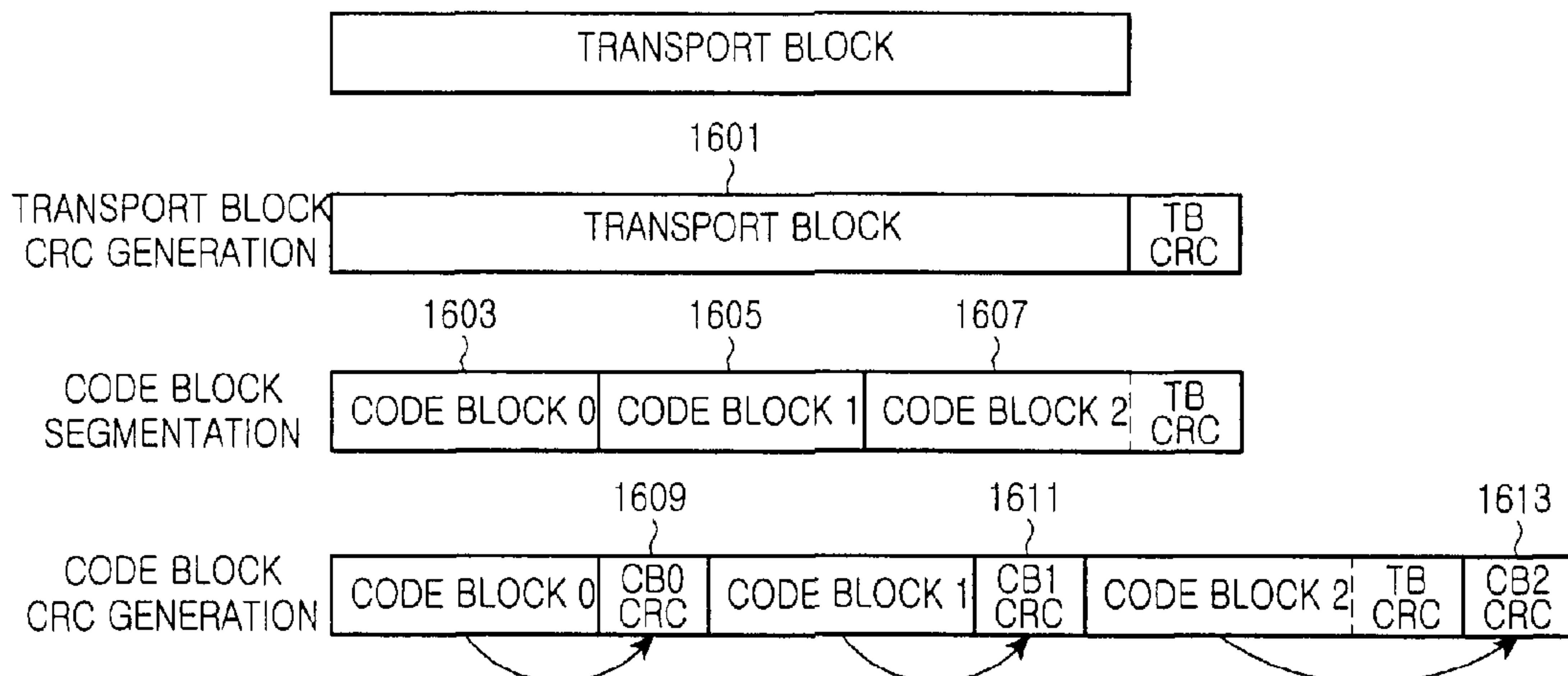
(12) **BREVET CANADIEN  
CANADIAN PATENT**

(13) **C**

(86) Date de dépôt PCT/PCT Filing Date: 2008/07/11  
(87) Date publication PCT/PCT Publication Date: 2009/01/15  
(45) Date de délivrance/Issue Date: 2017/06/20  
(85) Entrée phase nationale/National Entry: 2010/01/04  
(86) N° demande PCT/PCT Application No.: KR 2008/004102  
(87) N° publication PCT/PCT Publication No.: 2009/008682  
(30) Priorités/Priorities: 2007/07/12 (US60/929,790);  
2008/03/21 (US12/076,777)

(51) Cl.Int./Int.Cl. *H03M 13/09* (2006.01),  
*H03M 13/00* (2006.01)  
(72) Inventeurs/Inventors:  
PI, ZHOUYUE, US;  
KHAN, FAROOQ, US  
(73) Propriétaire/Owner:  
SAMSUNG ELECTRONICS CO., LTD., KR  
(74) Agent: MARKS & CLERK

(54) Titre : PROCEDES ET APPAREIL POUR CALCULER LE CRC POUR PLUSIEURS BLOCS DE CODE DANS UN  
SYSTEME DE COMMUNICATION  
(54) Title: METHODS AND APPARATUS TO COMPUTE CRC FOR MULTIPLE CODE BLOCKS IN A COMMUNICATION  
SYSTEM



(57) Abrégé/Abstract:

A method and a circuit for generating cyclic redundancy checks. The method calculates a plurality of cyclic redundancy checks for a transport block with a plurality of information bits. A transport block CRC is calculated for a transport block including a plurality of information bit. A transport block including the transport block CRC is segmented into a plurality of subsets and a plurality of cyclic redundancy checks are calculated for the plurality of subsets. At least one cyclic redundancy check among the plurality of cyclic redundancy checks is calculated based on a subset of information bits. In addition, a transport block cyclic redundancy check may be calculated based on all the information bits.

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

(19) World Intellectual Property Organization  
International Bureau(43) International Publication Date  
15 January 2009 (15.01.2009)

PCT

(10) International Publication Number  
WO 2009/008682 A1

## (51) International Patent Classification:

*H03M 13/09* (2006.01)    *H03M 13/00* (2006.01)

## (21) International Application Number:

PCT/KR2008/004102

## (22) International Filing Date:

11 July 2008 (11.07.2008)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

60/929,790	12 July 2007 (12.07.2007)	US
12/076,777	21 March 2008 (21.03.2008)	US

(71) **Applicant** (for all designated States except US): **SAMSUNG ELECTRONICS CO., LTD.** [KR/KR]; 416, Mae-tan-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do 442-742 (KR).

(72) **Inventors:** **PI, Zhouyue**; 4000 East Renner Rd., 1023, Richardson, Texas 75082 (US). **KHAN, Farooq**; 820 Saddlebrook Drive, Allen, Collin County, Texas 75002 (US).

(74) **Agent:** **LEE, Keon-Joo**; Mihwa Bldg. 110-2, Myon-gyun-dong 4-ga, Chongro-gu, Seoul 110-524 (KR).

(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).

**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:** METHODS AND APPARATUS TO COMPUTE CRC FOR MULTIPLE CODE BLOCKS IN A COMMUNICATION SYSTEM

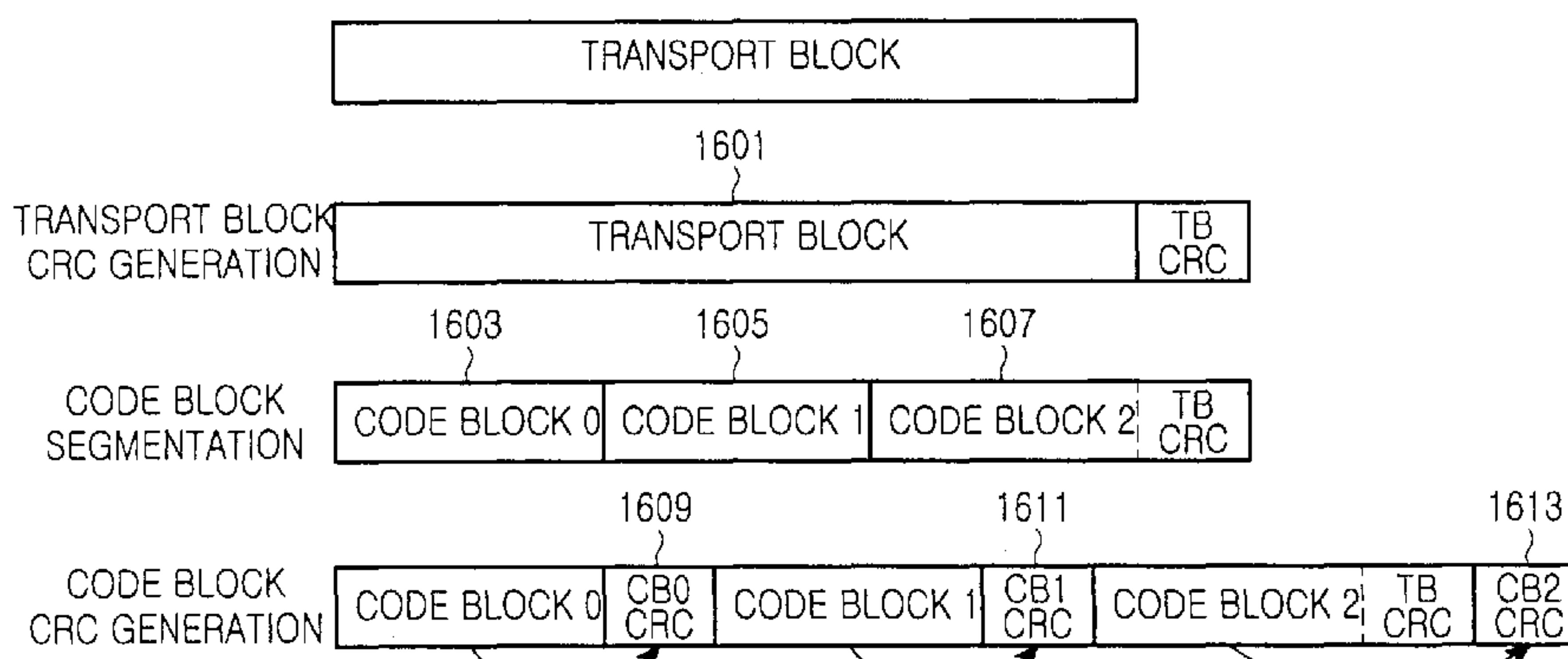


FIG.16

(57) **Abstract:** A method and a circuit for generating cyclic redundancy checks. The method calculates a plurality of cyclic redundancy checks for a transport block with a plurality of information bits. A transport block CRC is calculated for a transport block including a plurality of information bit. A transport block including the transport block CRC is segmented into a plurality of subsets and a plurality of cyclic redundancy checks are calculated for the plurality of subsets. At least one cyclic redundancy check among the plurality of cyclic redundancy checks is calculated based on a subset of information bits. In addition, a transport block cyclic redundancy check may be calculated based on all the information bits.

WO 2009/008682 A1

## **METHODS AND APPARATUS TO COMPUTE CRC FOR MULTIPLE CODE BLOCKS IN A COMMUNICATION SYSTEM**

### **BACKGROUND OF THE INVENTION**

#### **Field of the Invention**

The present invention relates to methods and apparatus to generate cyclic redundancy checks to multiple code blocks.

#### **Description of the Related Art**

A wireless communication system generally includes multiple base stations and multiple mobile stations, while a single base station often communicates with a set of mobile stations. The transmission from a base station to a mobile station is known as downlink communication. Likewise, the transmission from a mobile station to a base station is known as uplink communication. Both base stations and mobile stations may employ multiple antennas for transmitting and receiving radio wave signals. The radio wave signal may be either Orthogonal Frequency Division Multiplexing (OFDM) signals or Code Division Multiple Access (CDMA) signals. A mobile station may be either a PDA, laptop, or handheld device.

In a third Generation Partnership Project long term evolution (3GPP LTE) system, when a transport block is large, the transport block is segmented into multiple code blocks so that multiple coded packets can be generated, which is advantageous because of benefits such as enabling parallel processing or pipelining implementation and flexible trade off between power consumption and hardware complexity.

In a contemporary High Speed Data Shared Channel (HS-DSCH) design, only one 24-bit cyclic redundancy check (CRC) is generated for the whole transport block for the purpose of error detection for that block. If multiple code blocks are generated and transmitted in one transmission time interval (TTI), the receiver may correctly decode some of the code blocks but not the others. In that case, the receiver will feed back a non-acknowledgement (NAK) to the transmitter because the CRC for the transport block will not check.

## SUMMARY OF THE INVENTION

It is therefore an aspect of the present invention to provide improved methods and apparatus for generating cyclic redundancy checks for multiple code blocks in a communication system.

It is another aspect of the present invention to provide an improved method and apparatus for error detection in a communication system.

According to one aspect of the present invention, a method for communication is provided. A transport block CRC is calculated for a transport block including a plurality of information bit. A transport block included the transport block CRC is segmented into a plurality of subsets and a plurality of cyclic redundancy checks are calculated for the plurality of subsets.

The plurality of cyclic redundancy checks and the plurality of information bits are transmitted from a first node to a second node.

In response to the plurality of cyclic redundancy checks and the plurality of information bits received, the plurality of cyclic redundancy checks and the plurality of information bits are processed at the second node.

The subset of information bits may be jointly encoded by a certain type of forward error correcting code, such as a turbo code.

The subset of information bits and the at least one cyclic redundancy check that is calculated based on the subset of information bits may be jointly encoded.

A first cyclic redundancy check may be calculated for a first subset of information bits, and a second cyclic redundancy checks may be calculated for a second subset of information bits.

The first subset of information bits and the second subset of information bits may overlap with each other.

Alternatively, the first subset of information bits and the second subset of information bits may be separated from each other.

Still alternatively, the second subset of information bits may include the first subset of information bits.

At least one cyclic redundancy check among the plurality of cyclic redundancy checks may be calculated based on all of the information bits.

According to another aspect of the present invention, a method for communication is provided. At least one transport block of information bits are segmented into a plurality of code blocks. A plurality of code block cyclic redundancy checks are calculated for the plurality of code blocks, with at least one code block cyclic redundancy check being calculated based upon a corresponding code block. The plurality of code blocks and the plurality of code block cyclic redundancy checks are transmitted from a first node to a second node.

The bits in a code block selected from the plurality of code block may be jointly encoded using a certain type of forward error correcting code. In this case, a code block cyclic redundancy check is calculated based upon the jointly coded code block.

Each of the plurality of code block cyclic redundancy checks may be calculated based upon a corresponding one of the plurality of code blocks.

Each of the plurality of code block cyclic redundancy checks may be calculated based upon at least the corresponding one of the plurality of code blocks.

A transport block cyclic redundancy check may be calculated based on the transport block before segmenting the transport block.

The plurality of code blocks may include at least one code block from which no code block cyclic redundancy check is generated.

At least one code block cyclic redundancy check may be calculated based upon all of the plurality of code blocks.

According to yet another aspect of the present invention, a circuit for generating cyclic redundancy checks in data communications is provided with: an input port for receiving information data; an output port for outputting the information data and cyclic redundancy checks; a linear feedback shift register unit communicatively connected between the input port and the output port, and comprising L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of  $L-1$ ; a cyclic redundancy check register unit communicatively connected between the input port and the linear feedback shift register unit, and comprising L cyclic redundancy check registers; a first switch communicatively connected between the input port and the cyclic redundancy check register unit; a second switch communicatively connected

at a feedback loop of the linear feedback shift register unit; a third switch communicatively connected between the linear feedback shift register unit and the cyclic redundancy check register unit; and a fourth switch communicatively connected between the input port, the linear feedback shift register unit and the output port, and having a first position for connecting the input port and the output port, and a second position for connecting the linear feedback shift register unit and the output port.

The linear feedback shift register unit and the cyclic redundancy check register unit may be initialized to an all-zero state. The first switch may be set to connect the input port to the linear feedback shift register unit. The second switch may be set to connect the feedback loop of the linear feedback shift register unit. The third switch may be set to disconnect the linear feedback shift register unit and the cyclic redundancy check register unit. The fourth switch may be set to the first position to connect the input port with the output port. A code block of information data may be received via the input port. The first switch may be set to disconnect the input port and the linear feedback shift register unit. The second switch may be set to disconnect the feedback loop of the linear feedback shift register unit. The third switch may be set to connect the linear feedback shift register unit and the cyclic redundancy check register unit. The fourth switch may be set to the second position to connect the linear feedback shift register unit with the output port. The linear feedback shift register unit may be shifted L times to obtain the cyclic redundancy checks for the code block.

According to still another aspect of the present invention, a circuit for generating cyclic redundancy checks in data communications is provided with an input port for receiving information data; an output port for outputting the information data and cyclic redundancy checks; a linear feedback shift register unit communicatively connected between the input port and the output port, and comprising L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of  $L-1$ ; L state registers communicatively connected to corresponding ones of the L shift registers to write and read data values to and from the L shift registers; a first switch communicatively connected between the input port and the linear feedback shift

register unit; a second switch communicatively connected at a feedback loop of the linear feedback shift register unit; and a third switch communicatively connected between the input port, the linear feedback shift register unit and the output port, and having a first position for connecting the input port with the output port, and a second position for connecting the linear feedback shift register unit and the output port.

The linear feedback shift register unit and the state registers may be initialized to an all-zero state. The first switch may be set to connect the input port to the linear feedback shift register unit. The second switch may be set to connect the feedback loop of the linear feedback shift register unit. The third switch may be set to the first position to connect the input port with the output port. A code block of information data may be received via the input port. The data values in the L shift registers in the feedback shift register unit are written to the respectively corresponding state registers. The first switch may be set to disconnect the input port and the linear feedback shift register unit. The second switch may be set to disconnect the feedback loop of the linear feedback shift register unit. The third switch may be set to the second position to connect the linear feedback shift register unit with the output port. The linear feedback shift register unit are shifted L times to obtain the cyclic redundancy checks for the code block. Then, the first switch may be set to connect the input port to the linear feedback shift register unit; the second switch may be set to connect the feedback loop of the linear feedback shift register unit; and the third switch may be set to the first position to connect the input port with the output port. The data values in the state registers are written to the respectively corresponding shift registers in the feedback shift register unit.

According to still yet another aspect of the present invention, a circuit for generating cyclic redundancy checks in data communications is provided with an input port for receiving information data; an output port for outputting the information data and cyclic redundancy checks; a first linear feedback shift register unit communicatively connected between the input port and the output port, and comprising L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of  $L-1$ ; a second linear feedback shift register unit communicatively connected between the input port

and the output port being in parallel with the first linear feedback shift register unit, and comprising L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of L-1; a first switch communicatively connected between the input port and a common node between the first and second linear feedback shift register units; a second switch communicatively connected at a feedback loop of the first linear feedback shift register unit; a third switch communicatively connected between the input port, the common node between the first and second linear feedback shift register units, and the output port, and having a first position for connecting the input port with the output port, a second position for connecting the first linear feedback shift register unit and the output port, and a third position for connecting the second linear feedback shift register unit and the output port; and a fourth switch communicatively connected at a feedback loop of the second linear feedback shift register unit.

The first and second linear feedback shift register units and the cyclic redundancy check register unit may be initialized to an all-zero state. The first switch may be set to connect the input port to the common node between the first and second linear feedback shift register units; the second switch may be set to connect the feedback loop of the first linear feedback shift register unit; the third switch may be set to the first position to connect the input port with the output port; and the fourth switch may be set to connect the feedback loop of the second linear feedback shift register unit. A code block of information data may be received via the input port. A determination is made regarding whether the received code block is the last code block of the information data. When the received code block is not the last code block of the information data, the first switch may be set to disconnect the input port and the linear feedback shift register unit; the second switch may be set to disconnect the feedback loop of the linear feedback shift register unit; and the third switch may be set to the second position to connect the first linear feedback shift register unit with the output port. The first linear feedback shift register unit may be shifted L times to obtain the cyclic redundancy checks for the code block.

When the received code block of information data is the last code block of the information data, the third switch may be set to the third position to connect the second linear feedback shift register unit with the output port; and the fourth switch

may be set to disconnect the feedback loop of the linear feedback shift register unit. The second linear feedback shift register unit may be shifted L times to obtain the cyclic redundancy checks for the code block.

According to a further aspect of the present invention, a circuit for generating cyclic redundancy checks in data communications is provided with an input port for receiving information data; an output port for outputting the information data and cyclic redundancy checks; a linear feedback shift register unit communicatively connected between the input port and the output port, and comprising L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of  $L-1$ ; a first switch communicatively connected between the input port and the linear feedback shift register unit; a second switch communicatively connected at a feedback loop of the linear feedback shift register unit; and a third switch communicatively connected between the input port, the linear feedback shift register unit and the output port, and having a first position for connecting the input port with the output port, and a second position for connecting the linear feedback shift register unit and the output port.

The linear feedback shift register unit may be initialized to an all-zero state. The first switch may be set to connect the input port to the linear feedback shift register unit; the second switch may be set to connect the feedback loop of the linear feedback shift register unit; and the third switch may be set to the first position to connect the input port with the output port. A code block of information data may be received via the input port. The first switch may be set to disconnect the input port and the linear feedback shift register unit; the second switch may be set to disconnect the feedback loop of the linear feedback shift register unit; and the third switch may be set to the second position to connect the linear feedback shift register unit with the output port. The linear feedback shift register unit may be shifted L times to obtain the cyclic redundancy checks for the code block.

According to an aspect of the present invention, there is provided a method for generating Cyclic Redundancy Checks (CRCs) of information bits and transmitting the information bits together with the generated CRCs in a communication system, the method comprising the steps of:

generating a transport block CRC for a transport block including a plurality of information bits;

7a

segmenting the transport block including the transport block CRC into a plurality of subsets, wherein one of the plurality of subsets includes the transport block CRC; generating a plurality of CRCs for the plurality of subsets; jointly encoding the bits of each of the plurality of subsets and the corresponding CRC generated for the respective subset; and

transmitting the plurality of subsets and the plurality of CRCs for the plurality of subsets.

According to another aspect of the present invention, there is provided a communication apparatus, comprising:

- a first cyclic redundancy check (CRC) calculator configured to generate a transport block CRC for a transport block including a plurality of information bits;
- a segmentation unit configured to segment the transport block including the transport block CRC into a plurality of code blocks, wherein one of the plurality of code blocks includes the transport block CRC;
- a second CRC calculator configured to generate a plurality of CRCs for the plurality of code blocks;
- a channel encoder configured to jointly encode the bits of each of the plurality of code blocks and the corresponding CRC generated for the respective code block; and
- a transmitter configured to transmit the plurality of code blocks and the plurality of CRCs for the plurality of code blocks.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

A more complete appreciation of the invention, and many of the attendant advantages thereof, will be readily apparent as the same becomes better understood

by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference symbols indicate the same or similar components, wherein:

FIG. 1 is an illustration of an Orthogonal Frequency Division Multiplexing (OFDM) transceiver chain suitable for the practice of the principles of the present invention;

FIG. 2 is two coordinate graphs of OFDM subcarriers showing amplitude as a function of frequency;

FIG. 3 is an illustration of the waveforms for OFDM symbols in a time domain;

FIG. 4 is an illustration of single carrier frequency division multiple access transceiver chain;

FIG. 5 schematically shows a Hybrid Automatic Repeat request (HARQ) transceiver chain;

FIG. 6 schematically shows a Multiple Input Multiple Output (MIMO) system;

FIG. 7 schematically shows a precoded MIMO system;

FIG. 8 schematically shows a coding chain for High Speed Data Shared Channel (HS-DSCH) in a High Speed Downlink Packet Access (HSDPA) system;

FIG. 9 schematically shows a transport block cyclic redundancy check (CRC) and code block segmentation;

FIG. 10 is an illustration of using a linear feedback shift register (LFSR) for CRC computation;

FIG. 11 schematically shows High Speed Data Shared Channel (HS-DSCH) hybrid ARQ functionality;

FIG. 12 schematically shows long term evolution (LTE) downlink subframe structure;

FIG. 13 schematically shows LTE uplink subframe structure;

FIG. 14 schematically shows code block CRC;

FIG. 15 illustrates an example of code block segmentation;

FIG. 16 schematically illustrates code block (CB) CRCs and transport block (TB) CRCs according to one embodiment of the principles of the present invention;

FIG. 17 schematically illustrates code block (CB) CRCs and transport block (TB) CRCs according to another embodiment of the principles of the present invention;

FIG. 18 schematically illustrates code block (CB) CRCs and transport block (TB) CRCs according to yet another embodiment of the principles of the present invention;

FIG. 19 schematically illustrates code block (CB) CRCs and transport block (TB) CRCs according to still another embodiment of the principles of the present invention;

FIG. 20 schematically illustrates code block (CB) CRCs and transport block (TB) CRCs according to a further embodiment of the principles of the present invention;

FIG. 21 schematically illustrates a CRC computation circuit for multiple code blocks constructed as an embodiment according to the principles of the present invention;

FIG. 22 schematically illustrates a CRC computation circuit for multiple code blocks constructed as another embodiment according to the principles of the present invention;

FIG. 23 schematically illustrates a CRC computation circuit for multiple code blocks constructed as still another embodiment according to the principles of the present invention; and

FIG. 24 schematically illustrates a CRC computation circuit for multiple code blocks constructed as a further embodiment according to the principles of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

Orthogonal Frequency Division Multiplexing (OFDM) is a technology to multiplex data in frequency domain. Modulation symbols are carried on frequency sub-carriers. FIG. 1 illustrates an Orthogonal Frequency Division Multiplexing (OFDM) transceiver chain. In a communication system using OFDM technology, at transmitter chain 110, control signals or data 111 is modulated by modulator 112 into

-10-

a series of modulation symbols, that are subsequently serial-to-parallel converted by Serial/Parallel (S/P) converter 113. Inverse Fast Fourier Transform (IFFT) unit 114 is used to transfer the signals from frequency domain to time domain into a plurality of OFDM symbols. Cyclic prefix (CP) or zero prefix (ZP) is added to each OFDM symbol by CP insertion unit 116 to avoid or mitigate the impact due to multipath fading. Consequently, the signal is transmitted by transmitter (Tx) front end processing unit 117, such as an antenna (not shown), or alternatively, by fixed wire or cable. At receiver chain 120, assuming perfect time and frequency synchronization are achieved, the signal received by receiver (Rx) front end processing unit 121 is processed by CP removal unit 122. Fast Fourier Transform (FFT) unit 124 transfers the received signal from time domain to frequency domain for further processing.

In a OFDM system, each OFDM symbol consists of multiple sub-carriers. Each sub-carrier within an OFDM symbol carries a modulation symbol. FIG. 2 illustrates the OFDM transmission scheme using sub-carrier 1, sub-carrier 2, and sub-carrier 3. Because each OFDM symbol has finite duration in time domain, the sub-carriers overlap with each other in frequency domain. The orthogonality is, however, maintained at the sampling frequency assuming the transmitter and the receiver has perfect frequency synchronization, as shown in FIG. 2. In the case of frequency offset due to imperfect frequency synchronization or high mobility, the orthogonality of the sub-carriers at sampling frequencies is destroyed, resulting in inter-carrier-interference (ICI).

A time domain illustration of the transmitted and received OFDM symbols is shown in FIG. 3. As shown in FIG. 3, Due to multipath fading, the CP portion (CP1, CP2) of the received signal is often corrupted by the previous OFDM symbol. As long as the CP is sufficiently long, the received OFDM symbol without CP should, however, only contain its own signal convoluted by the multipath fading channel. In general, a Fast Fourier Transform (FFT) is taken at the receiver side to allow further processing frequency domain. The advantage of OFDM over other transmission schemes is its robustness to multipath fading. The multipath fading in time domain translates into frequency selective fading in frequency domain. With the cyclic prefix or zero prefix added, the inter-symbol-interference between adjacent OFDM

symbols are avoided or largely alleviated. Moreover, because each modulation symbol is carried over a narrow bandwidth, it experiences a single path fading. Simple equalization scheme can be used to combat frequency selection fading.

Single carrier frequency division multiple access (SC-FDMA), which utilizes single carrier modulation and frequency domain equalization is a technique that has similar performance and complexity as those of an OFDMA system. One advantage of SC-FDMA is that the SC-FDMA signal has lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure. Low PAPR normally results in high efficiency of power amplifier, which is particularly important for mobile stations in uplink transmission. SC-FDMA is selected as the uplink multiple access scheme in 3GPP long term evolution (LTE). An example of the transceiver chain for SC-FDMA is shown in FIG. 4. At the transmitter side, the data or control signal is serial to parallel (S/P) converted by a S/P converter 401. Discrete Fourier transform (DFT) will be applied to time-domain data or control signal by a DFT transformer 402 before the time-domain data is mapped to a set of sub-carriers by a sub-carrier mapping unit 403. To ensure low PAPR, normally the DFT output in the frequency domain will be mapped to a set of contiguous sub-carriers. Then IFFT, normally with larger size than the DFT, will be applied by an IFFT transformer 404 to transform the signal back to time domain. After parallel to serial (P/S) conversion by a P/S converter 405, cyclic prefix (CP) will be added by a CP insertion unit 406 to the data or the control signal before the data or the control signal is transmitted to a transmission front end processing unit 407. The processed signal with a cyclic prefix added is often referred to as a SC-FDMA block. After the signal passes through a communication channel 408, e.g., a multipath fading channel in a wireless communication system, the receiver will perform receiver front end processing by a receiver front end processing unit 409, remove the CP by a CP removal unit 410, apply FFT by a FFT transformer 412 and frequency domain equalization 413. Inverse Discrete Fourier transform (IDFT) 414 will be applied after the equalized signal is demapped in frequency domain. The output of IDFT will be passed for further time-domain processing such as demodulation and decoding after parallel to serial (P/S) converting by a P/S converter 415.

-12-

In packet-based wireless data communication systems, control signals transmitted through control channels, i.e., control channel transmission, generally accompany data signals transmitted through data channels, i.e., data transmission. Control channel information, including control channel format indicator (CCFI), acknowledgement signal (ACK), packet data control channel (PDCCH) signal, carries transmission format information for the data signal, such as user ID, resource assignment information, Payload size, modulation, Hybrid Automatic Repeat reQuest (HARQ) information, MIMO related information.

Hybrid Automatic Repeat reQuest (HARQ) is widely used in communication systems to combat decoding failure and improve reliability. FIG. 5 schematically shows a general Hybrid Automatic Repeat reQuest (HARQ) transceiver chain including Encoder 501, Subpacket Generator 502, Transceiver Chain 503 and Decoder 504. Each data packet is coded using certain forward error correction (FEC) scheme. Each subpacket generated in Subpacket Generator 502 may only contain a portion of the coded bits. If the transmission for subpacket  $k$  fails, as indicated by a NAK in a feedback acknowledgement channel 505, a retransmission subpacket, subpacket  $k+1$ , is transmitted to help the receiver decode the packet. The retransmission subpackets may contain different coded bits than the previous subpackets. The receiver may softly combine or jointly decode all the received subpackets to improve the chance of decoding. Normally, a maximum number of transmissions is configured in consideration of both reliability, packet delay, and implementation complexity.

Multiple antenna communication systems, which is often referred to as multiple input multiple output (MIMO), are widely used in wireless communication to improve system performance. In a MIMO system shown in FIG. 6, the transmitter 601 has multiple antennas 602 capable of transmitting independent signals and the receiver 603 is equipped with multiple receive antennas 604. MIMO systems degenerates to single input multiple output (SIMO) if there is only one transmission antenna or if there is only one stream of data transmitted. MIMO systems degenerates to multiple input single output (MISO) if there is only one receive antenna. MIMO systems degenerates to single input single output (SISO) if there is only one transmission antenna and one receive antenna. MIMO technology can

-13-

significant increase throughput and range of the system without any increase in bandwidth or overall transmit power. In general, MIMO technology increases the spectral efficiency of a wireless communication system by exploiting the additional dimension of freedom in the space domain due to multiple antennas. There are many categories of MIMO technologies. For example, spatial multiplexing schemes increase the transmission rate by allowing multiple data streaming transmitted over multiple antennas. Transmit diversity methods such as space-time coding take advantage of spatial diversity due to multiple transmit antennas. Receiver diversity methods utilizes the spatial diversity due to multiple receive antennas. Beamforming technologies improve received signal gain and reducing interference to other users. Spatial division multiple access (SDMA) allows signal streams from or to multiple users to be transmitted over the same time-frequency resources. The receivers can separate the multiple data streams by the spatial signature of these data streams. Note these MIMO transmission techniques are not mutually exclusive. In fact, many MIMO schemes are often used in an advanced wireless systems.

When the channel is favorable, e.g., the mobile speed is low, it is possible to use closed-loop MIMO scheme to improve system performance. In a closed-loop MIMO systems, the receivers feedback the channel condition and/or preferred Tx MIMO processing schemes. The transmitter utilizes this feedback information, together with other considerations such as scheduling priority, data and resource availability, to jointly optimize the transmission scheme. A popular closed loop MIMO scheme is called MIMO precoding. With precoding, the transmit data streams are pre-multiplied by a matrix before being passed on to the multiple transmit antennas. As shown in FIG. 7, assume there are  $N_t$  transmit antennas 702 and  $N_r$  receive antennas 704. Denote the channel between the  $N_t$  transmit antennas 702 and the  $N_r$  receive antennas 704 as  $H$ . Therefore  $H$  is an  $N_t \times N_r$  matrix. If the transmitter 701 has knowledge about  $H$ , the transmitter can choose the most advantageous transmission scheme according to  $H$ . For example, if maximizing throughput is the goal, the precoding matrix can be chosen to be the right singular matrix of  $H$ , if the knowledge of  $H$  is available at the transmitter. By doing so, the effective channel for the multiple data streams at the receiver side 703 can be diagonalized, eliminating the interference between the multiple data streams. However, the overhead required

-14-

to feedback the exact value of  $H$  is often prohibitive. In order to reduce feedback overhead, a set of precoding matrices are defined to quantize the space of the possible values that  $H$  could substantiate. With the quantization, a receiver feeds back the preferred precoding scheme, normally in the form of the index of the preferred precoding matrix, the rank, and the indices of the preferred precoding vectors. The receiver may also feed back the associated CQI values for the preferred precoding scheme.

Another perspective of a MIMO system is whether the multiple data streams for transmission are encoded separately or encoded together. If all the layers for transmission are encoded together, we call it a single codeword (SCW) MIMO system.

In a LTE system, when a transport block is large, the transport block is segmented into multiple code blocks so that multiple coded packets can be generated, which is advantageous because of benefits such as enabling parallel processing or pipelining implementation and flexible trade off between power consumption and hardware complexity. As an example, the encoding process of the High Speed Data Shared Channel (HS-DSCH) in a High Speed Downlink Packet Access (HSDPA) system is illustrated in the FIG. 8. In the current HS-DSCH design, only one 24-bit cyclic redundancy check (CRC) is generated for the whole transport block for the purpose of error detection for that block. If multiple code blocks are generated and transmitted in one transmission time interval (TTI), the receiver may correctly decode some of the code blocks but not the others. In that case, the receiver will feedback a non-acknowledgement (NAK) to the transmitter because the CRC for the transport block will not check. The reference number 901 to 905 shows the relationship of transport block, transport block CRC (TB CRC), and code block segmentation in FIG. 9.

Assume we use an  $L$ -bit CRC polynomial to generate the code block CRC. Denote the CRC generation polynomial by:

$$g(x) = g_0x^L + g_1x^{L-1} + \dots + g_{L-1}x + g_L. \quad (1)$$

In general, for a message:

$$m(x) = m_0x^{M-1} + m_1x^{M-2} + \dots + m_{M-2}x + m_{M-1}, \quad (2)$$

-15-

the CRC encoding is performed in a systematic form. Denote the CRC parity bits of the message as  $p_0, p_1, \dots, p_{L-1}$ , which can also be represented as a polynomial of:

$$p(x) = p_0x^{L-1} + p_1x^{L-2} + \dots + p_{L-2}x + p_{L-1}. \quad (3)$$

The polynomial,

$$m(x) \cdot x^L - p(x) = m_0x^{M+L-1} + m_1x^{M+L-2} + \dots + m_{M-2}x^{L+1} + m_{M-1}x^L + p_0x^{L-1} + p_1x^{L-2} + \dots + p_{L-2}x + p_{L-1} \quad (4)$$

yields a remainder equal to 0 when divided by  $g(x)$ .

Note that if each bit in the message is binary, the message can be represented as a polynomial defined on binary Galois field (GF(2)). In that case, the operation of '+' and '-' is the same. In other words, if the message bits are binary, the message with CRC attached can be represented by either  $m(x) \cdot x^L + p(x)$  or  $m(x) \cdot x^L - p(x)$ . In the rest of this invention, we assume the message bits are binary for the sake of convenience. The ideas disclosed in this invention may, however, certainly apply when the message bits are non-binary.

One reason of the popularity of CRC is because of its simplicity in implementation. CRC calculation can be easily implemented by a linear feedback shift register (LFSR). LFSR can be used as a circuit for polynomial division. As shown in FIG. 10, assume an L-bit CRC is used, LFSR 1000 has  $L$  shift registers( $R_0 \sim R_{L-1}$ ). Switches 1001, 1003 and 1005 are initially placed at position X. The message bit  $m_0, m_1, \dots, m_{M-1}$  are fed into LFSR 1000 one at a time in an order of increasing index. After the last bit ( $m_{M-1}$ ) has been fed into LFSR 1000, switches 1001, 1003 and 1005 are moved to position Y. LFSR 1000 is shifted by another  $L$  times to produce the CRC at the output of the rightmost register. Note the LFSR in FIG. 9 is only an example. There are certainly other implementations of LFSR for polynomial division and CRC calculation.

The hybrid ARQ functionality matches the number of bits at the output of the channel coder to the total number of bits of the High Speed Physical Downlink Shared Channel (HS-PDSCH) set to which the High Speed Data Shared Channel (HS-DSCH) is mapped. The hybrid ARQ functionality is controlled by the redundancy version (RV) parameters. The exact set of bits at the output of the hybrid ARQ functionality depends on the number of input bits, the number of output

bits, and the RV parameters. The hybrid ARQ functionality includes two rate-matching stages 1101 and 1103, and a virtual buffer 1105 as shown in FIG. 11. The output bits of the channel coder are segmented into systematic bits, parity bits 1 and parity bits 2 by bit separation stage 1107 and are inputted to the rate-matching stages. First rate matching stage 1101 matches the number of input bits to virtual IR buffer 1105, information about which is provided by higher layers. Note that, if the number of input bits does not exceed the virtual IR buffering capability, first rate-matching stage 1101 is transparent. Second rate matching stage 1103 matches the number of bits at the output of first rate matching stage 1101 to the number of physical channel bits available in the HS-PDSCH set in the TTI. The output bits of second rate matching stage 1103 are collected by a bit collection stage 1109 and are transmitted to a wireless network.

The downlink subframe structure of LTE is shown in FIG. 12. In a typical configuration, each subframe is 1 ms long, containing 14 OFDM symbols as shown in a vertical axis. Assume the OFDM symbols in a subframe are indexed from 0 to 13. Reference symbols (RS) for antenna 0 and 1 are located in OFDM symbols 0(1201), 4(1203), 7(1205), and 11(1207). If present, reference symbols (RS) for antennas 2 and 3 are located in OFDM symbols 1(1211) and 8(1213). The control channels, including Control Channel Format Indicator (CCFI), acknowledgement channel (ACK), packet data control channel (PDCCH), are transmitted in the first one, or two, or three OFDM symbols. The number of OFDM symbols used for control channel is indicated by CCFI. For example, the control channels can occupy the first OFDM symbol, or the first two OFDM symbols, or the first three OFDM symbols. Data channels, i.e., Physical Downlink Shared Channel (PDSCH), are transmitted in other OFDM symbols.

The uplink subframe structure (for data transmissions) is shown in FIG. 13. Note the LTE uplink is a SC-FDMA based system, which is very much like an OFDMA system with some differences. Similar to an OFDM symbol, each SC-FDMA block has a cyclic prefix (CP). For data transmissions, the reference signals (RSs) are located at the 4-th SC-FDMA block 1301 and the 11-th SC-FDMA block 1303, while the rest of the SC-FDMA blocks carrying data. Note that FIG. 13 only shows the time-domain structure of an uplink subframe. For each individual UE, its

transmission may only occupy a portion of the whole bandwidth in frequency domain. And different users and control signals are multiplexed in the frequency domain via SC-FDMA.

In this invention, we propose methods and apparatus to compute multiple CRCs for a transmission to improve the reliability of the transmission and reduce the transmitter and receiver complexity.

Aspects, features, and advantages of the invention are readily apparent from the following detailed description, simply by illustrating a number of particular embodiments and implementations, including the best mode contemplated for carrying out the invention. The invention is also capable of other and different embodiments, and its several details can be modified in various obvious respects, all without departing from the scope of the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive. The invention is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings. In the following illustrations, we use data channel in LTE systems as an example. The technique illustrated here, however, can certainly be used in other channel in LTE systems, and other data, control, or other channels in other systems whenever applicable.

We first illustrate the concept of transport block, code block, and code block Cyclic Redundancy Check (CRC). A portion of the encoding processing chain at the transmitter side is shown in FIG. 14. Multiple transport blocks in a TTI can be serially concatenated, if necessary. If the number of bits after transport concatenation is larger than  $Z$ , which is the maximum size of a code block in question, then code block segmentation is performed after the concatenation of the transport blocks. Note that in this invention, the transport blocks may or may not contain transport block CRC before the segmentation. After the code block segmentation, CRC can be generated for some, or all, of the code blocks. After the code block CRC is attached to a corresponding code block, the channel coder encodes the code block to which the CRC is attached. The hybrid ARQ functionality matches the number of bits outputted from the channel coder to the total number of bits of the High Speed Physical Downlink Shared Channel (HS-PDSCH) set to which the High Speed Data Shared Channel (HS-DSCH) is mapped. For illustration purpose, let's assume

-18-

code block CRC is generated for every code block, although the ideas disclosed in this invention certainly apply otherwise. For ease of illustration, we assume there is only one transport block. All the embodiments in this invention apply, however, to cases with multiple transport blocks and transport block concatenation. Also note that although we often use transmitter processing to illustrate the ideas of the invention, all the embodiments in this invention apply to CRC computation at both the transmitter and the receiver.

Denote the input bits to CRC computation by  $a_0, a_1, \dots, a_{A-1}$  where  $A$  is the size of the transport block. We call the input bits the information bits. Again, the methods described in this invention apply regardless of whether there is one or multiple transport block or whether the transport blocks contain transport block CRC or not. Assume we use an  $L$ -bit CRC polynomial to generate the code block CRC. Denote the CRC generation polynomial by:

$$g(x) = g_0x^L + g_1x^{L-1} + \dots + g_{L-1}x + g_L. \quad (5)$$

The transport block can be represented by a polynomial:

$$a(x) = a_0x^{A-1} + a_1x^{A-2} + \dots + a_{A-2}x + a_{A-1}. \quad (6)$$

Assume with code block segmentation, the transport block message is segmented into  $C$  code blocks. Denote the bits in code block  $i$  by  $b_{i,0}, b_{i,1}, \dots, b_{i,(B_i-1)}$ , where  $B_i$  is the size of the code block  $i$ ,  $i = 0, 1, \dots, C-1$ . Note the polynomial representation of code block  $i$  is:

$$b_i(x) = b_{i,0}x^{B_i-1} + b_{i,1}x^{B_i-2} + \dots + b_{i,(B_i-2)}x + b_{i,(B_i-1)}. \quad (7)$$

$$\text{Obviously, } A = \sum_{i=0}^{C-1} B_i.$$

Without loss of generality, we further assume a natural order of mapping from the information bits in the transport block 1501 to the code blocks 1503, ..., 1505, as shown in FIG. 15. We define:

$$D_i = \sum_{j=0}^{i-1} B_j, \text{ for } i = 0, 1, \dots, C. \quad (8)$$

$$\text{In other words, } D_0 = 0, D_1 = B_0, D_2 = B_0 + B_1, \dots, D_C = \sum_{i=0}^{C-1} B_i = A.$$

The transport block is segmented into  $C$  code blocks. The information bits in the  $i$ -th code block are as follows:

-19-

$$b_{i,0} = a_{D_i} \quad b_{i,1} = a_{D_i+1} \quad \dots \quad b_{i,B_i} = a_{D_{i+1}-1}, \text{ for } i = 0, 1, \dots, C-1. \quad (9)$$

In this way, the relationship between the transport block and the code blocks can be established as follows,

$$a(x) = \sum_{i=0}^{C-1} [b_i(x) \cdot x^{A-D_{i+1}}] \quad (10)$$

We further define:

$$a_k(x) = \sum_{i=0}^k [b_i(x) \cdot x^{D_{k+1}-D_{i+1}}], \text{ for } k = 0, 1, \dots, C-1. \quad (11)$$

where  $a_k(x)$  is the polynomial presentation of the information bits up to the  $k$ -th code block, including information bits in the previous code blocks. It is easy to see that  $a_0(x) = b_0(x)$ , and  $a_{C-1}(x) = a(x)$ . For the sake of simplicity, in the rest of the invention, these notations are used without repeated definition.

In a first embodiment according to the principles of the present invention, in a transmission of a first plurality of bits with a second plurality of CRCs or in a receiving process of such a transmission, at least one CRC is computed based on a subset of bits of the first plurality of bits such that at least one bit of the first plurality of bits is not in the said subset. In an example shown in FIG. 16, a transport block CRC is generated from a transport block and a transport block 1601 including the transport block CRC is segmented code block 0 1603, code block 1 1605, code block 2 1607. CB0\_CRC 1609 is computed based on information bits in Code Block 0 1603 but not based on information bits in Code Block 1 1605 or Code Block 2 1607. In doing so, a UE can use the CB0\_CRC 1609 to check whether the information bits in Code Block 0 1603 are received correctly before finishing the receiver processing for Code Block 1 1605 and Code Block 2 1607. This feature is particularly beneficial in terms of UE complexity reduction and power saving. The code block CRC can be used for purposes such as, but not limited to, providing error detection for the corresponding code block or code blocks, early stopping of iterative turbo decoding that can achieve power saving and statistical multiplexing of decoding capacity among code blocks, detecting decoding error of one code block that can avoid unnecessary decoding of other code blocks in the event of decoding error of one code block, etc.

-20-

In a second embodiment according to the principles of the present invention, in a transmission of a first plurality of bits with a second plurality of CRCs or in the receiver processing of such a transmission, at least one CRC is computed based on a subset of the first plurality of bits that are jointly encoded by some type of forward error correcting code. For example, as shown in FIG. 16, CB0\_CRC 1609 is computed based on the bits in Code Block 0 1603, a subset of all the bits in the transport block. The bits in Code Block 0 1603 are jointly encoded by some forward-error-correcting (FEC) code such as turbo code. FEC coding sometimes is also called channel coding. Note that CB0\_CRC 1609 is normally also jointly encoded with information bits in Code Block 0 1603 to achieve error protection for both the information bits and the CRC bits. By synchronizing the block of information bits for CRC computation and the block of information bits for FEC channel coding, a UE can use the code block CRC during the decoding process and determining whether the corresponding code block is decoded correctly. And this process can be done separately for each code block with a code block CRC, either in a parallel or a pipeline and serial fashion.

In a third embodiment according to the principles of the present invention, in a transmission of a first plurality of bits with a second plurality of CRCs or in the receiver processing of such a transmission, a first CRC is computed based on a first subset of bits while a second CRC is computed based on a second subset of bits. One example is shown in FIG. 16. In this example, the “subset of bits” is referred to as a code block. A transport block 1601 including the transport block CRC is computed for the transport block. Then the transport block is segmented into three code blocks. A CRC is computed for each code block. CB0\_CRC 1609, which is the code block CRC attached to Code Block 0 1603, is derived based on the bits in Code Block 0; CB1\_CRC 1611, which is the code block CRC attached to Code Block 1 1605, is derived based on the bits in Code Block 1; CB2\_CRC 1613, which is the code block CRC attached to Code Block 2 1607, is derived based on the bits in Code Block 2 including the transport block CRC. Also note that, in this example, the first subset of bits from which a first CRC is derived does not overlap with the second subset of bits from which a second CRC is derived. The subsets of bits can, however, certainly overlap without departing from the disclosure of this invention. Also note

-21-

that some subsets may include all the bits in the transmission. Also note that it is not necessary to compute CRCs for all the code blocks to use this invention. Some code block may not have code block CRC. Also note that a subset can also include bits in multiple code blocks. For example, as shown in FIG. 17, CB0\_CRC 1709 is derived based on the subset of bits that include the bits in Code Block 0 1703; CB1\_CRC 1711 is derived based on the subset of bits that include both the bits in Code Block 0 1709 and the bits in Code Block 1 1705; CB2\_CRC 1713 is derived based on the subset of bits that include the bits in Code Block 0 1703, the bits in Code Block 1 1705, and the bits in Code Block 2 1707.

In a fourth embodiment according to the principles of the present invention, in a transmission of a first plurality of bits with a second plurality of CRCs or in the receiver processing of such a transmission, the bits upon which a first CRC is derived are a subset of bits upon which a second CRC is derived. One example is shown in FIG. 17. For the purpose of illustration, we only show three code blocks. A transport block CRC is computed for the transport block. Then a transport block 1701 including the transport block CRC is segmented into three code blocks. A CRC is computed for each code block. CB0\_CRC 1709, which is the code block CRC attached to Code Block 0 1703, is derived based on the bits in Code Block 0; CB1\_CRC 1711, which is the code block CRC attached to Code Block 1 1705, is derived based on the bits in Code Block 0 and Code Block 1; CB2\_CRC 1713, which is the code block CRC attached to Code Block 2 1707, is derived based on the bits in Code Block 0 1703, Code Block 1 1705, and Code Block 2 1707. By doing so, we improve the miss detection performance of these CRCs, comparing with the CRCs derived based on a single code block. We assume the transport block is  $a(x) = a_0x^{A-1} + a_1x^{A-2} + \dots + a_{A-2}x + a_{A-1}$ , where  $A$  is the transport block size. If transport block CRC (TB CRC) is used, the TB CRC is included in the message. As defined earlier, the transport block  $a(x)$  is segmented into  $C$  code blocks with code block  $i$  represented by  $b_i(x)$ . We compute one CRC, namely CB0\_CRC, and attach it to the first code block. The CB0\_CRC can be derived from some or all of the bits in the first code block. We denote CB0\_CRC by:

$$p_0(x) = p_{0,0}x^{L-1} + p_{0,1}x^{L-2} + \dots + p_{0,L-2}x + p_{0,L-1}. \quad (12)$$

-22-

One example of computing CB0\_CRC is by finding the remainder of  $b_0(x) \cdot x^L$  divided by the CRC generator polynomial  $g(x)$ , in which  $p_0(x)$  can be represented as:

$$p_0(x) = b_0(x) \cdot x^L - q_0(x) \cdot g(x) \quad (13)$$

where  $q_0(x)$  is the quotient of  $b_0(x) \cdot x^L$  divided by  $g(x)$ . We compute another CRC, namely CB1\_CRC, and attach it to the second code block. CB1\_CRC can be derived from some or all of the bits in the first code block and some or all of the bits in the second code block. We denote CB1\_CRC by:

$$p_1(x) = p_{1,0}x^{L-1} + p_{1,1}x^{L-2} + \dots + p_{1,L-2}x + p_{1,L-1}. \quad (14)$$

One example of computing CB1\_CRC is by finding the remainder of  $(b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L$  divided by the CRC generator polynomial  $g(x)$ , in which  $p_1(x)$  can be represented as:

$$p_1(x) = (b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L - q_1(x) \cdot g(x), \quad (15)$$

where  $q_1(x)$  is the quotient of  $(b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L$  divided by  $g(x)$ . By deriving CB1\_CRC based on both the information bits in the first code block and the information bits in the second code block, we reduce the miss detection probability because CB1\_CRC can be used to detect error of information bits in the first code block and the second code block.

Obviously, if there are more than two code blocks, we can extend the operations in similar ways. For example, the CRC attached to Code Block 2 can be derived from bits in Code Block 0, Code Block 1, and Code Block 2. Alternatively, the CRC attached to one code block does not need to be derived based on the bits from all of the previous code blocks, including the current code block. For example, the CRC attached to Code Block 2 can be derived from the bits in Code Block 1 and Code Block 2, but not the bits in Code Block 0. Note this embodiment also applies when there is no transport block CRC, as shown in FIG. 18. If the error detection of the CB CRC is reliably enough, TB CRC may not be needed.

In a fifth embodiment according to the principles of the present invention, in a transmission of a first plurality of bits with a second plurality of CRCs or in the receiver processing of such a transmission, a transport block CRC is derived from all the bits in a transport block before the code block segmentation while there is at least one subset of bits from which no code block CRC is computed. As shown in FIG. 19,

-23-

a transport block CRC is computed based on bits in the transport block. Then the transport block 1901, including the transport block CRC, is segmented into three code blocks. In this example, CB0\_CRC 1909 is computed based upon bits in Code Block 0 1903; CB1\_CRC 1911 is computed based upon bits in Code Block 0 1903 and Code Block 1 1905. Because there is a transport block CRC that covers all the bits in the transport block, code block CRC for Code Block 2, however, is not necessary. The CB0\_CRC 1909 can be used for stopping turbo decoding iterations for Code Block 0 1903; the CB1\_CRC 1911 can be used for stopping turbo decoding iteration for Code Block 1 1905; and the TB\_CRC can be used for stopping turbo decoding iteration for Code Block 2 1907. At the same time, TB\_CRC provide error detection for the whole transport block.

In a sixth embodiment according to the principles of the present invention, in a transmission of a first plurality of information bits with a second plurality of CRCs or in the receiver processing of such a transmission, a first CRC is derived from all the information bits while a second CRC is derived from a subset of the information bits. As shown in FIG. 20, no transport block CRC is computed before code block segmentation. The transport block 2001 is segmented into three code blocks. Code block CRC is computed for each of the three code blocks. CB0\_CRC 2009 is derived from the bits in Code Block 0 2003; CB1\_CRC 2011 is derived from the bits in Code Block 1 2005; CB2\_CRC 2013 is derived from the bits in Code Block 0 2003, Code Block 1 2005, and Code Block 2 2007. The CB0\_CRC 2009 can be used for stopping turbo decoding iterations or error detection for Code Block 0 2003; the CB1\_CRC 2011 can be used for stopping turbo decoding iteration or error detection for Code Block 1 2005; and the CB2\_CRC 2013 can be used for stopping turbo decoding iteration and error detection for Code Block 2 2007. At the same time, CB2\_CRC 2013 provides error detection for the whole transport block.

In the following embodiments, we illustrate how linear feedback shift register (LFSR) based circuits can be used to efficiently calculate multiple CRCs for a plurality of information bits. Note that although we use the transmitter side CRC generation for illustration purpose, it is straightforward for a person of ordinary skill in the art to apply these methods to the receiver processing. For the sake of convenience, we assume the CRC calculation circuit is initialized to all-zero state.

-24-

The ideas disclosed in this invention may apply, however, when the initial state of the LFSR are set to non-zero state.

In a seventh embodiment according to the principles of the present invention, a first plurality of CRCs for a second plurality of information bits can be computed recursively with one single CRC calculation circuit. We compute one CRC, namely CB0\_CRC, and attach it to the first code block. The CB0\_CRC can be derived from some or all of the bits in the first code block. We denote CB0\_CRC by

$$p_0(x) = p_{0,0}x^{L-1} + p_{0,1}x^{L-2} + \dots + p_{0,L-2}x + p_{0,L-1}. \quad (16)$$

One example of computing CB0\_CRC is by finding the remainder of  $b_0(x) \cdot x^L$  divided by the CRC generator polynomial  $g(x)$ , in which  $p_0(x)$  can be represented as:

$$p_0(x) = b_0(x) \cdot x^L - q_0(x) \cdot g(x) \quad (17)$$

where  $q_0(x)$  is the quotient of  $b_0(x) \cdot x^L$  divided by  $g(x)$ . We compute another CRC, namely CB1\_CRC, and attach it to the second code block. CB1\_CRC can be derived from the bits in the first code block and the bits in the second code block. We denote CB1\_CRC by

$$p_1(x) = p_{1,0}x^{L-1} + p_{1,1}x^{L-2} + \dots + p_{1,L-2}x + p_{1,L-1}. \quad (18)$$

In other words, CB1\_CRC is the remainder of  $(b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L$  divided by the CRC generator polynomial  $g(x)$ , in which  $p_1(x)$  can be represented as:

$$p_1(x) = (b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L - q_1(x) \cdot g(x), \quad (19)$$

where  $q_1(x)$  is the quotient of  $(b_0(x) \cdot x^{B_1} + b_1(x)) \cdot x^L$  divided by  $g(x)$ . By deriving CB1\_CRC based on both the information bits in the first code block and the information bits in the second code block, we reduce the miss detection probability because CB1\_CRC can be used to detect error in both the first code block and the second code block. Similarly, the CRC for the  $k$ -th code block can be computed as the remainder of  $a_k(x) \cdot x^L$  divided by  $g(x)$ . In other words,

$$p_k(x) = a_k(x) \cdot x^L - q_k(x) \cdot g(x) \quad (20)$$

where  $q_k(x)$  is the quotient of  $a_k(x) \cdot x^L$  divided by  $g(x)$ . Note that:

$$a_k(x) = a_{k-1}(x) \cdot x^{B_k} + b_k(x). \quad (21)$$

This way of computing CRC lends itself well to a simple CRC calculation method. The CRC for the  $k$ -th code block can be represented as

-25-

$$\begin{aligned} p_k(x) &= [a_{k-1}(x) \cdot x^L \cdot x^{B_k} + b_k(x) \cdot x^L] - q_k(x) \cdot g(x) \\ &= p_{k-1}(x) \cdot x^{B_k} + b_k(x) \cdot x^L + [q_{k-1}(x) \cdot x^{B_k} - q_k(x)] \cdot g(x) \end{aligned} \quad (22)$$

In other words, the CRC of  $a_k(x)$  is the same as the CRC of  $p_{k-1}(x) \cdot x^{B_k} + b_k(x) \cdot x^L$ .

One example of circuit to recursively compute the CRC  $p_i(x)$ ,  $i = 0, 1, \dots, C-1$  is shown in FIG. 21. As shown in FIG. 21, the circuit for computing the CRC is constructed with an input port 2109 for receiving information data, an output port 2111 for outputting the information data and CRC, a linear feedback shift register (LFSR) unit 2100 communicatively connected between input port 2109 and output port 2111. LFSR unit 2100 includes L shift registers 2115, L AND gates 2113 (represented by “ $\times$ ” surround by a circle) and L XOR gates 2117 (represented by “ $+$ ” surround by a circle). A cyclic redundancy check register unit 2119 is connected between input port 2109 and LFSR unit 2100. Cyclic redundancy check register unit 2119 includes L cyclic redundancy check registers. A first switch 2101 is located between input port 2109 and cyclic redundancy check register unit 2119. First switch has a position X to connect input port 2109 and cyclic redundancy check register unit 2119, and a position Y to disconnect input port 2109 and cyclic redundancy check register unit 2119. A second switch 2103 is located at a feedback loop of LFSR unit 2100. Second switch 2103 has a position X to connect the feedback loop of LFSR unit 2100, and a position Y to disconnect the feedback loop of LFSR unit 2100. A third switch 2105 is located between LFSR unit 2100 and cyclic redundancy check register unit 2119. Third switch 2105 has a position X to disconnect LFSR unit 2100 and cyclic redundancy check register unit 2119, and a position Y to connect LFSR unit 2100 and cyclic redundancy check register unit 2119. A fourth switch 2107 is located between input port 2109, LFSR unit 2100 and output port 2111. Fourth switch 2107 has a position X to connect input port 2109 and output port 2111, and a position Y to connect LFSR unit 2100 and output port 2111. The switches can be any contemporary electronic switches such as, for example, any contemporary field effect transistors (FETs). The corresponding procedure for operating the circuit shown in FIG. 21 is outlined as follows:

Initialize LFSR unit 2100 to an all-zero state; Set  $k = 0$ ; Initialize the CRC registers to zero; Set all switches 2101, 2103, 2105 and 2107 at position X.

-26-

Input  $b_k(x)$  into the circuit, one bit at a time. Note the LFSR is also shifted once for every bit input.

Change all 2101, 2103, 2105 and 2107 switches to position Y.

Shift LFSR unit 2100 and the CRC registers  $L$  times to output  $p_k(x)$ , which is the  $L$ -bit CRC.

Reset LFSR unit 2100 to all-zero state; Change all switches to position X.

Increase k.

If  $k < C$ , go to Step 2.

The CRC attached to the  $k$ -th code block can be represented by Equation 20:  $p_k(x) = a_k(x) \cdot x^L - q_k(x) \cdot g(x)$ . In other words, the CRC of the  $k$ -th code block is computed based on the information bits of the  $k$ -th code block and all previous code blocks. As we can see, the calculation of the code block CRCs is the same as the calculation of the transport block CRC, except that after input each code block to the circuit, the CRC should be stored and added back at some point into the CRC calculation for the next code block. In this way, separate circuits and extra computation complexity for calculating code block CRC and transport block CRC are avoided. In fact, the last code block CRC equals to a transport block CRC. This structure fits well with the pipelining structure of the multiple code blocks. In addition, the miss detection performance of the transport block is guaranteed at the minimum. Note that Equation (20) is only for the case when the  $k$ -th code block CEC is calculated based upon the information bits of the  $k$ -th code block and all previous code blocks.

Alternatively, another example of circuit to recursively compute the CRC  $p_i(x)$ ,  $i = 0, 1, \dots, C-1$  is shown in FIG. 22 according to an eighth embodiment of the principles of the present invention. As shown in FIG. 22, the circuit is constructed with an input port 2215 for receiving information data, an output port 2217 for outputting the information data and CRC, a LFSR unit 2200 connected between input port 2215 and output port 2217. LFSR unit 2200 includes L shift registers. The circuit is further constructed with L state registers 2213 connected to corresponding ones of the L shift registers to write and read data values to and from the L shift registers. A first switch 2201 is located between input port 2215 and LFSR unit 2200. First switch 2201 has a position X to connect input port 2215 and

-27-

LFSR unit 2200, and a position Y to disconnect input port 2215 and LFSR unit 2200. A second switch 2203 is located at a feedback loop of LFSR unit 2200. Second switch 2203 has a position X to connect the feedback loop of LFSR unit 2200, and a position Y to disconnect the feedback loop of LFSR unit 2200. A third switch 2205 is located between input port 2215, LFSR unit 2200 and output port 2217. Third switch 2205 has a position X for connecting input port 2215 with output port 2217, and a position Y for connecting LFSR unit 2200 and output port 2217. This circuit achieves the same CRC computation as the circuit shown in FIG. 21. The corresponding procedure is outlined as follows:

Initialize LFSR unit 2200 to all-zero state; Set  $k = 0$ ; Initialize state registers 2213 to zero; Set all switches 2201, 2203 and 2205 at position X.

Input  $b_k(x)$  into the circuit via input port 2215, one bit at a time. Note the LFSR is also shifted once for every bit input.

Write the value of shift registers in LFSR unit 2200 to the corresponding state registers 2213; Change all switches 2201, 2203 and 2205 to position Y.

Shift LFSR unit 2200  $L$  times to obtain  $p_k(x)$ , which is the  $L$ -bit CRC.

Change all switches 2201, 2203 and 2205 to position X; Write the value of state registers 2213 into the corresponding shift registers in LFSR unit 2200.

Increase K.

If  $k < C$ , go to Step 2.

Another method to compute CRCs for multiple code blocks is to use two LFSRs according to a ninth embodiment of the principles of the present invention. As shown in FIG. 23, the circuit is constructed with an input port 2311 for receiving information data, an output port 2313 for outputting the information data and cyclic redundancy checks, a first LFSR unit 2300 connected between input port 2311 and output port 2313, and including L shift registers, a second LFSR unit 2301 connected between input port 2311 and output port 2313, being in parallel with first LFSR unit 2300, and comprising L shift registers. A first switch 2303 is located between input port 2311 and a common node 2317 between first and second LFSR units 2300 and 2301. First switch has a position X for connecting input port 2311 with common node 2317, and a position Y for disconnecting input port 2311 with common node 2317. A second switch 2305 is located at a feedback loop of first LFSR unit 2300.

-28-

Second switch 2305 has a position X for connecting the feedback loop of first LFSR unit 2300, and a position Y for disconnecting the feedback loop of first LFSR unit 2300. A third switch 2307 is located between input port 2311, common node 2317 between first and second LFSR units 2300 and 2301, and output port 2313. Third switch 2307 has a position X for connecting input port 2311 with output port 2313, a position Y for connecting first LFSR unit 2300 and output port 2313, and a position Z for connecting second LFSR unit 2301 and output port 2313. A fourth switch 2309 is located a feedback loop of second LFSR unit 2301. Fourth switch 2309 has a position X for connecting the feedback loop of second LFSR unit 2301, and a position Z for disconnecting the feedback loop of second LFSR unit 2301. This method can be outlined as follows:

Initialize first LFSR unit 2300 and second LFSR unit 2301 to all-zero state; Set  $k = 0$ ; Set all switches 2303, 2305, 2307 and 2309 at position X.

Input  $b_k(x)$  into the circuit via input port 2311, one bit at a time. Note that both first LFSR unit 2300 and second LFSR unit 2301 are also shifted once for every bit input.

Change first switch 2303 to position Y.

If  $k = C-1$ , go to Step 8; Otherwise, change switches 2305 and 2307 to position Y.

Shift first LFSR unit 2300  $L$  times to obtain  $p_k(x)$ , which is the  $L$ -bit CRC for the  $k$ -th code block.

Change switches 2303, 2305 and 2307 to position X; Reset first LFSR unit 2300.

Increase  $k$ , go to Step 2.

Change switches 2305 and 2307 to position Z.

Shift second LFSR 2301  $L$  times to obtain  $p_{C-1}(x)$ , which is the  $L$ -bit CRC for the last code block.

This method computes the  $k$ -th code block CRC only based on information bits in the  $k$ -th code block, except the last code block. Therefore, the  $k$ -th code block CRC, except the last code block CRC, can be represented by:

$$p_k(x) = b_k(x) \cdot x^L - q_k(x) \cdot g(x), \text{ for } k = 0, 1, \dots, C-2, \quad (23)$$

-29-

where C is the total number of code blocks. The last code block CRC is computed by LFSR2 and is derived from information bits in all the code blocks. Therefore, the last code block CRC can be represented by:

$$p_k(x) = a_k(x) \cdot x^L - q_k(x) \cdot g(x), \text{ for } k = C - 1. \quad (24)$$

Another method is to insert  $L$  0's at the bit positions for all code block CRCs to the message  $a(x)$  before input  $a(x)$  to the CRC calculation circuit according to a tenth embodiment of the principles of the present invention. An example of this implementation is illustrated in FIG. 24. The circuit is constructed with an input port 2407 for receiving information data, an output port 2409 for outputting the information data and CRCs, and a LFSR unit 2400 connected between input port 2407 and output port 2409, and including L shift registers for transforming the information data with a cyclic redundancy check generation polynomial  $g(x)$  having a degree of  $L-1$ . A first switch 2401 is located between input port 2407 and LFSR unit 2400. First switch 2401 has a position X for connecting input port 2407 and LFSR unit 2400, and a position Y for disconnecting input port 2407 and LFSR unit 2400. A second switch 2403 is located at a feedback loop of LFSR unit 2400. Second switch 2403 has a position X for connecting the feedback loop of LFSR unit 2400, and a position Y for disconnection the feedback loop of LFSR unit 2400. A third switch 2405 is located between input port 2407, LFSR unit 2400 and output port 2409. Third switch 2405 has a position X for connecting input port 2407 with output port 2409, and a position Y for connecting LFSR unit 2400 and output port 2409. Note that the  $L$  0's is added implicitly by changing the switches' position from X to Y for  $L$  shifts. Essentially, in this case, we allow the initial state of the LFSR to be dependant on the previous code blocks and thus enabling the current CRC to protect the bits in the current code block and previous code blocks. This method can be outlined as follows:

Initialize LFSR unit 2400 to all-zero state; Set  $k = 0$ ; Set all switches 2401, 2403 and 2405 at position X.

Input  $b_k(x)$  into the circuit via input port 2407, one bit at a time. Note the LFSR is also shifted once for every bit input.

Change all switches 2401, 2403 and 2405 to position Y.

-30-

Shift LSFR unit 2400  $L$  times to obtain  $p_k(x)$ , which is the  $L$ -bit CRC for the  $k$ -th code block.

Change all switches to position X.

Increase  $k$ .

If  $k < C$ , go to Step 2.

While the invention has been shown and described in connection with the preferred embodiments, it will be apparent to those skilled in the art that modifications and variations can be made without departing from the scope of the invention as defined by the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for generating Cyclic Redundancy Checks (CRCs) of information bits and transmitting the information bits together with the generated CRCs in a communication system, the method comprising the steps of:

generating a transport block CRC for a transport block including a plurality of information bits;

segmenting the transport block including the transport block CRC into a plurality of subsets, wherein one of the plurality of subsets includes the transport block CRC;

generating a plurality of CRCs for the plurality of subsets;

jointly encoding the bits of each of the plurality of subsets and the corresponding CRC generated for the respective subset; and

transmitting the plurality of subsets and the plurality of CRCs for the plurality of subsets.

2. The method of claim 1, wherein the step of generating the plurality of CRCs for the plurality of subsets further comprises generating n-th CRC based on n-th subset of the information bits.

3. The method of claim 1, wherein in the generating the plurality of CRCs, at least one CRC among the plurality of CRCs is generated based on the plurality of subsets.

4. The method of claim 1, wherein in the step of generating the plurality of CRCs, the last CRC among the plurality of CRCs is generated based on the last subset including the transport block CRC.

5. The method of any one of claims 1 to 4, wherein the jointly encoding is performed by a certain type of forward error correcting code.

6. The method of claim 5, wherein the certain type of forward error correcting code comprises a turbo code.

7. The method of claim 1, wherein the number of bits of the transport block CRC and a number of bits of the CRC for the subset are same.
8. The method of claim 6, wherein the plurality of subsets are separated from each other.
9. The method of claim 1, wherein at least one subset among the plurality of subsets comprises at least one of other subset.
10. The method of claim 1, wherein at least one CRC among the plurality of CRCs is generated based on all of the information bits.
11. The method of claim 1, wherein each of the plurality of CRCs is generated based upon a combination of the corresponding one of the plurality of subsets and other subsets that are proceeding the corresponding subset.
12. A communication apparatus, comprising:
  - a first cyclic redundancy check (CRC) calculator configured to generate a transport block CRC for a transport block including a plurality of information bits;
  - a segmentation unit configured to segment the transport block including the transport block CRC into a plurality of code blocks, wherein one of the plurality of code blocks includes the transport block CRC;
  - a second CRC calculator configured to generate a plurality of CRCs for the plurality of code blocks;
  - a channel encoder configured to jointly encode the bits of each of the plurality of code blocks and the corresponding CRC generated for the respective code block; and
  - a transmitter configured to transmit the plurality of code blocks and the plurality of CRCs for the plurality of code blocks.
13. The apparatus of claim 12, wherein the transport block CRC comprises L parity bits.

14. The apparatus of claim 12, wherein each of the plurality of CRCs for the plurality of code blocks comprises L parity bits.
15. The apparatus of any one of claims 12 to 14, wherein each of the code blocks and the plurality of CRCs for the plurality of code blocks are transmitted in an uplink communication transmission by a user equipment.
16. The apparatus of any one of claims 12 to 14, wherein each of the code blocks and the plurality of CRCs for the plurality of code blocks are transmitted in a downlink communication transmission by a base station.
17. The apparatus of any one of claims 12 to 16, wherein the channel encoder jointly encodes each of the code blocks and each of the plurality of CRCs for the plurality of code blocks by a certain type of forward error correcting code.
18. The apparatus of claim 17, wherein the certain type of forward error correcting code comprises a turbo code.
19. The apparatus of any one of claims 12 to 18, wherein the number of bits of the transport block CRC and a number of bits of the plurality of CRCs for the plurality of code blocks are same.

1/23

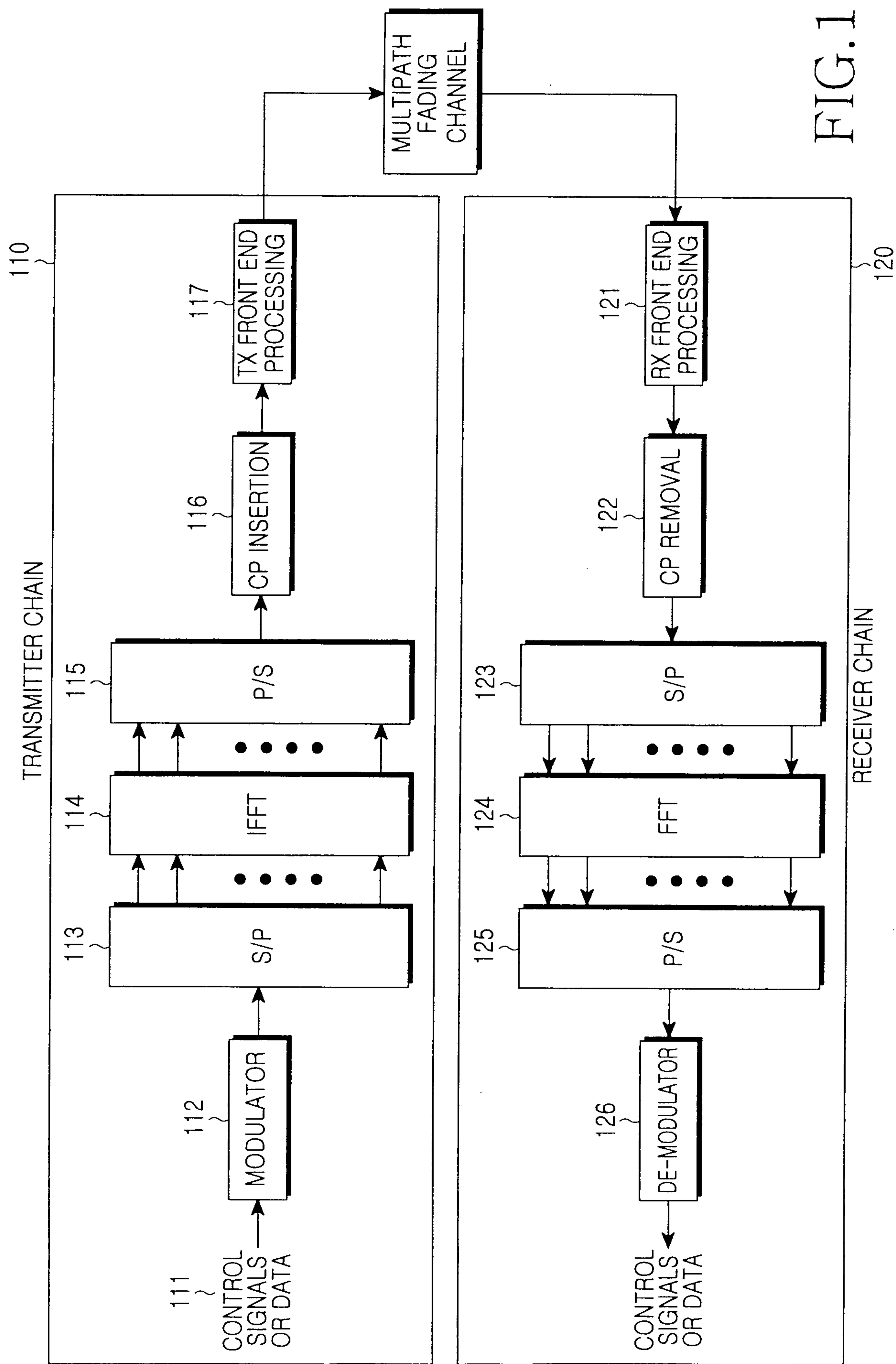


FIG. 1

2/23

## ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

..... SUB-CARRIER 0 —— SUB-CARRIER 1 - - - SUB-CARRIER 2

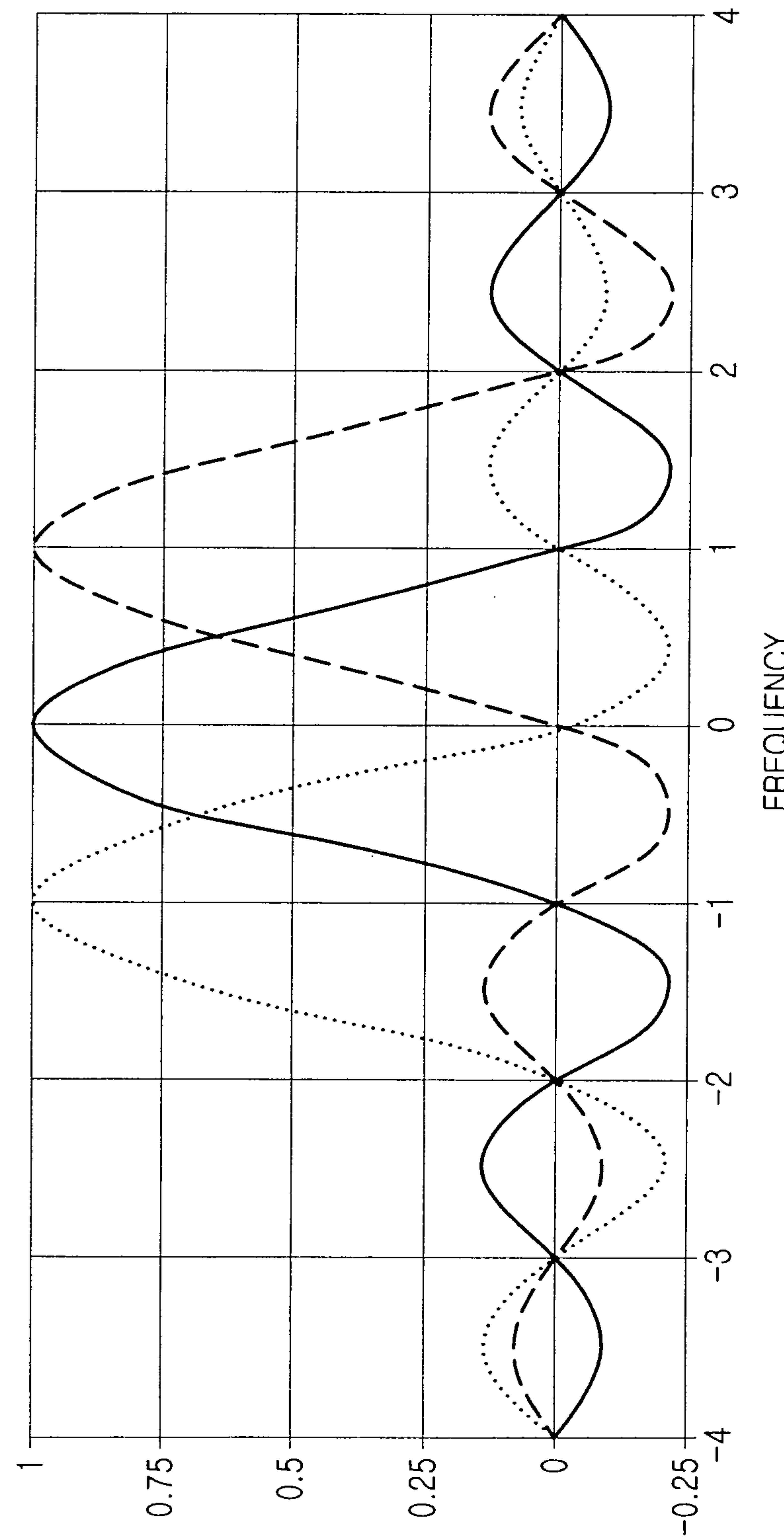


FIG. 2

3/23

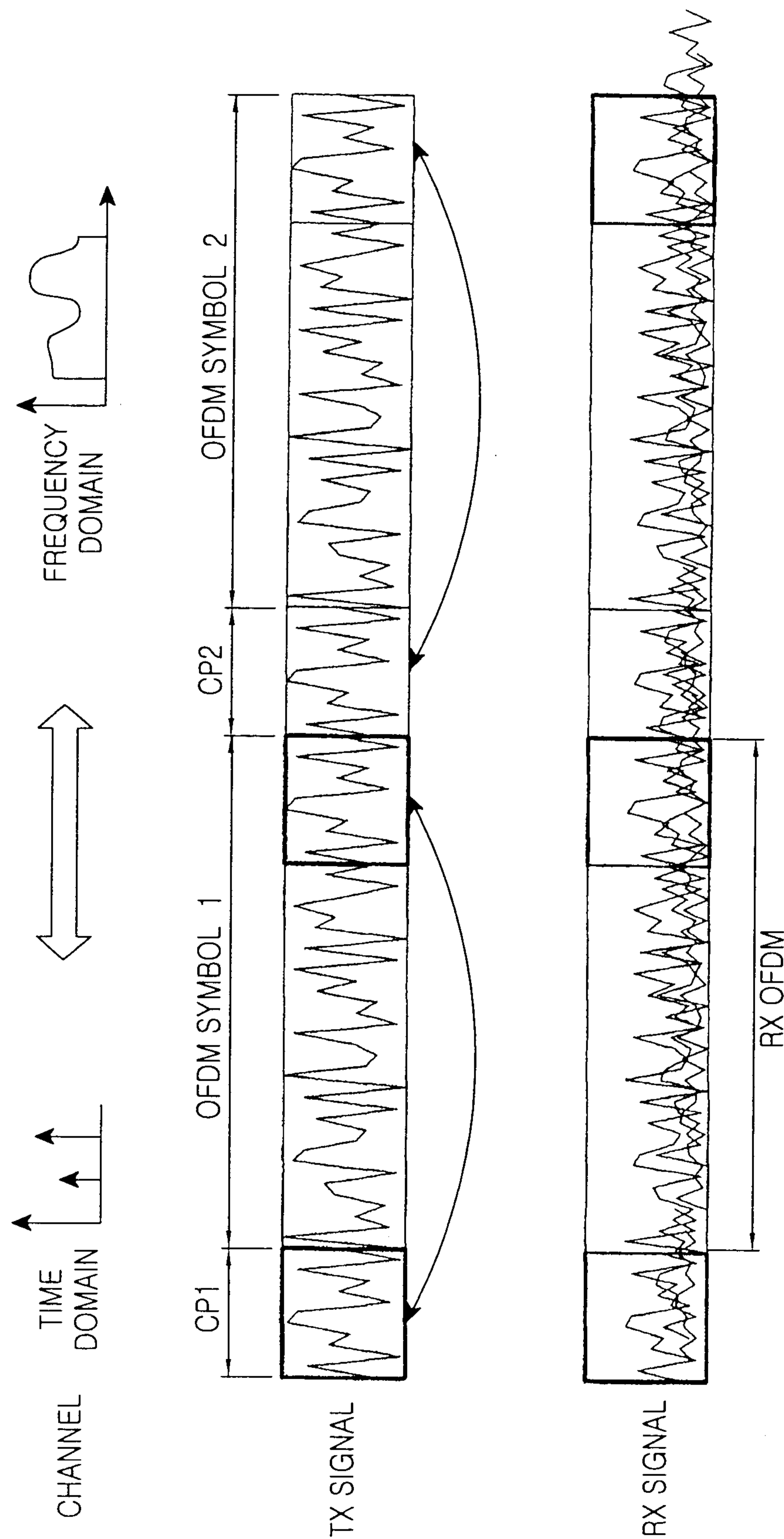


FIG. 3

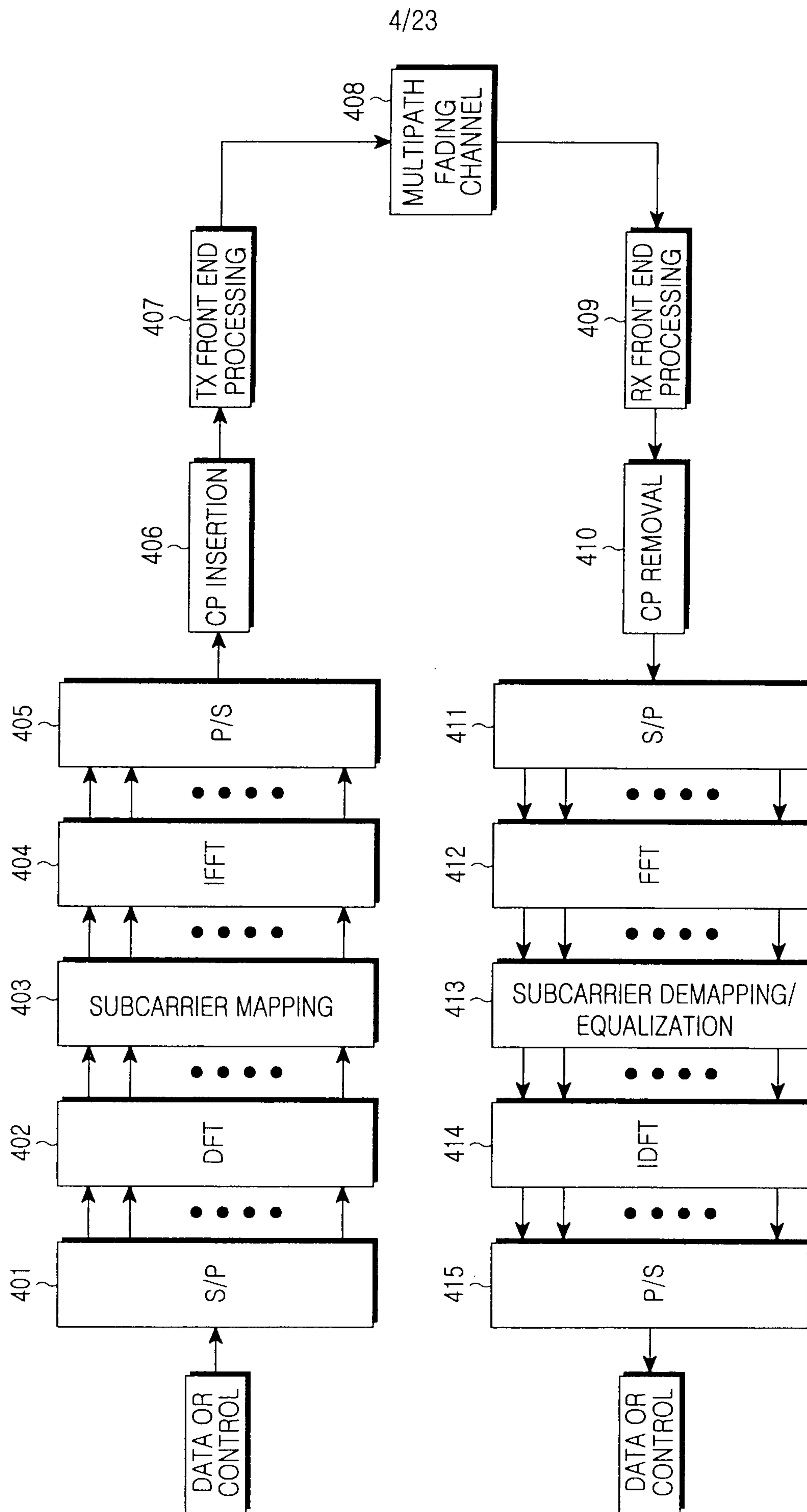


Fig.

5/23

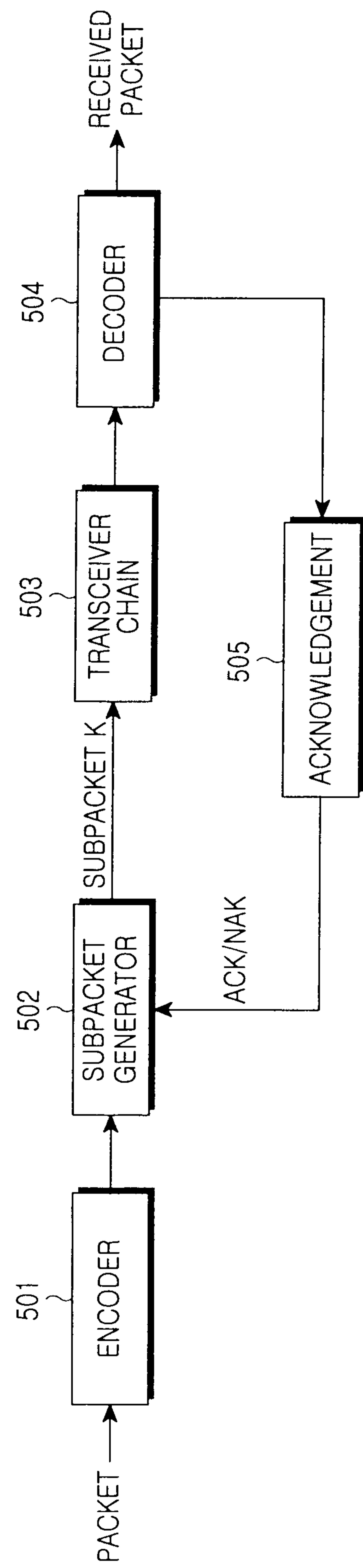


FIG.5

6/23

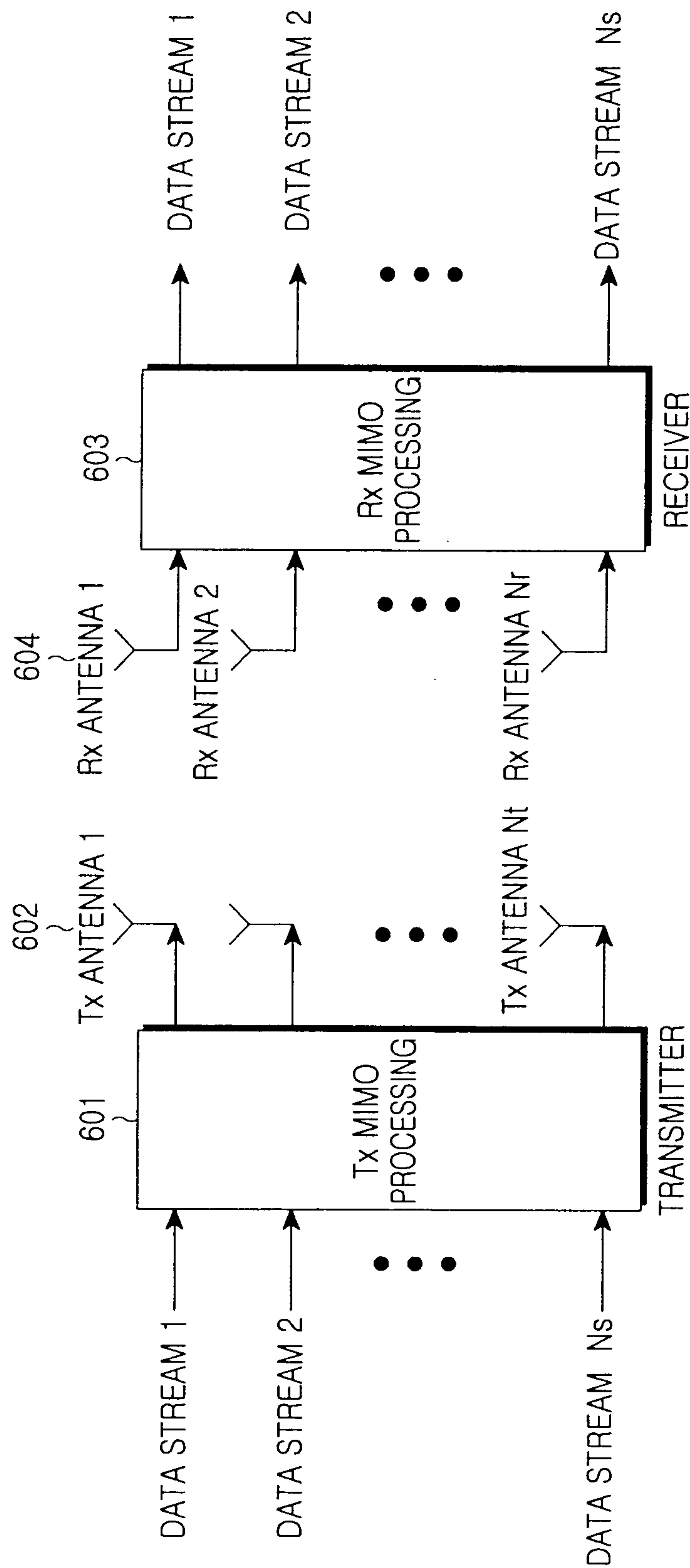


FIG. 6

7/23

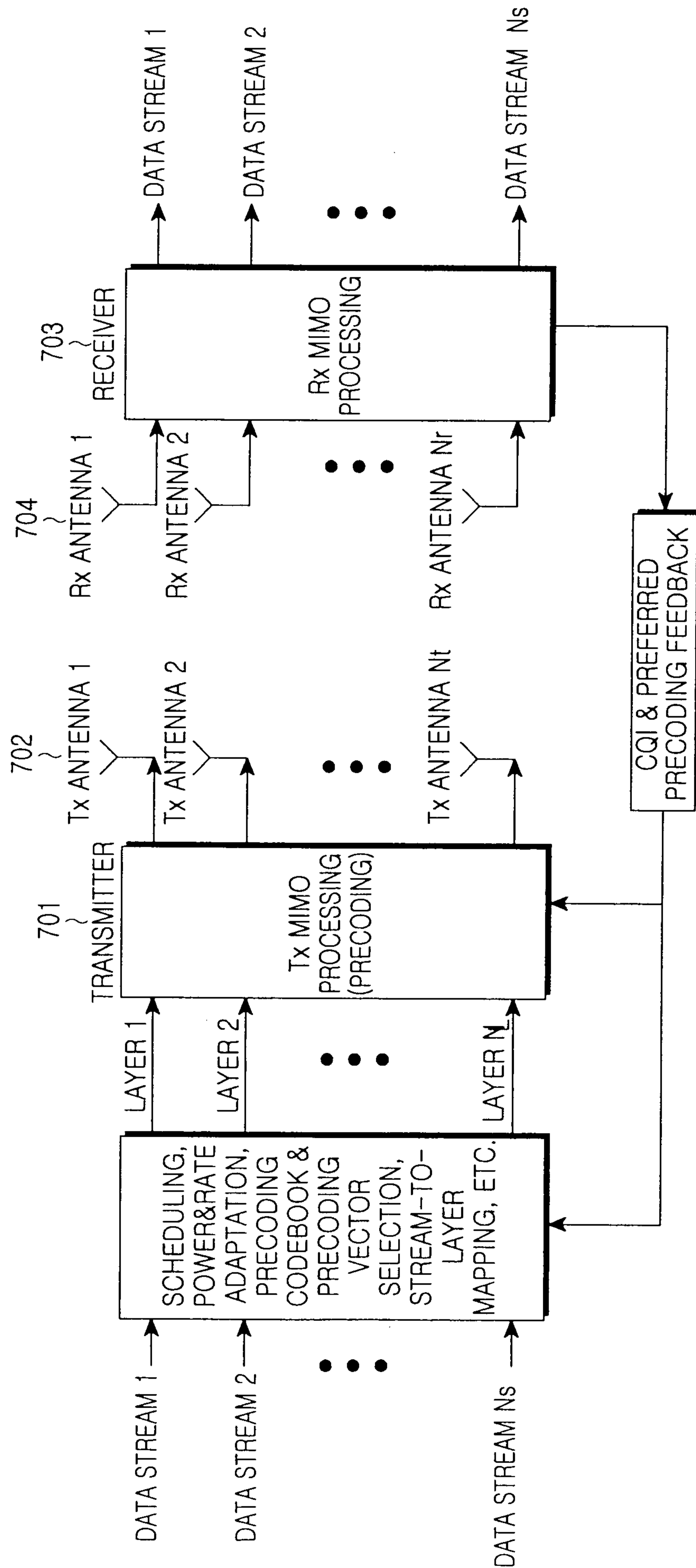


FIG. 7

8/23

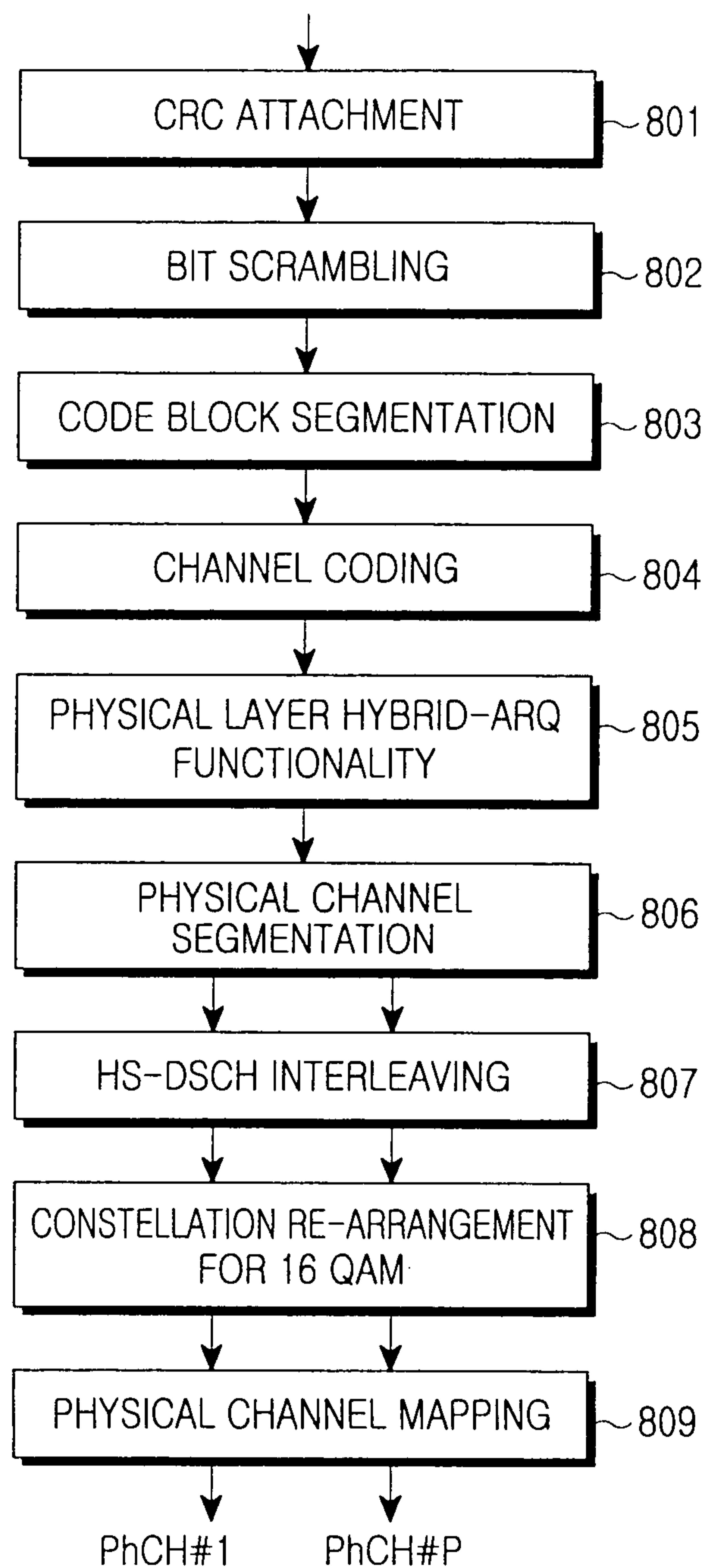


FIG.8

9/23

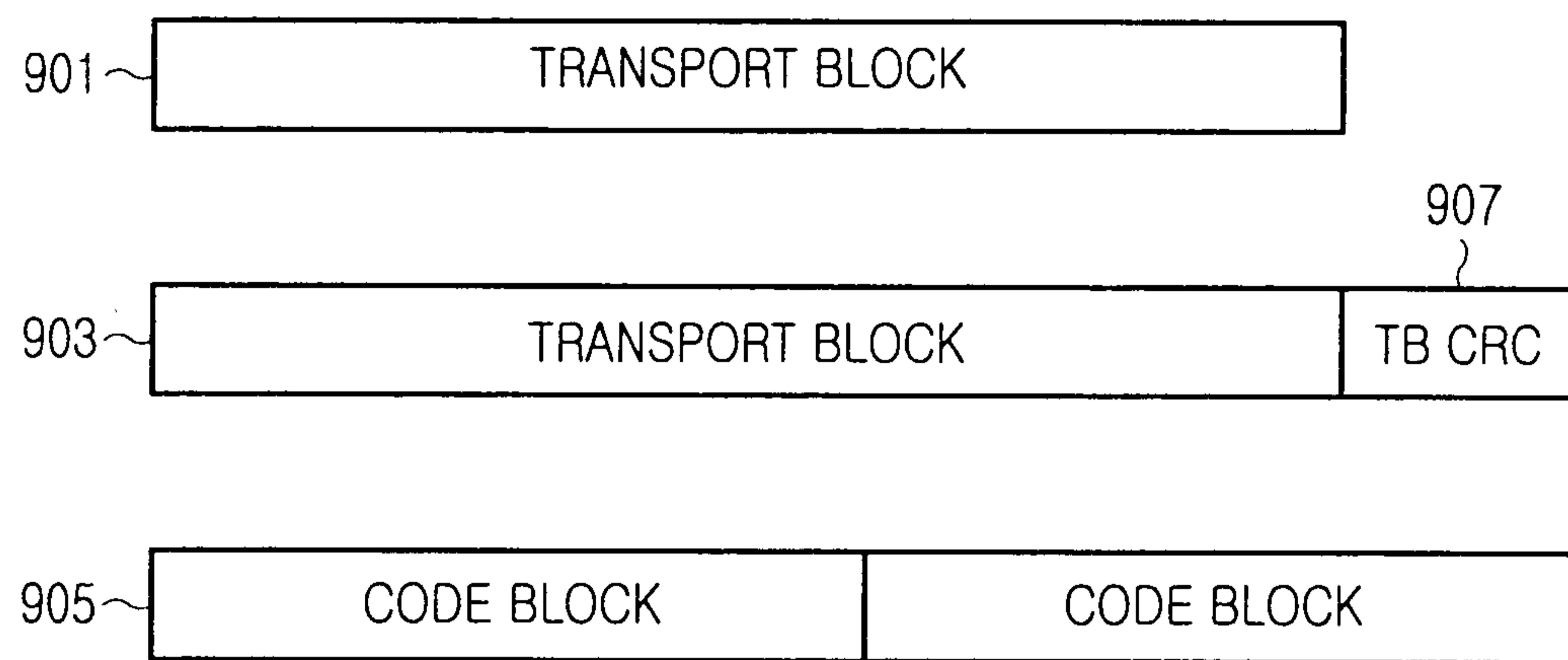


FIG.9

10/23

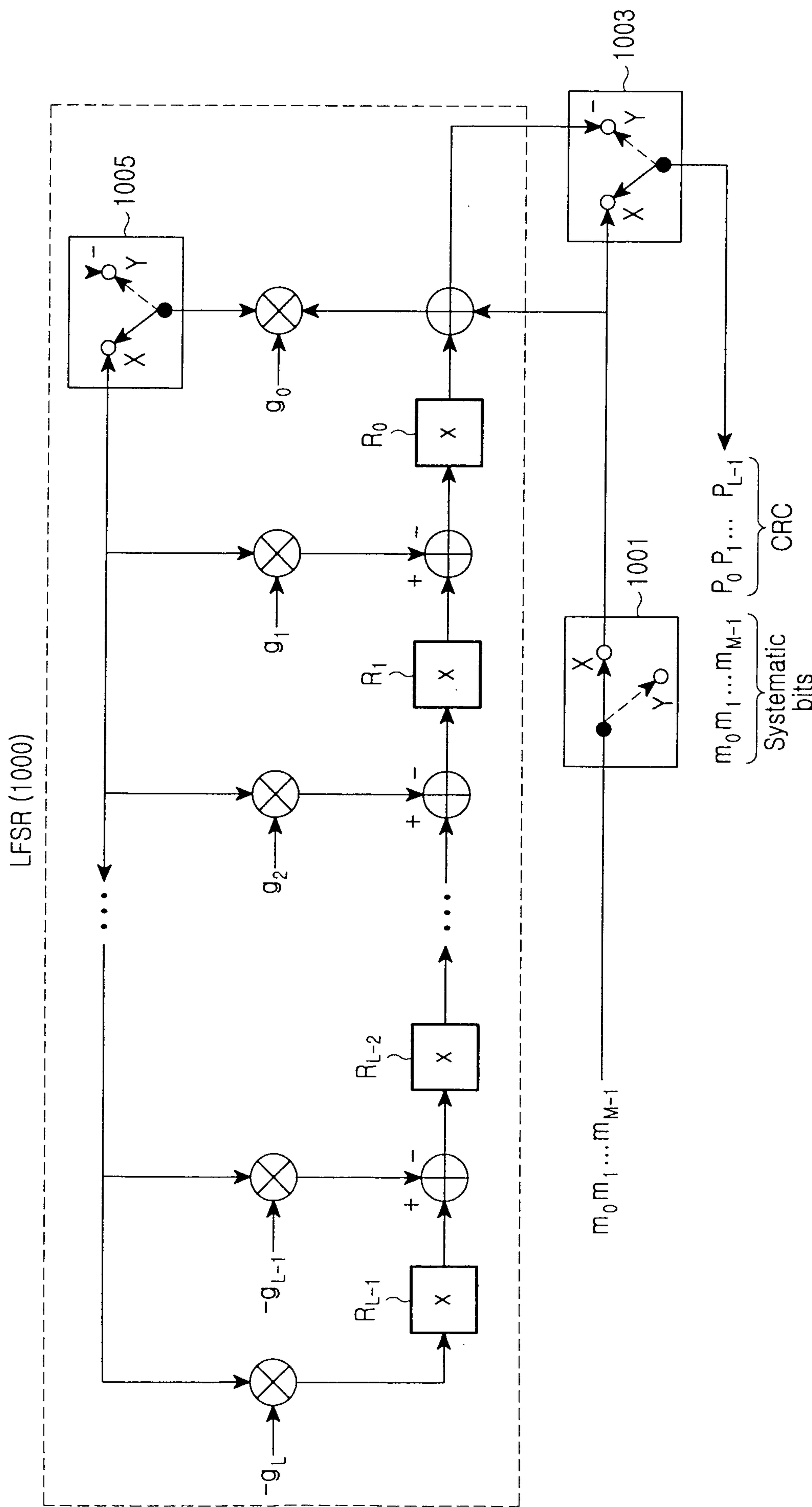


FIG. 10

11/23

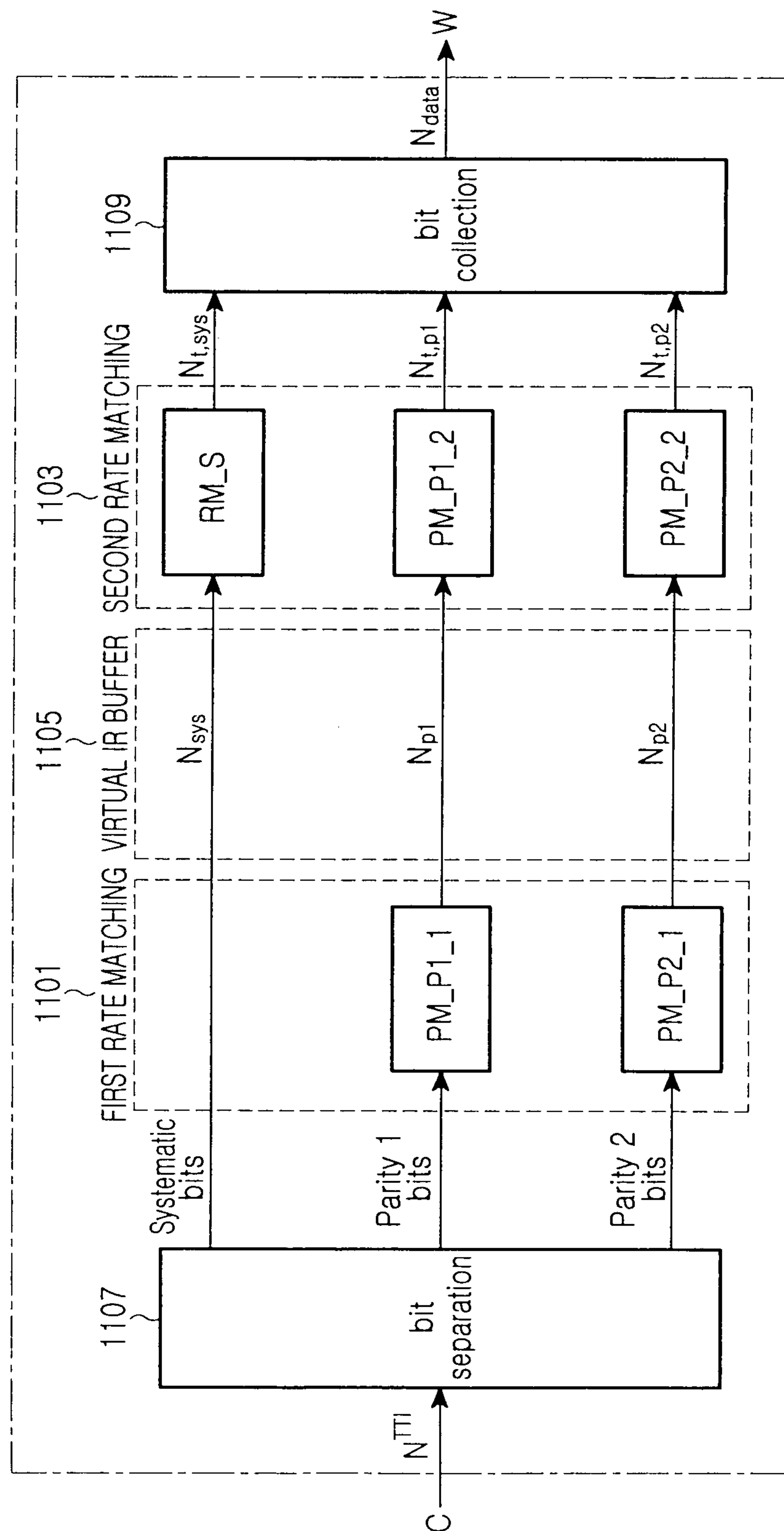


FIG. 11

12/23

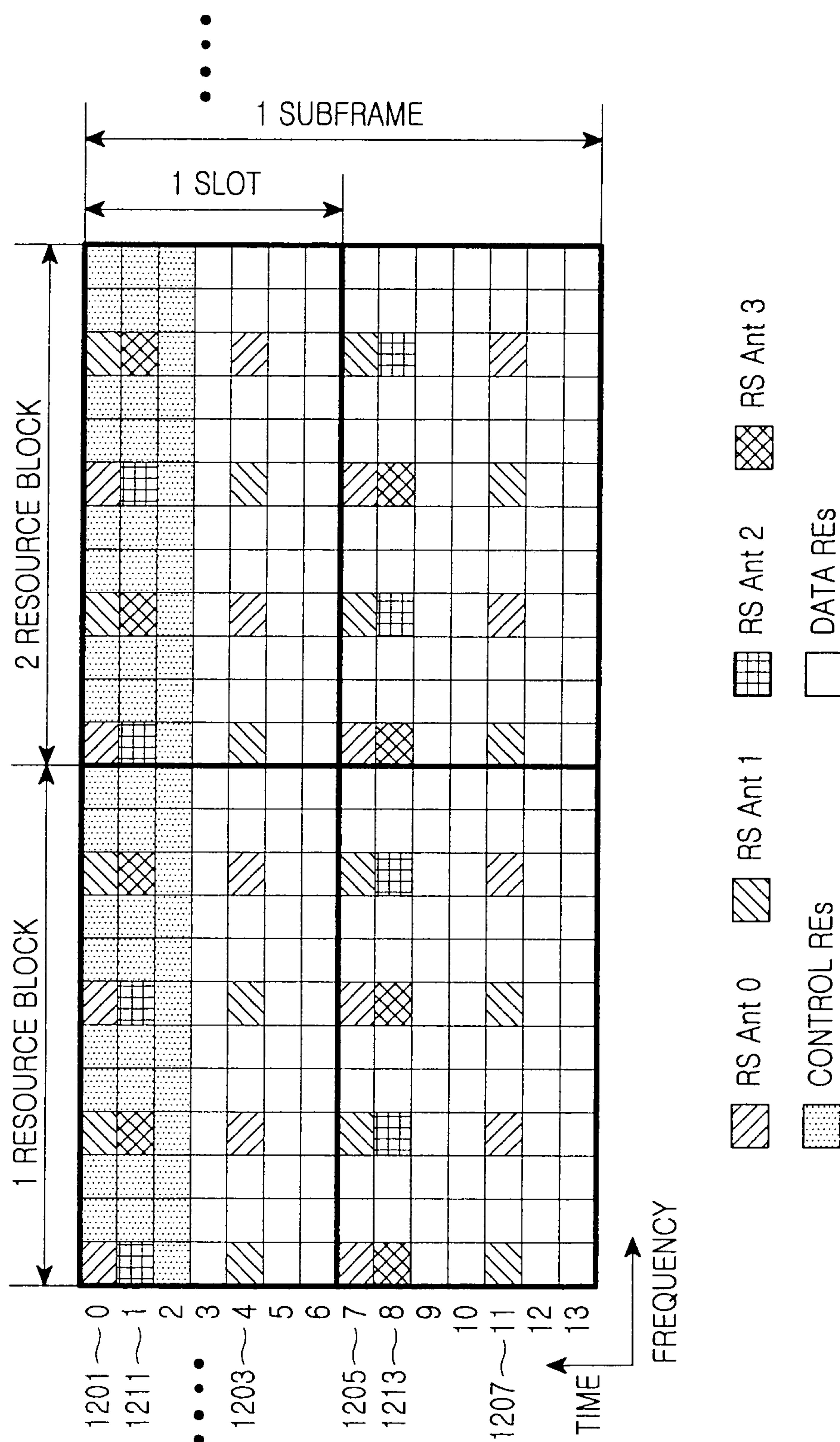


FIG. 12

13/23

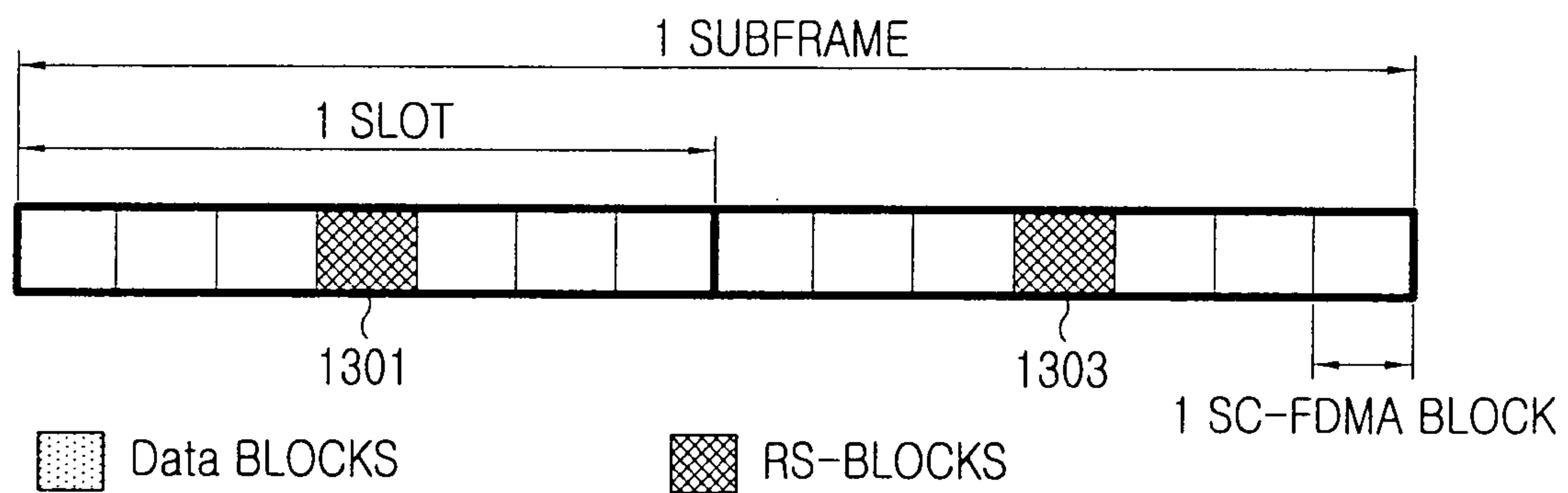


FIG.13

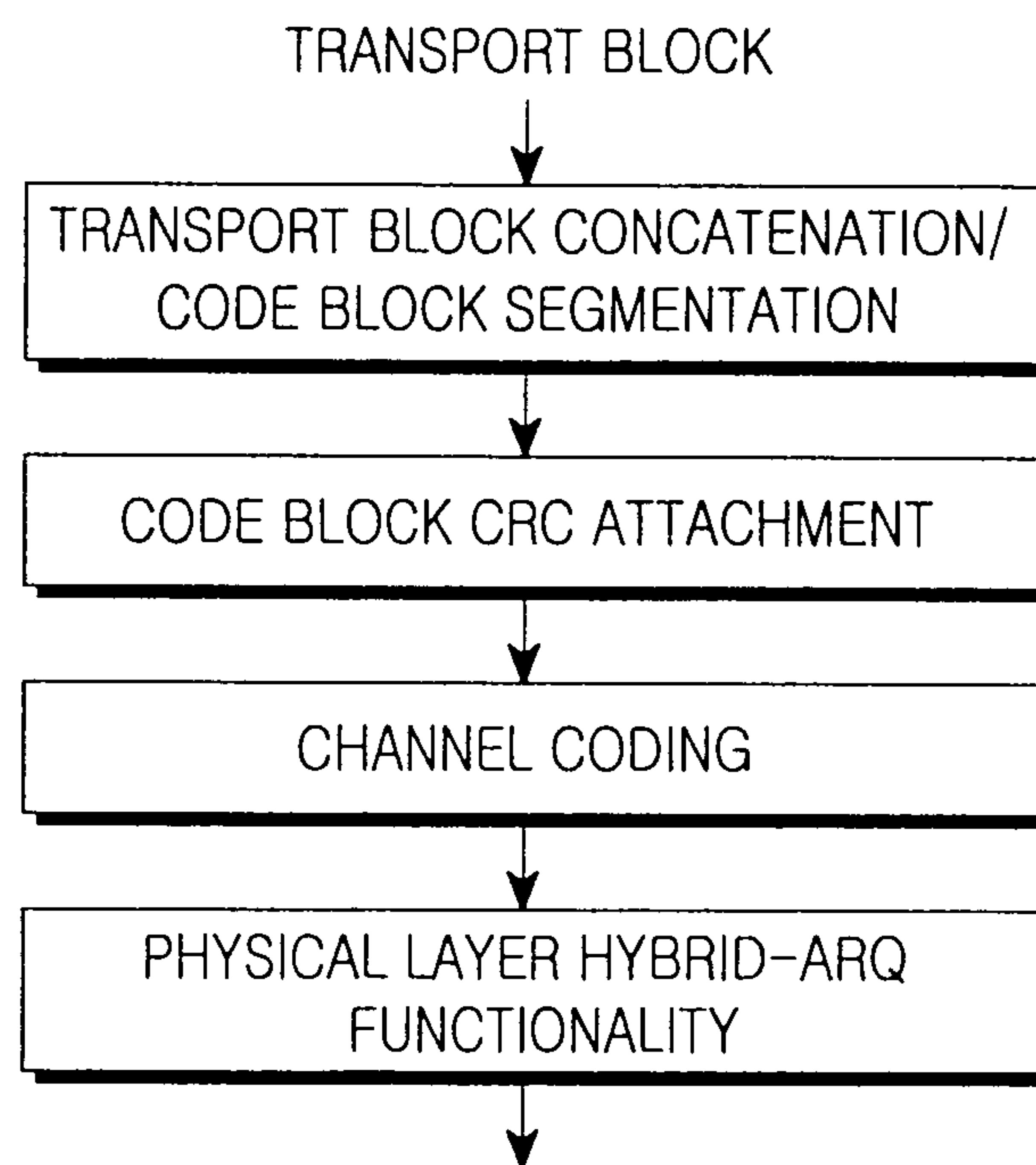


FIG.14

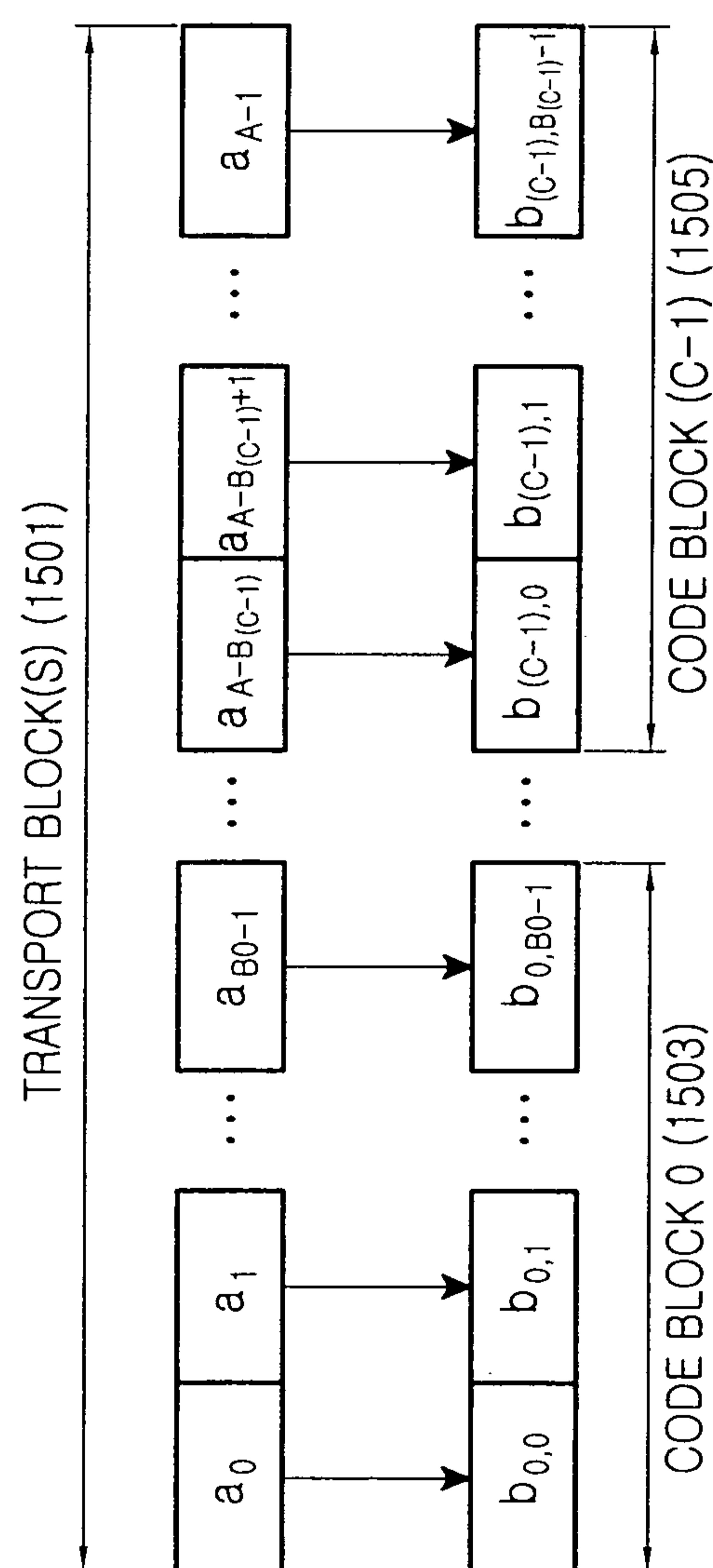
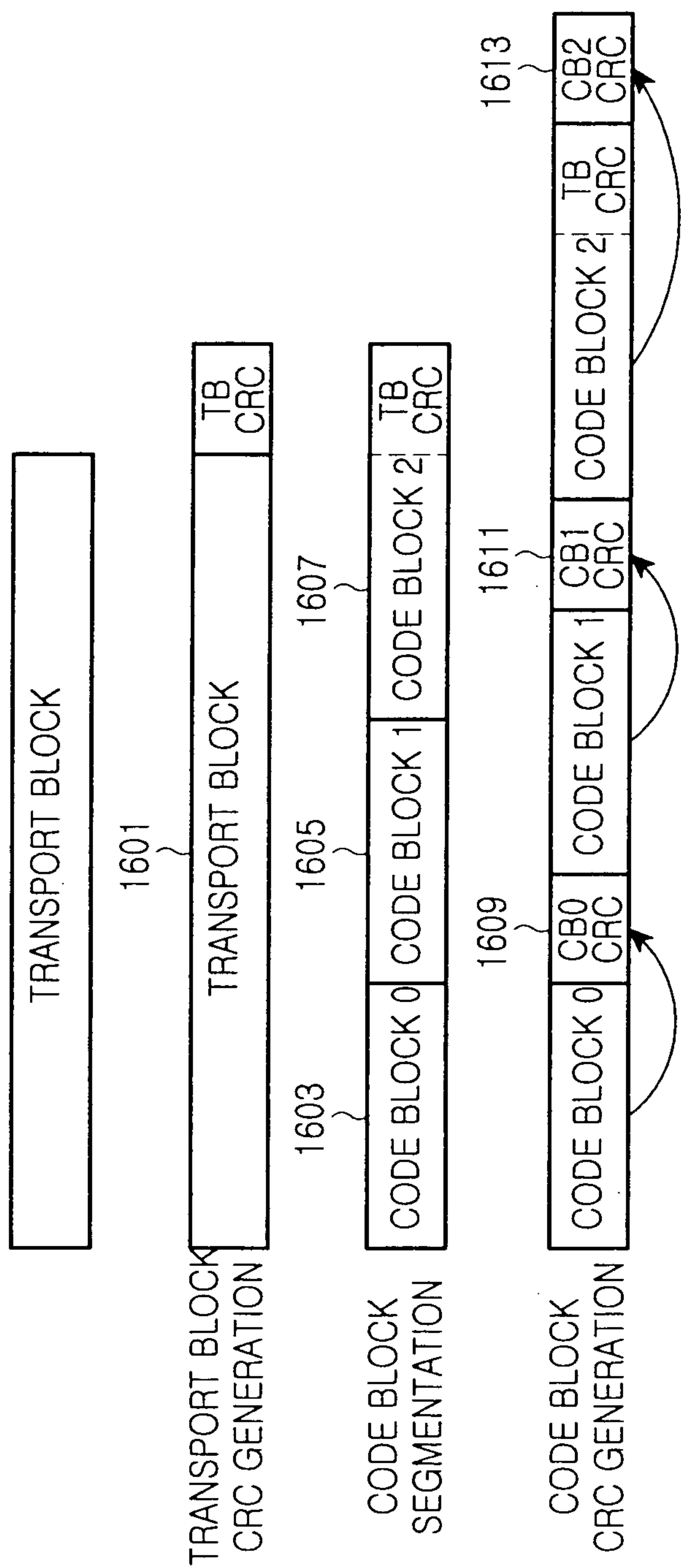


FIG. 15



6  
T  
G.  
T  
E

16/23

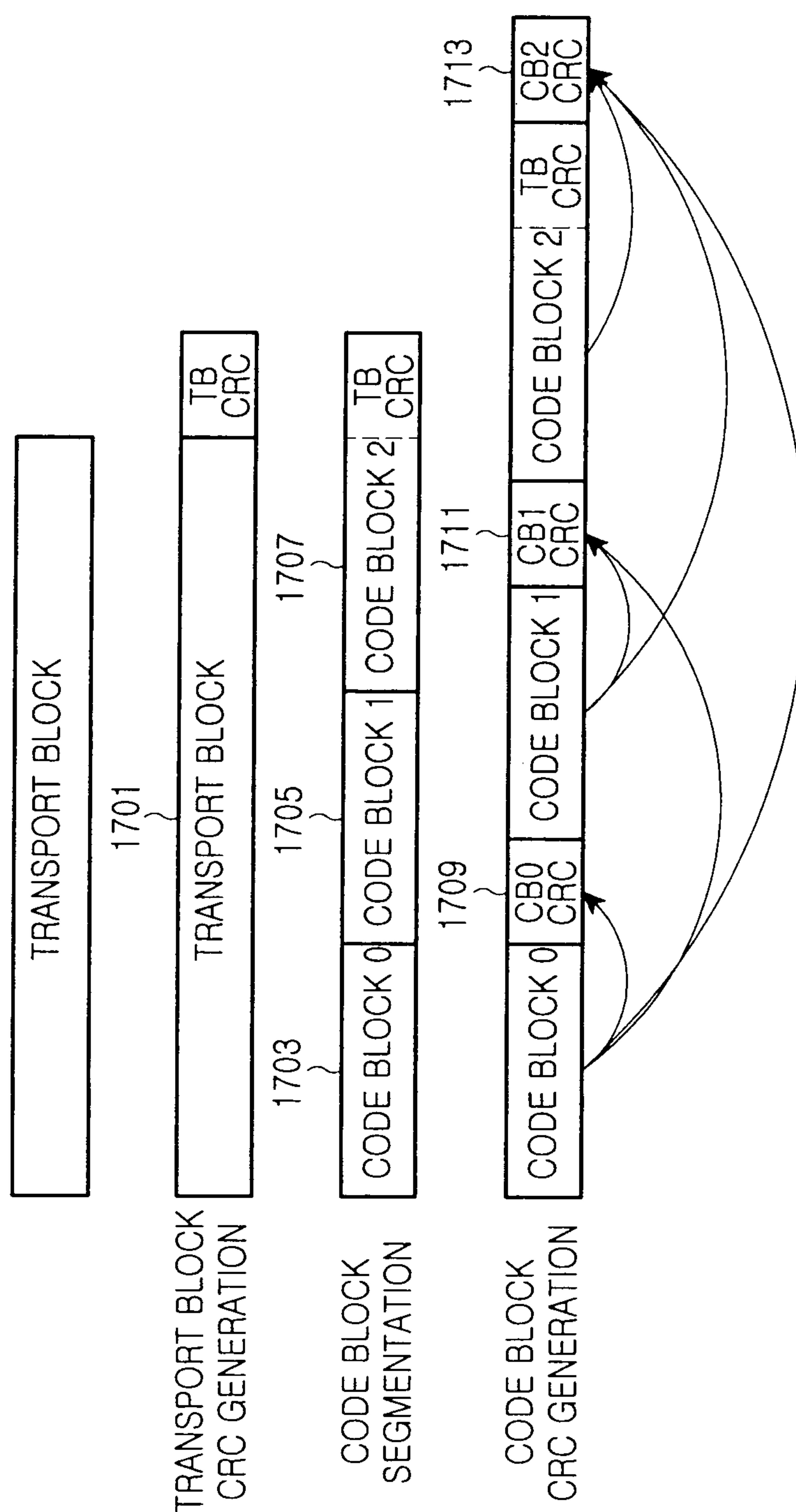


FIG. 17

17/23

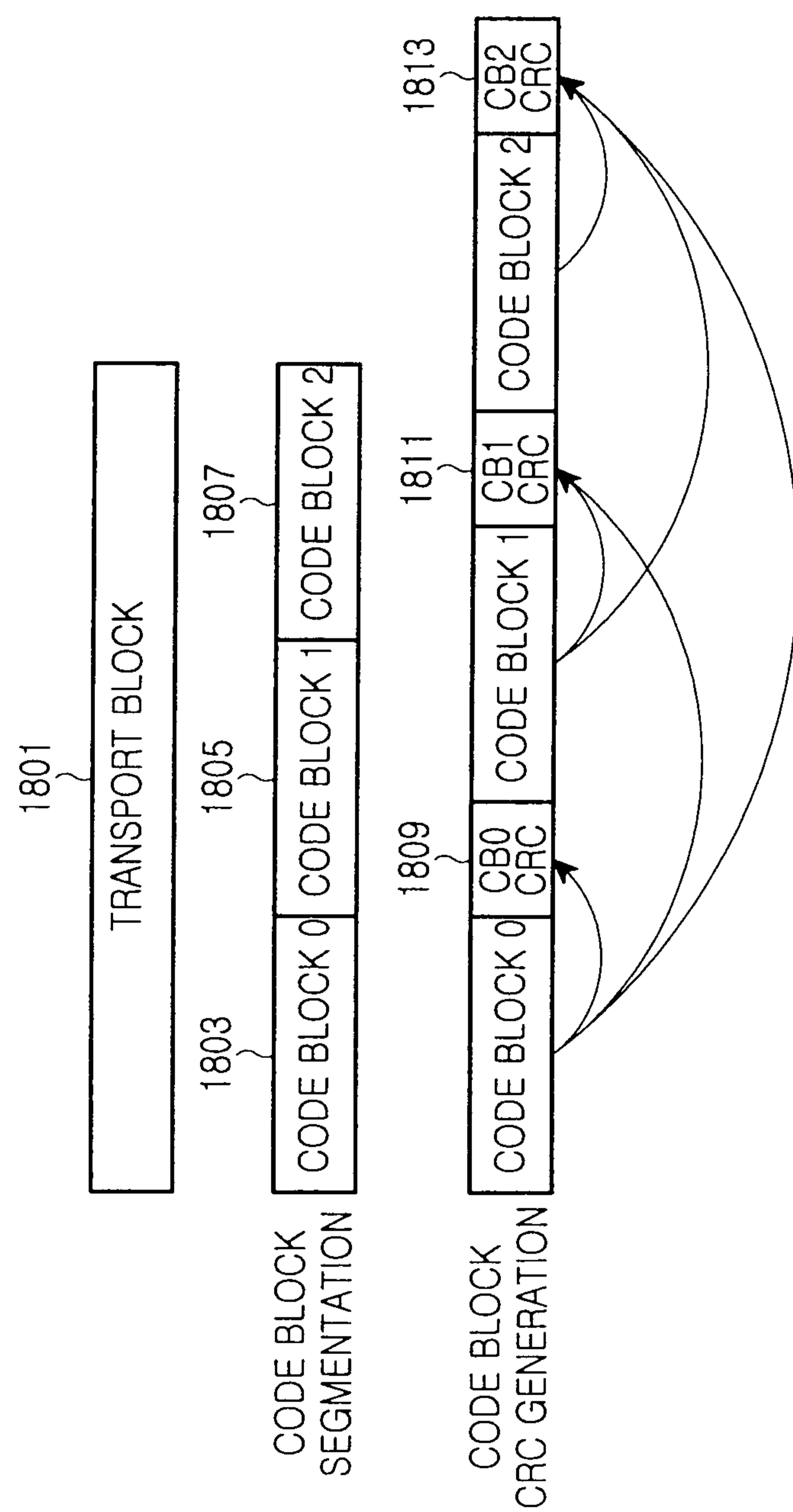


FIG. 18

18/23

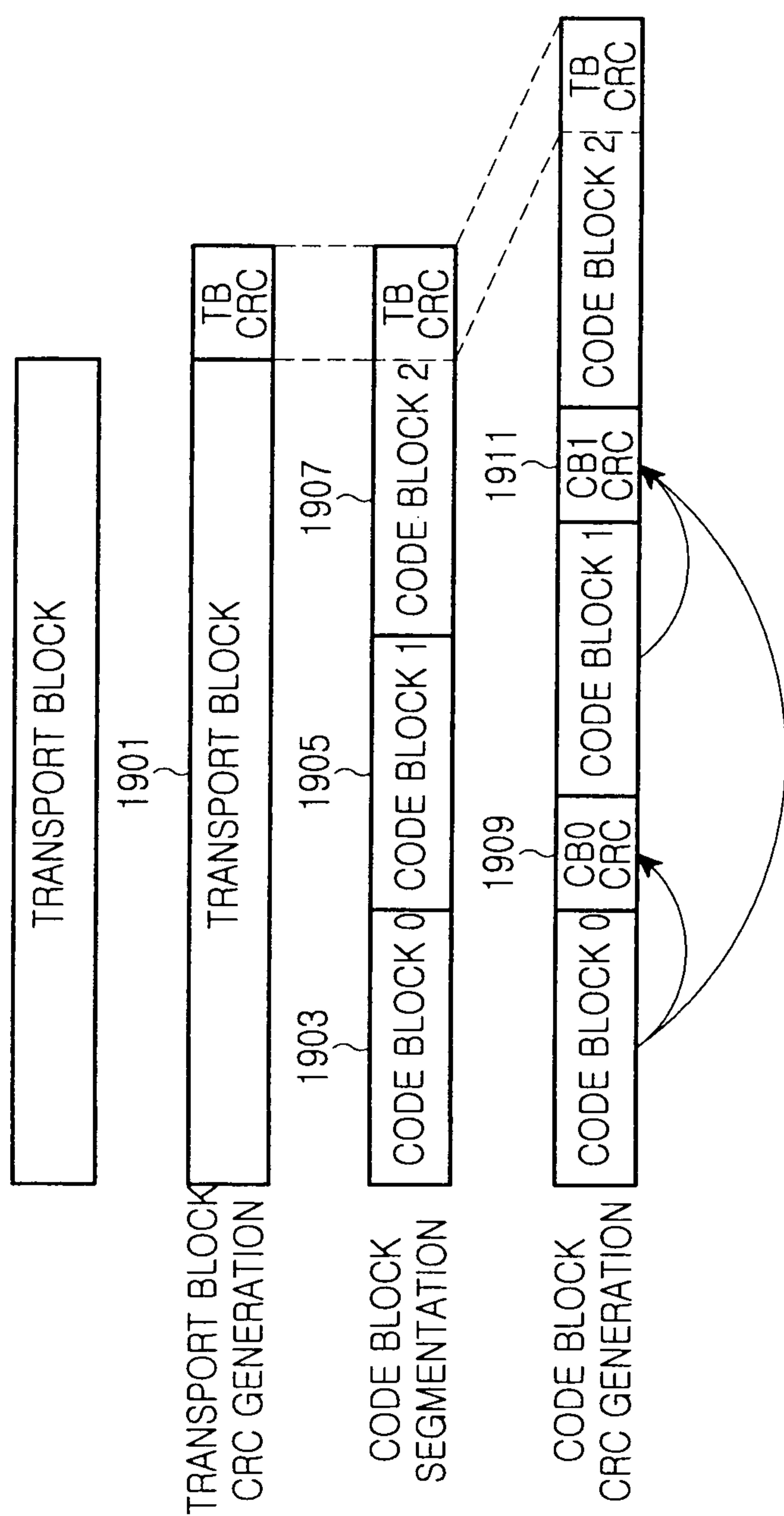


FIG. 19

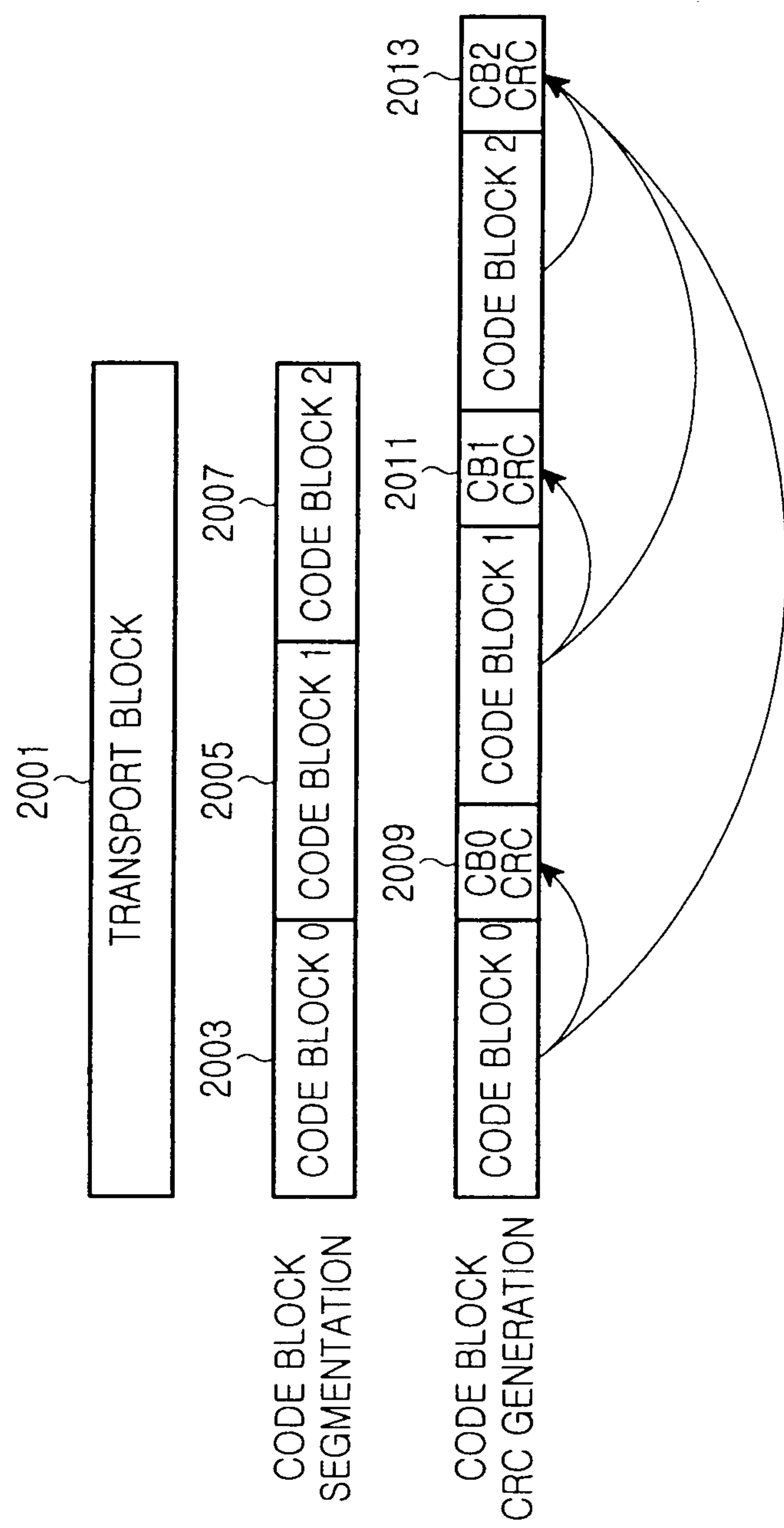
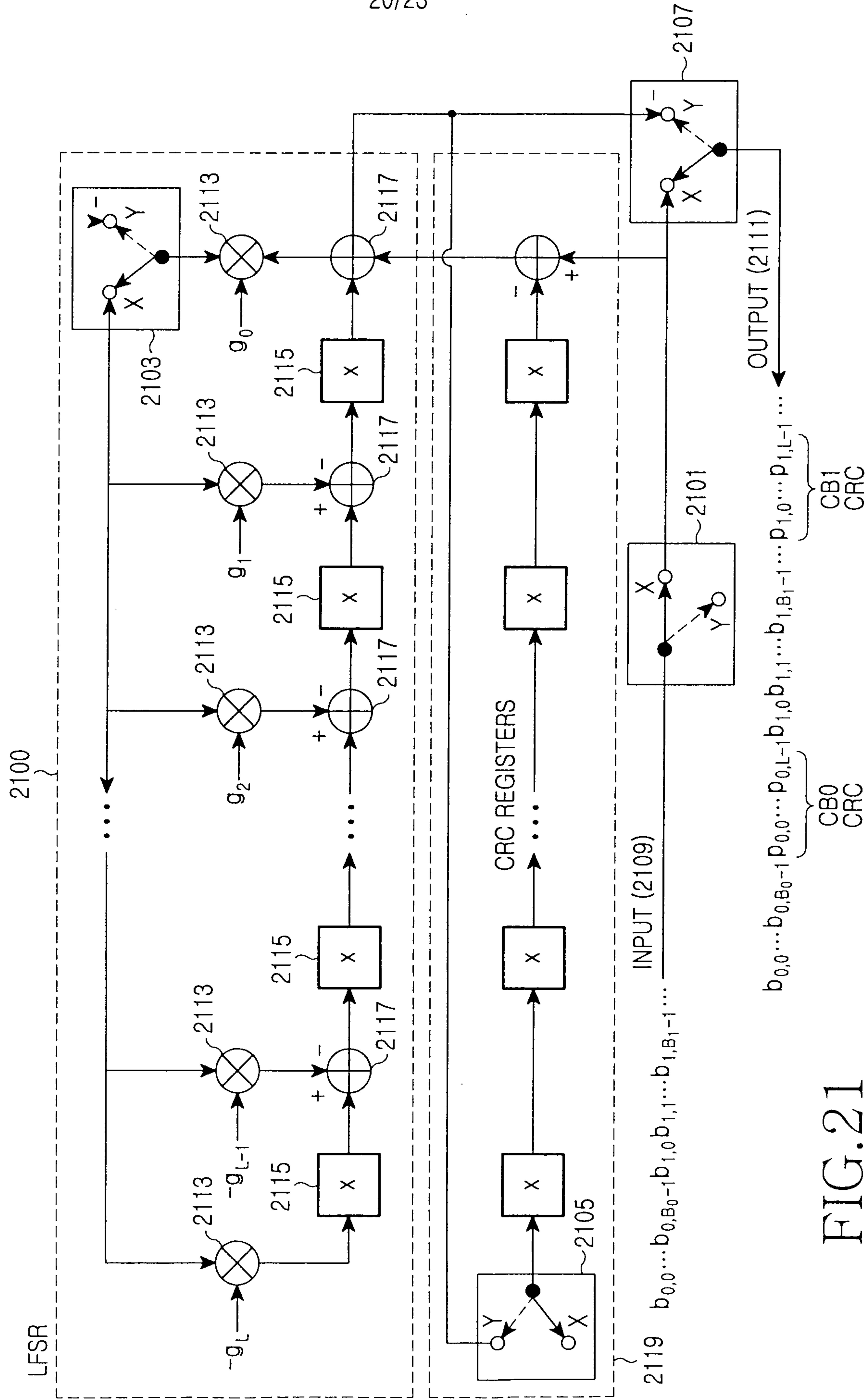


FIG. 20

20/23



12. G. E.

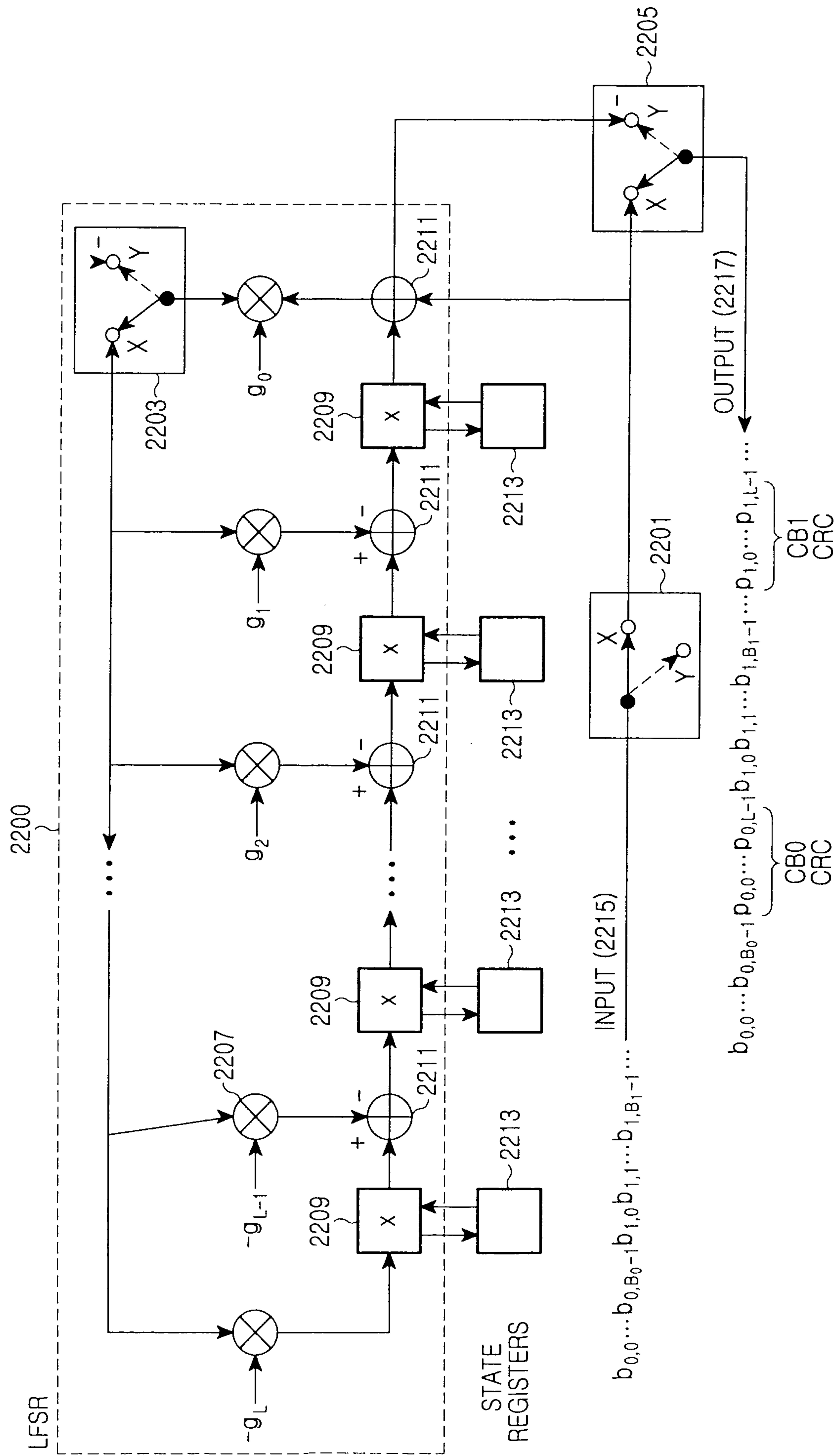


FIG. 22

22/23


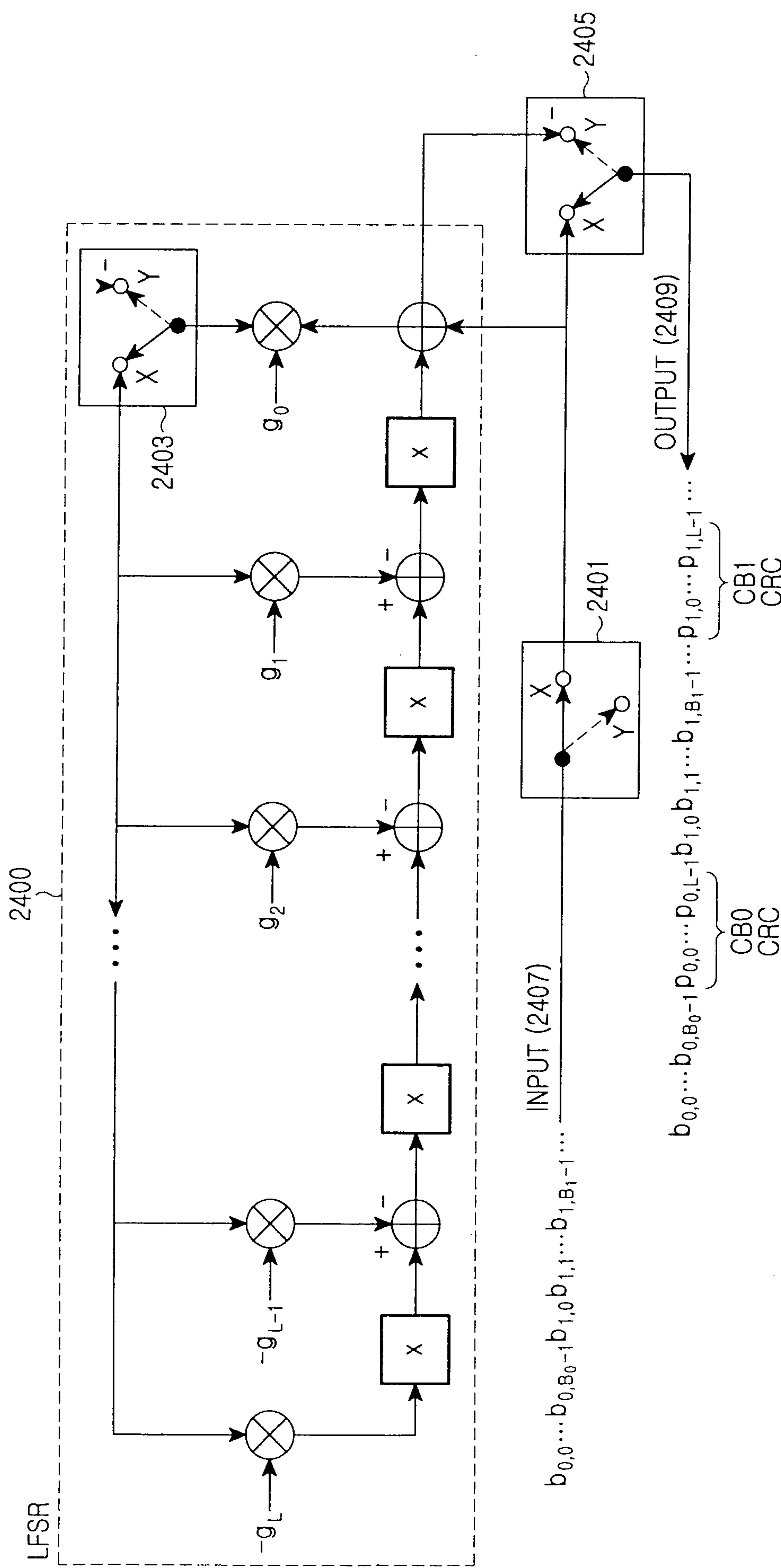


FIG. 23

23/23



# FIG. 24

