

## Description

DATA PROCESSING APPARATUS AND DATA PROCESSING METHOD AS  
WELL AS ENCODING APPARATUS AND ENCODING METHOD

## Technical Field

[0001]

This invention relates to a data processing apparatus and a data processing method as well as an encoding apparatus and an encoding method, and particularly to a data processing apparatus and a data processing method as well as an encoding apparatus and an encoding method which can improve, for example, the tolerance to errors.

[0002]

The LDPC (Low Density Parity Check) code has a high error correction capacity and, in recent years, begins to be adopted widely in transmission systems including satellite digital broadcasting systems such as, for example, the DVB (Digital Video Broadcasting)-S.2 system used in Europe (refer to, for example, Non-Patent Document 1). Further, it is investigated to adopt the LDPC code also in terrestrial digital broadcasting of the next generation.

[0003]

It is being found by recent research that a performance proximate to the Shannon limit is provided by the LDPC code as the code length is increased similarly to a turbo code and so forth. Further, since the LDPC code has a property that the minimum distance increases in proportion to the code length, it has a characteristic that it has a superior block error probability characteristic. Also it is advantageous that a so-called error floor phenomenon which is observed in a decoding characteristic of the turbo code and so forth little occurs.

[0004]

In the following, such an LDPC code as described above is described particularly. It is to be noted that the LDPC code is a linear code, and although it is not necessarily be a two-dimensional code, the following description is given under the assumption that it is a two-dimensional code.

[0005]

The LDPC code has the most significant characteristic in that a parity check matrix which defines the LDPC code is a sparse matrix. Here, the sparse matrix is a matrix in which the number of those

elements whose value is "1" is very small (matrix in which almost all elements are 0).

[0006]

FIG. 1 shows an example of a parity check matrix  $H$  of an LDPC code.

[0007]

In the parity check matrix  $H$  of FIG. 1, the weight of each column (column weight) (number of "1") (weight) is "3" and the weight of each row (row weight) is "6."

[0008]

In encoding by LDPC codes (LDPC encoding), for example, a generator matrix  $G$  is produced based on a parity check matrix  $H$  and this generator matrix  $G$  is multiplied by two-dimensional information bits to produce a codeword (LDPC code).

[0009]

In particular, an encoding apparatus which carries out LDPC encoding first calculates a generator matrix  $G$  which satisfies an expression  $GH^T = 0$  together with a transposed matrix  $H^T$  of a parity check matrix  $H$ . Here, if the generator matrix  $G$  is a  $K \times N$  matrix, then the encoding apparatus multiplies the generator matrix  $G$  by a bit string (vector  $u$ ) of  $K$  information bits to produce a codeword  $c$  ( $= uG$ ) of  $N$  bits. The codeword (LDPC code)

produced by the encoding apparatus is received by the reception side through a predetermined communication path.

[0010]

Decoding of the LDPC code can be carried out using an algorithm proposed as probabilistic decoding (Probabilistic Decoding) by the Gallager, that is, a message passing algorithm by belief propagation on a so-called Tanner graph including a variable node (also called message node) and a check node. In the following description, each of the variable node and the check node is suitably referred to simply as node.

[0011]

FIG. 2 illustrates a procedure of decoding of an LDPC code.

[0012]

It is to be noted that, in the following description, a real number value where the "0" likelihood in the value of the  $n$ th code bit of an LDPC code (one codeword) received by the reception side is represented in a log likelihood ratio is suitably referred to as reception value  $u_{0i}$ . Further, a message outputted from a check node is represented by  $u_j$  and a message outputted from a variable node is represented by  $v_i$ .

[0013]

First, in decoding of an LDPC code, as seen in FIG. 2, an LDPC code is received and a message (check node message)  $u_j$  is initialized to "0" and besides a variable  $k$  which assumes an integer as a counter of repeated processes is initialized to "0" at step S11, whereafter the processing advances to step S12. At step S12, mathematical operation represented by an expression (1) (variable node mathematical operation) is carried out based on the reception value  $u_{oi}$  obtained by the reception of the LDPC code to determine a message (variable node message)  $v_i$ . Further, mathematical operation represented by an expression (2) (check node mathematical operation) is carried out based on the message  $v_i$  to determine the message  $u_j$ .

[0014]

[Expression 1]

$$v_i = u_{oi} + \sum_{j=1}^{d_v-1} u_j \quad \dots (1)$$

[0015]

[Expression 2]

$$\tanh\left(\frac{u_j}{2}\right) = \prod_{i=1}^{d_c-1} \tanh\left(\frac{v_i}{2}\right) \quad \dots (2)$$

[0016]

Here,  $d_v$  and  $d_c$  in the expression (1) and the

expression (2) are parameters which can be selected arbitrarily and represent the number of "1s" in a vertical direction (column) and a horizontal direction (row) of the parity check matrix  $H$ . For example, in the case of a (3, 6) code,  $d_v = 3$  and  $d_c = 6$ .

[0017]

It is to be noted that, in the variable node mathematical operation of the expression (1) and the check node mathematical operation of the expression (2), the range of the mathematical operation is 1 to  $d_v - 1$  or 1 to  $d_c - 1$  because a message inputted from an edge (line interconnecting a variable node and a check node) from which a message is to be outputted is not made an object of the mathematical operation. Meanwhile, the check node mathematical operation of the expression (2) is carried out by producing in advance a table of a function  $R(v_1, v_2)$  represented by an expression (3) defined by one output with respect to two inputs  $v_1$  and  $v_2$  and using the table successively (recursively) as represented by an expression (4).

[0018]

[Expression 3]

$$x = 2 \tanh^{-1} \{ \tanh(v_1 / 2) \tanh(v_2 / 2) \} = R(v_1, v_2) \quad \dots (3)$$

[0019]

[Expression 4]

$$u_j = R(v_1, R(v_2, R(v_3, \dots, R(v_{d_c-2}, v_{d_c-1})))) \quad \dots (4)$$

[0020]

At step S12, the variable k is incremented by "1" further, and the processing advances to step S13. At step S13, it is decided whether or not the variable k is higher than a predetermined repeated decoding time number C. If it is decided at step S13 that the variable k is not higher than C, then the processing returns to step S12, and similar processing is repeated thereafter.

[0021]

On the other hand, if it is decided at step S13 that the variable k is higher than C, then the processing advances to step S14, at which a message  $v_i$  as a decoding result to be outputted finally by carrying out mathematical operation represented by an expression (5) is determined and outputted, thereby ending the decoding process of the LDPC code.

[0022]

[Expression 5]

$$v_i = u_{oi} + \sum_{j=1}^{d_v} u_j \quad \dots (5)$$

[0023]

Here, the mathematical operation of the expression

(5) is carried out, different from the variable node mathematical operation of the expression (1), using messages  $u_j$  from all edges connecting to the variable node.

[0024]

FIG. 3 illustrates an example of the parity check matrix  $H$  of a  $(3, 6)$  LDPC code (encoding rate:  $1/2$ , code length: 12).

[0025]

In the parity check matrix  $H$  of FIG. 3, the weight of a column is 3 and the weight of a row is 6 similarly as in FIG. 1.

[0026]

FIG. 4 shows a Tanner graph of the parity check matrix  $H$  of FIG. 3.

[0027]

Here, in FIG. 4, a check node is represented by "+," and a variable node is represented by "=". A check node and a variable node correspond to a row and a column of the parity check matrix  $H$ , respectively. A connection between a check node and a variable node is an edge and corresponds to "1" of an element of the parity check matrix.

[0028]

In particular, where the element in the  $j$ th row of

the  $i$ th column of the parity check matrix is 1, the  $i$ th variable node (node of "=") from above and the  $j$ th check node (node of "+") from above are connected by an edge. The edge represents that a code bit corresponding to the variable node has a constraint condition corresponding to the check node.

[0029]

In the sum product algorithm (Sum Product Algorithm) which is a decoding method for LDPC codes, variable node mathematical operation and check node mathematical cooperation are carried out repetitively.

[0030]

FIG. 5 illustrates the variable node mathematical operation carried out with regard to a variable node.

[0031]

With regard to the variable node, a message  $v_i$  corresponding to an edge to be calculated is determined by variable node mathematical operation of the expression (1) which uses messages  $u_1$  and  $u_2$  from the remaining edges connecting to the variable node and the reception value  $u_{0i}$ . Also a message corresponding to any other edge is determined similarly.

[0032]

FIG. 6 illustrates the check node mathematical

operation carried out at a check node.

[0033]

Here, the check node mathematical operation of the expression (2) can be carried out by rewriting the expression (2) into an expression (6) using the relationship of an expression  $a \times b = \exp\{\ln(|a|) + \ln(|b|)\} \times \text{sign}(a) \times \text{sign}(b)$ . It is to be noted that  $\text{sign}(x)$  is 1 where  $x \geq 0$  but is -1 where  $x < 0$ .

[0034]

[Expression 6]

$$\begin{aligned}
 u_j &= 2 \tanh^{-1} \left( \prod_{i=1}^{d_c-1} \tanh \left( \frac{v_i}{2} \right) \right) \\
 &= 2 \tanh^{-1} \left[ \exp \left\{ \sum_{i=1}^{d_c-1} \ln \left( \left| \tanh \left( \frac{v_i}{2} \right) \right| \right) \right\} \times \prod_{i=1}^{d_c-1} \text{sign} \left( \tanh \left( \frac{v_i}{2} \right) \right) \right] \\
 &= 2 \tanh^{-1} \left[ \exp \left\{ - \left( \sum_{i=1}^{d_c-1} - \ln \left( \left| \tanh \left( \frac{v_i}{2} \right) \right| \right) \right) \right\} \times \prod_{i=1}^{d_c-1} \text{sign}(v_i) \right] \quad \dots (6)
 \end{aligned}$$

[0035]

Further, if, where  $x \geq 0$ , a function  $\phi(x)$  is defined as an expression  $\phi(x) = \ln(\tanh(x/2))$ , then since an expression  $\phi^{-1}(x) = 2 \tanh^{-1}(e^{-x})$  is satisfied, the expression (6) can be transformed into an expression (7).

[0036]

[Expression 7]

$$u_j = \phi^{-1} \left( \sum_{i=1}^{d_c-1} \phi(v_i) \right) \times \prod_{i=1}^{d_c-1} \text{sign}(v_i) \quad \dots (7)$$

[0037]

At the check node, the check node mathematical operation of the expression (2) is carried out in accordance with the expression (7).

[0038]

In particular, at the check node, the message  $u_j$  corresponding to the edge to be calculated is determined by check node mathematical operation of the expression (7) using messages  $v_1, v_2, v_3, v_4$  and  $v_5$  from the remaining edges connecting to the check node. Also a message corresponding to any other edge is determined in a similar manner.

[0039]

It is to be noted that the function  $\phi(x)$  of the expression (7) can be represented also as  $\phi(x) = \ln((e^x + 1)/(e^x - 1))$ , and where  $x > 0$ ,  $\phi(x) = \phi^{-1}(x)$ . When the functions  $\phi(x)$  and  $\phi^{-1}(x)$  are incorporated in hardware, while they are sometimes incorporated using an LUT (Look Up Table), such LUTs become the same LUT.

[0040]

## Disclosure of Invention

### Technical Problem

[0041]

The LDPC code is adopted in DVB-S.2 which is a standard for satellite digital broadcasting and DVB-T.2 which is a standard for terrestrial digital broadcasting of the next generation. Further, it is planned to adopt the LDPC code in DVB-C.2 which is a standard for CATV (Cable Television) digital broadcasting of the next generation.

[0042]

In digital broadcasting in compliance with a standard for DVB such as DVB-S.2, an LDPC code is converted (symbolized) into symbols of orthogonal modulation (digital modulation) such as QPSK (Quadrature Phase Shift Keying), and the symbols are mapped to signal points and transmitted.

[0043]

In symbolization of an LDPC code, replacement of code bits of the LDPC code is carried out in a unit of two or more bits, and code bits after such replacement are determined as bits of a symbol.

[0044]

While various methods have been proposed as a

method for replacement of code bits for symbolization of an LDPC code, proposal of a method which further improves the tolerance to various errors in comparison with methods proposed already is demanded.

[0045]

Further, also with regard to the LDPC code itself, proposal of an LDPC code which improves the tolerance to errors in comparison with the LDPC codes prescribed in DVB standards such as the DVB-S.2 standard is demanded.

[0046]

Embodiments of the present invention make it possible to improve the tolerance to errors.

Technical Solution

[0047]

A data processing apparatus or a data processing method according to an embodiment of the present invention is a data processing apparatus or a data processing method, wherein, where code bits of an LDPC (Low Density Parity Check) code having a code length of  $N$  bits are written in a column direction of storage means for storing the code bits in a row direction and the column direction and  $m$  bits of the code bits of the LDPC code read out in the row direction are set as one symbol, and besides a

predetermined positive integer is represented by  $b$ , the storage means stores  $mb$  bits in the row direction and stores  $N/(mb)$  bits in the column direction, the code bits of the LDPC code being written in the column direction of the storage means and read out in the row direction, the data processing apparatus including replacement means for or a replacing step of replacing, where the  $mb$  code bits read out in the row direction of the storage means set as  $b$  symbols, the  $mb$  code bits such that the code bits after the replacement form the symbol bits representative of the symbols, the LDPC code being an LDPC code which is prescribed in the DVB-S.2 or DVB-T.2 standard and which has a code length  $N$  of 64,800 and has an encoding rate of  $2/3$ , the  $m$  bits being 8 bits while the integer  $b$  is 2, the 8 bits of the LDPC code being mapped as one symbol to ones of 256 signal points prescribed in 256QAM, the storage means having 16 columns for storing  $8 \times 2$  bits in the row direction and storing  $64,800/(8 \times 2)$  bits in the column direction, the replacement means carrying out, where the  $i+1$ th bit from the most significant bit of the  $8 \times 2$  code bits read out in the row direction of the storage means is represented as bit  $b_i$  and the  $i+1$ th bit from the most significant bit of the  $8 \times 2$  symbol bits of two successive symbols is represented as bit  $y_i$ ,

replacement for allocating the bit  $b_0$  to the bit  $y_{15}$ , the bit  $b_1$  to the bit  $y_7$ , the bit  $b_2$  to the bit  $y_1$ , the bit  $b_3$  to the bit  $y_5$ , the bit  $b_4$  to the bit  $y_6$ , the bit  $b_5$  to the bit  $y_{13}$ , the bit  $b_6$  to the bit  $y_{11}$ , the bit  $b_7$  to the bit  $y_9$ , the bit  $b_8$  to the bit  $y_8$ , the bit  $b_9$  to the bit  $y_{14}$ , the bit  $b_{10}$  to the bit  $y_{12}$ , the bit  $b_{11}$  to the bit  $y_3$ , the bit  $b_{12}$  to the bit  $y_0$ , the bit  $b_{13}$  to the bit  $y_{10}$ , the bit  $b_{14}$  to the bit  $y_4$ , and the bit  $b_{15}$  to the bit  $y_2$ .

[0048]

In the embodiment as described above, the LDPC code is an LDPC code which is prescribed in the DVB-S.2 or DVB-T.2 standard and which has a code length  $N$  of 64,800 and has an encoding rate of  $2/3$ , and the  $m$  bits are 8 bits while the integer  $b$  is 2. The 8 bits of the LDPC code are mapped as one symbol to ones of 256 signal points prescribed in 256QAM. The storage means has 16 columns for storing  $8 \times 2$  bits in the row direction and stores  $64,800/(8 \times 2)$  bits in the column direction. In this instance, where the  $i+1$ th bit from the most significant bit of the  $8 \times 2$  code bits read out in the row direction of the storage means is represented as bit  $b_i$  and the  $i+1$ th bit from the most significant bit of the  $8 \times 2$  symbol bits of two successive symbols is represented as bit  $y_i$ , replacement for allocating the bit

$b_0$  to the bit  $y_{15}$ , the bit  $b_1$  to the bit  $y_7$ , the bit  $b_2$  to the bit  $y_1$ , the bit  $b_3$  to the bit  $y_5$ , the bit  $b_4$  to the bit  $y_6$ , the bit  $b_5$  to the bit  $y_{13}$ , the bit  $b_6$  to the bit  $y_{11}$ , the bit  $b_7$  to the bit  $y_9$ , the bit  $b_8$  to the bit  $y_8$ , the bit  $b_9$  to the bit  $y_{14}$ , the bit  $b_{10}$  to the bit  $y_{12}$ , the bit  $b_{11}$  to the bit  $y_3$ , the bit  $b_{12}$  to the bit  $y_0$ , the bit  $b_{13}$  to the bit  $y_{10}$ , the bit  $b_{14}$  to the bit  $y_4$ , and the bit  $b_{15}$  to the bit  $y_2$ , is carried out.

[0049]

According to a first aspect of the present invention, there is provided an encoding means for or an encoding step of carrying out encoding by an LDPC code which has a code length of 64,800 bits and an encoding rate of  $2/3$ , a parity check matrix of the LDPC code being configured such that elements of the value 1 of an information matrix, which corresponds to the code length of the parity check matrix and an information length corresponding to the encoding rate, decided by a parity check matrix initial value table representative of the positions of the elements of the value 1 of the information matrix are arranged in a period of every 360 columns in the column direction, the parity check matrix initial value table being formed from

317 2255 2324 2723 3538 3576 6194 6700 9101 10057 12739  
17407 21039  
1958 2007 3294 4394 12762 14505 14593 14692 16522 17737  
19245 21272 21379  
127 860 5001 5633 8644 9282 12690 14644 17553 19511 19681  
20954 21002  
2514 2822 5781 6297 8063 9469 9551 11407 11837 12985  
15710 20236 20393  
1565 3106 4659 4926 6495 6872 7343 8720 15785 16434 16727  
19884 21325  
706 3220 8568 10896 12486 13663 16398 16599 19475 19781  
20625 20961 21335  
4257 10449 12406 14561 16049 16522 17214 18029 18033  
18802 19062 19526 20748  
412 433 558 2614 2978 4157 6584 9320 11683 11819 13024  
14486 16860  
777 5906 7403 8550 8717 8770 11436 12846 13629 14755  
15688 16392 16419  
4093 5045 6037 7248 8633 9771 10260 10809 11326 12072  
17516 19344 19938  
2120 2648 3155 3852 6888 12258 14821 15359 16378 16437  
17791 20614 21025  
1085 2434 5816 7151 8050 9422 10884 12728 15353 17733  
18140 18729 20920

856 1690 12787

6532 7357 9151

4210 16615 18152

11494 14036 17470

2474 10291 10323

1778 6973 10739

4347 9570 18748

2189 11942 20666

3868 7526 17706

8780 14796 18268

160 16232 17399

1285 2003 18922

4658 17331 20361

2765 4862 5875

4565 5521 8759

3484 7305 15829

5024 17730 17879

7031 12346 15024

179 6365 11352

2490 3143 5098

2643 3101 21259

4315 4724 13130

594 17365 18322

5983 8597 9627

10837 15102 20876

10448 20418 21478

3848 12029 15228

708 5652 13146

5998 7534 16117

2098 13201 18317

9186 14548 17776

5246 10398 18597

3083 4944 21021

13726 18495 19921

6736 10811 17545

10084 12411 14432

1064 13555 17033

679 9878 13547

3422 9910 20194

3640 3701 10046

5862 10134 11498

5923 9580 15060

1073 3012 16427

5527 20113 20883

7058 12924 15151

9764 12230 17375

772 7711 12723

555 13816 15376

10574 11268 17932

15442 17266 20482

390 3371 8781

10512 12216 17180

4309 14068 15783

3971 11673 20009

9259 14270 17199

2947 5852 20101

3965 9722 15363

1429 5689 16771

6101 6849 12781

3676 9347 18761

350 11659 18342

5961 14803 16123

2113 9163 13443

2155 9808 12885

2861 7988 11031

7309 9220 20745

6834 8742 11977

2133 12908 14704

10170 13809 18153

13464 14787 14975

799 1107 3789

3571 8176 10165

5433 13446 15481  
3351 6767 12840  
8950 8974 11650  
1430 4250 21332  
6283 10628 15050  
8632 14404 16916  
6509 10702 16278  
15900 16395 17995  
8031 18420 19733  
3747 4634 17087  
4453 6297 16262  
2792 3513 17031  
14846 20893 21563  
17220 20436 21337  
275 4107 10497  
3536 7520 10027  
14089 14943 19455  
1965 3931 21104  
2439 11565 17932  
154 15279 21414  
10017 11269 16546  
7169 10161 16928  
10284 16791 20655  
36 3175 8475

2605 16269 19290  
 8947 9178 15420  
 5687 9156 12408  
 8096 9738 14711  
 4935 8093 19266  
 2667 10062 15972  
 6389 11318 14417  
 8800 18137 18434  
 5824 5927 15314  
 6056 13168 15179  
 3284 13138 18919  
 13115 17259 17332.  
 [0049a]

According to a second aspect of the present invention, there is provided an encoding method for an encoding apparatus which carries out encoding by an LDPC (Low Density Parity Check) code, comprising: a step carried out by said encoding apparatus of carrying out encoding by an LDPC code which has a code length of 64,800 bits and an encoding rate of  $2/3$ ; a parity check matrix of the LDPC code being configured such that elements of the value 1 of an information matrix, which corresponds to the code length of the parity check matrix and an information length corresponding to the encoding rate, decided by a parity check matrix initial value table representative of the positions of the elements of the value 1 of the information matrix are arranged in a period of every 360 columns in the column direction; the parity check matrix initial value table being formed from

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 17407 21039  
 1958 2007 3294 4394 12762 14505 14593 14692 16522 17737

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127 860 5001 5633 8644 9282 12690 14644 17553 19511 19681  
20954 21002

2514 2822 5781 6297 8063 9469 9551 11407 11837 12985 15710  
20236 20393

1565 3106 4659 4926 6495 6872 7343 8720 15785 16434 16727  
19884 21325

706 3220 8568 10896 12486 13663 16398 16599 19475 19781  
20625 20961 21335

4257 10449 12406 14561 16049 16522 17214 18029 18033 18802  
19062 19526 20748

412 433 558 2614 2978 4157 6584 9320 11683 11819 13024  
14486 16860

777 5906 7403 8550 8717 8770 11436 12846 13629 14755 15688  
16392 16419

4093 5045 6037 7248 8633 9771 10260 10809 11326 12072 17516  
19344 19938

2120 2648 3155 3852 6888 12258 14821 15359 16378 16437  
17791 20614 21025

1085 2434 5816 7151 8050 9422 10884 12728 15353 17733 18140  
18729 20920

856 1690 12787

6532 7357 9151

4210 16615 18152

11494 14036 17470

2474 10291 10323

1778 6973 10739

4347 9570 18748

2189 11942 20666

3868 7526 17706

8780 14796 18268

160 16232 17399

1285 2003 18922  
4658 17331 20361  
2765 4862 5875  
4565 5521 8759  
3484 7305 15829  
5024 17730 17879  
7031 12346 15024  
179 6365 11352  
2490 3143 5098  
2643 3101 21259  
4315 4724 13130  
594 17365 18322  
5983 8597 9627  
10837 15102 20876  
10448 20418 21478  
3848 12029 15228  
708 5652 13146  
5998 7534 16117  
2098 13201 18317  
9186 14548 17776  
5246 10398 18597  
3083 4944 21021  
13726 18495 19921  
6736 10811 17545  
10084 12411 14432  
1064 13555 17033  
679 9878 13547  
3422 9910 20194  
3640 3701 10046  
5862 10134 11498  
5923 9580 15060  
1073 3012 16427

5527 20113 20883  
7058 12924 15151  
9764 12230 17375  
772 7711 12723  
555 13816 15376  
10574 11268 17932  
15442 17266 20482  
390 3371 8781  
10512 12216 17180  
4309 14068 15783  
3971 11673 20009  
9259 14270 17199  
2947 5852 20101  
3965 9722 15363  
1429 5689 16771  
6101 6849 12781  
3676 9347 18761  
350 11659 18342  
5961 14803 16123  
2113 9163 13443  
2155 9808 12885  
2861 7988 11031  
7309 9220 20745  
6834 8742 11977  
2133 12908 14704  
10170 13809 18153  
13464 14787 14975  
799 1107 3789  
3571 8176 10165  
5433 13446 15481  
3351 6767 12840  
8950 8974 11650

1430 4250 21332  
6283 10628 15050  
8632 14404 16916  
6509 10702 16278  
15900 16395 17995  
8031 18420 19733  
3747 4634 17087  
4453 6297 16262  
2792 3513 17031  
14846 20893 21563  
17220 20436 21337  
275 4107 10497  
3536 7520 10027  
14089 14943 19455  
1965 3931 21104  
2439 11565 17932  
154 15279 21414  
10017 11269 16546  
7169 10161 16928  
10284 16791 20655  
36 3175 8475  
2605 16269 19290  
8947 9178 15420  
5687 9156 12408  
8096 9738 14711  
4935 8093 19266  
2667 10062 15972  
6389 11318 14417  
8800 18137 18434  
5824 5927 15314  
6056 13168 15179  
3284 13138 18919

13115 17259 17332.

[0050]

In the aspects as described above, encoding by an LDPC code whose code length is 64,800 bits and whose encoding rate is  $2/3$  is carried out. The parity check matrix of the LDPC code is configured such that elements of the value 1 of an information matrix, which corresponds to the code length of the parity check matrix and an information length corresponding to the encoding rate, decided by a parity check matrix initial value table representative of the positions of the elements of the value 1 of the information matrix are arranged in a period of every 360 columns in the column direction. The

parity check matrix initial value table is formed from

317 2255 2324 2723 3538 3576 6194 6700 9101 10057 12739

17407 21039

1958 2007 3294 4394 12762 14505 14593 14692 16522 17737

19245 21272 21379

127 860 5001 5633 8644 9282 12690 14644 17553 19511 19681

20954 21002

2514 2822 5781 6297 8063 9469 9551 11407 11837 12985

15710 20236 20393

1565 3106 4659 4926 6495 6872 7343 8720 15785 16434 16727

19884 21325

706 3220 8568 10896 12486 13663 16398 16599 19475 19781

20625 20961 21335

4257 10449 12406 14561 16049 16522 17214 18029 18033

18802 19062 19526 20748

412 433 558 2614 2978 4157 6584 9320 11683 11819 13024

14486 16860

777 5906 7403 8550 8717 8770 11436 12846 13629 14755

15688 16392 16419

4093 5045 6037 7248 8633 9771 10260 10809 11326 12072

17516 19344 19938

2120 2648 3155 3852 6888 12258 14821 15359 16378 16437

17791 20614 21025

1085 2434 5816 7151 8050 9422 10884 12728 15353 17733

18140 18729 20920

856 1690 12787

6532 7357 9151

4210 16615 18152

11494 14036 17470

2474 10291 10323

1778 6973 10739

4347 9570 18748

2189 11942 20666

3868 7526 17706

8780 14796 18268

160 16232 17399

1285 2003 18922

4658 17331 20361

2765 4862 5875

4565 5521 8759

3484 7305 15829

5024 17730 17879

7031 12346 15024

179 6365 11352

2490 3143 5098

2643 3101 21259

4315 4724 13130

594 17365 18322

5983 8597 9627  
10837 15102 20876  
10448 20418 21478  
3848 12029 15228  
708 5652 13146  
5998 7534 16117  
2098 13201 18317  
9186 14548 17776  
5246 10398 18597  
3083 4944 21021  
13726 18495 19921  
6736 10811 17545  
10084 12411 14432  
1064 13555 17033  
679 9878 13547  
3422 9910 20194  
3640 3701 10046  
5862 10134 11498  
5923 9580 15060  
1073 3012 16427  
5527 20113 20883  
7058 12924 15151  
9764 12230 17375  
772 7711 12723

555 13816 15376  
10574 11268 17932  
15442 17266 20482  
390 3371 8781  
10512 12216 17180  
4309 14068 15783  
3971 11673 20009  
9259 14270 17199  
2947 5852 20101  
3965 9722 15363  
1429 5689 16771  
6101 6849 12781  
3676 9347 18761  
350 11659 18342  
5961 14803 16123  
2113 9163 13443  
2155 9808 12885  
2861 7988 11031  
7309 9220 20745  
6834 8742 11977  
2133 12908 14704  
10170 13809 18153  
13464 14787 14975  
799 1107 3789

3571 8176 10165  
5433 13446 15481  
3351 6767 12840  
8950 8974 11650  
1430 4250 21332  
6283 10628 15050  
8632 14404 16916  
6509 10702 16278  
15900 16395 17995  
8031 18420 19733  
3747 4634 17087  
4453 6297 16262  
2792 3513 17031  
14846 20893 21563  
17220 20436 21337  
275 4107 10497  
3536 7520 10027  
14089 14943 19455  
1965 3931 21104  
2439 11565 17932  
154 15279 21414  
10017 11269 16546  
7169 10161 16928  
10284 16791 20655

36 3175 8475

2605 16269 19290

8947 9178 15420

5687 9156 12408

8096 9738 14711

4935 8093 19266

2667 10062 15972

6389 11318 14417

8800 18137 18434

5824 5927 15314

6056 13168 15179

3284 13138 18919

13115 17259 17332.

[0051]

It is to be noted that the data processing apparatus may be an independent apparatus or may be an internal block which composes one apparatus.

Advantageous Effect

[0052]

According to embodiments of the present invention, the tolerance to errors can be improved.

Brief Description of Drawings

[0053]

[FIG. 1] FIG. 1 is a view illustrating a parity check

matrix  $H$  of an LDPC code.

[FIG. 2] FIG. 2 is a flow chart illustrating a decoding procedure of an LDPC code.

[FIG. 3] FIG. 3 is a view illustrating an example of a parity error matrix of an LDPC code.

[FIG. 4] FIG. 4 is a view showing a Tanner graph of a parity check matrix.

[FIG. 5] FIG. 5 is a view showing a variable node.

[FIG. 6] FIG. 6 is a view showing a check node.

[FIG. 7] FIG. 7 is a view showing an example of a configuration of an embodiment of a transmission system to which the present invention is applied.

[FIG. 8] FIG. 8 is a block diagram showing an example of a configuration of a transmission apparatus 11.

[FIG. 9] FIG. 9 is a view illustrating a parity check matrix.

[FIG. 10] FIG. 10 is a view illustrating a parity matrix.

[FIG. 11] FIG. 11 is a view illustrating a parity check matrix of an LDPC code and column weights prescribed in the DVB-S.2 standard.

[FIG. 12] FIG. 12 is a view illustrating a signal point arrangement of 16QAM.

[FIG. 13] FIG. 13 is a view illustrating a signal point arrangement of 64QAM.

[FIG. 14] FIG. 14 is a view illustrating a signal point arrangement of 64QAM.

[FIG. 15] FIG. 15 is a view illustrating a signal point arrangement of 64QAM.

[FIG. 16] FIG. 16 is a view illustrating processing of a demultiplexer 25.

[FIG. 17] FIG. 17 is a view illustrating processing of the demultiplexer 25.

[FIG. 18] FIG. 18 is a view showing a Tanner graph regarding decoding of an LDPC code.

[FIG. 19] FIG. 19 is a view showing a parity matrix  $H_T$  having a staircase structure and a Tanner graph corresponding to the parity matrix  $H_T$ .

[FIG. 20] FIG. 20 is a view showing the parity matrix  $H_T$  of a parity check matrix  $H$  corresponding to the LDPC code after parity interleaving.

[FIG. 21] FIG. 21 is a view illustrating a conversion parity check matrix.

[FIG. 22] FIG. 22 is a view illustrating processing of a column twist interleaver 24.

[FIG. 23] FIG. 23 is a view illustrating column numbers of a memory 31 necessary for the column twist interleaving and addresses of writing starting positions.

[FIG. 24] FIG. 24 is a view illustrating column numbers

of the memory 31 necessary for the column twist interleaving and addresses of writing starting positions.

[FIG. 25] FIG. 25 is a flow chart illustrating a transmission process.

[FIG. 26] FIG. 26 is a view showing a model of a communication path adopted in a simulation.

[FIG. 27] FIG. 27 is a view illustrating a relationship between an error rate obtained by the simulation and a Doppler frequency  $f_d$  of a flutter.

[FIG. 28] FIG. 28 is a view illustrating a relationship between an error rate obtained by the simulation and a Doppler frequency  $f_d$  of a flutter.

[FIG. 29] FIG. 29 is a block diagram showing an example of a configuration of an LDPC encoding section 21.

[FIG. 30] FIG. 30 is a flow chart illustrating a process of LDPC encoding section.

[FIG. 31] FIG. 31 is a view illustrating a parity check matrix initial value table of an encoding rate of  $2/3$  and a code length of 16,200.

[FIG. 32] FIG. 32 is a view illustrating a parity check matrix initial value table of an encoding rate of  $2/3$  and a code length of 64,800.

[FIG. 33] FIG. 33 is a view illustrating the parity check matrix initial value table of the encoding rate of  $2/3$

and the code length of 64,800.

[FIG. 34] FIG. 34 is a view illustrating the parity check matrix initial value table of the encoding rate of  $2/3$  and the code length of 64,800.

[FIG. 35] FIG. 35 is a view illustrating a parity check matrix initial value table of an encoding rate of  $3/4$  and a code length of 16,200.

[FIG. 36] FIG. 36 is a view illustrating a parity check matrix initial value table of an encoding rate of  $3/4$  and a code length of 64,800.

[FIG. 37] FIG. 37 is a view illustrating the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 38] FIG. 38 is a view illustrating the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 39] FIG. 39 is a view illustrating the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 40] FIG. 40 is a view illustrating a parity check matrix initial value table of an encoding rate of  $4/5$  and a code length of 16,200.

[FIG. 41] FIG. 41 is a view illustrating a parity check matrix initial value table of an encoding rate of  $4/5$  and

a code length of 64,800.

[FIG. 42] FIG. 42 is a view illustrating the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 43] FIG. 43 is a view illustrating the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 44] FIG. 44 is a view illustrating the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 45] FIG. 45 is a view illustrating a parity check matrix initial value table of an encoding rate of  $5/6$  and a code length of 16,200.

[FIG. 46] FIG. 46 is a view illustrating a parity check matrix initial value table of an encoding rate of  $5/6$  and a code length of 64,800.

[FIG. 47] FIG. 47 is a view illustrating the parity check matrix initial value table of the encoding rate of  $5/6$  and the code length of 64,800.

[FIG. 48] FIG. 48 is a view illustrating the parity check matrix initial value table of the encoding rate of  $5/6$  and the code length of 64,800.

[FIG. 49] FIG. 49 is a view illustrating the parity check matrix initial value table of the encoding rate of  $5/6$

and the code length of 64,800.

[FIG. 50] FIG. 50 is a view illustrating a parity check matrix initial value table of an encoding rate of  $8/9$  and a code length of 16,200.

[FIG. 51] FIG. 51 is a view illustrating the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 52] FIG. 52 is a view illustrating the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 53] FIG. 53 is a view illustrating the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 54] FIG. 54 is a view illustrating the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 55] FIG. 55 is a view illustrating a parity check matrix initial value table of an encoding rate of  $9/10$  and a code length of 64,800.

[FIG. 56] FIG. 56 is a view illustrating the parity check matrix initial value table of the encoding rate of  $9/10$  and the code length of 64,800.

[FIG. 57] FIG. 57 is a view illustrating the parity check matrix initial value table of the encoding rate of  $9/10$

and the code length of 64,800.

[FIG. 58] FIG. 58 is a view illustrating the parity check matrix initial value table of the encoding rate of  $9/10$  and the code length of 64,800.

[FIG. 59] FIG. 59 is a view illustrating a method of determining a parity check matrix  $H$  from a parity check matrix initial table.

[FIG. 60] FIG. 60 is a view illustrating a replacement process in accordance with the existing methods.

[FIG. 61] FIG. 61 is a view illustrating a replacement process in accordance with the existing methods.

[FIG. 62] FIG. 62 is a view illustrating code bit groups and symbol bit groups where an LDPC code having a code length of 64,800 and an encoding rate of  $2/3$  is modulated by 256QAM and the multiple  $b$  is 2.

[FIG. 63] FIG. 63 is a view illustrating an allocation rule where an LDPC code having a code length of 64,800 and an encoding rate of  $2/3$  is modulated by 256QAM and the multiple  $b$  is 2.

[FIG. 64] FIG. 64 is a view illustrating replacement of code bits in accordance with the allocation rule where an LDPC code having a code length of 64,800 and an encoding rate of  $2/3$  is modulated by 256QAM and the multiple  $b$  is 2.

[FIG. 65] FIG. 65 is a view illustrating BERs where a replacement process of a new replacement method and where a replacement process of an existing method is carried out.

[FIG. 66] FIG. 66 is a view illustrating an example of a parity check matrix initial value table for an LDPC code whose  $E_b/N_0$  as a performance threshold value is better than that of a standard code.

[FIG. 67] FIG. 67 is a view illustrating the example of the parity check matrix initial value table for an LDPC code whose  $E_b/N_0$  as a performance threshold value is better than that of the standard code.

[FIG. 68] FIG. 68 is a view illustrating the example of the parity check matrix initial value table for an LDPC code whose  $E_b/N_0$  as a performance threshold value is better than that of the standard code.

[FIG. 69] FIG. 69 is a view illustrating relationships of the  $E_s/N_0$  and the BER regarding the standard code and a proposed code.

[FIG. 70] FIG. 70 is a block diagram showing an example of a configuration of a reception apparatus 12.

[FIG. 71] FIG. 71 is a flow chart illustrating a reception process.

[FIG. 72] FIG. 72 is a view illustrating an example of a

parity check matrix of an LDPC code.

[FIG. 73] FIG. 73 is a view illustrating a matrix (conversion parity check matrix) obtained by applying row replacement and column replacement to a parity check matrix.

[FIG. 74] FIG. 74 is a view illustrating a conversion parity check matrix divided into a unit of  $5 \times 5$  bits.

[FIG. 75] FIG. 75 is a block diagram showing an example of a configuration of a decoding apparatus in which node mathematical operation is carried out collectively for  $P$  nodes.

[FIG. 76] FIG. 76 is a block diagram showing an example of a configuration of a LDPC decoding section 56.

[FIG. 77] FIG. 77 is a block diagram showing an example of a configuration of an embodiment of a computer to which the present invention is applied.

[FIG. 78] FIG. 78 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $2/3$  and a code length of 16,200.

[FIG. 79] FIG. 79 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $2/3$  and a code length of 64,800.

[FIG. 80] FIG. 80 is a view illustrating the example of the parity check matrix initial value table of the

encoding rate of  $2/3$  and the code length of 64,800.

[FIG. 81] FIG. 81 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $2/3$  and the code length of 64,800.

[FIG. 82] FIG. 82 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $3/4$  and a code length of 16,200.

[FIG. 83] FIG. 83 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $3/4$  and a code length of 64,800.

[FIG. 84] FIG. 84 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 85] FIG. 85 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 86] FIG. 86 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $3/4$  and the code length of 64,800.

[FIG. 87] FIG. 87 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $4/5$  and a code length of 16,200.

[FIG. 88] FIG. 88 is a view illustrating an example of a parity check matrix initial value table of an encoding

rate of  $4/5$  and a code length of 64,800.

[FIG. 89] FIG. 89 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 90] FIG. 90 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 91] FIG. 91 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $4/5$  and the code length of 64,800.

[FIG. 92] FIG. 92 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $5/6$  and a code length of 16,200.

[FIG. 93] FIG. 93 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $5/6$  and a code length of 64,800.

[FIG. 94] FIG. 94 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $5/6$  and the code length of 64,800.

[FIG. 95] FIG. 95 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $5/6$  and the code length of 64,800.

[FIG. 96] FIG. 96 is a view illustrating the example of the parity check matrix initial value table of the

encoding rate of  $5/6$  and the code length of 64,800.

[FIG. 97] FIG. 97 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $8/9$  and a code length of 16,200.

[FIG. 98] FIG. 98 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 99] FIG. 99 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 100] FIG. 100 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 101] FIG. 101 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $8/9$  and the code length of 64,800.

[FIG. 102] FIG. 102 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $9/10$  and a code length of 64,800.

[FIG. 103] FIG. 103 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $9/10$  and the code length of 64,800.

[FIG. 104] FIG. 104 is a view illustrating the example of the parity check matrix initial value table of the

encoding rate of  $9/10$  and the code length of 64,800.

[FIG. 105] FIG. 105 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $9/10$  and the code length of 64,800.

[FIG. 106] FIG. 106 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $1/4$  and a code length of 64,800.

[FIG. 107] FIG. 107 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $1/4$  and the code length of 64,800.

[FIG. 108] FIG. 108 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $1/3$  and a code length of 64,800.

[FIG. 109] FIG. 109 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $1/3$  and the code length of 64,800.

[FIG. 110] FIG. 110 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $2/5$  and a code length of 64,800.

[FIG. 111] FIG. 111 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $2/5$  and the code length of 64,800.

[FIG. 112] FIG. 112 is a view illustrating an example of a parity check matrix initial value table of an encoding

rate of  $1/2$  and a code length of 64,800.

[FIG. 113] FIG. 113 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $1/2$  and the code length of 64,800.

[FIG. 114] FIG. 114 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $1/2$  and the code length of 64,800.

[FIG. 115] FIG. 115 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $3/5$  and a code length of 64,800.

[FIG. 116] FIG. 116 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $3/5$  and the code length of 64,800.

[FIG. 117] FIG. 117 is a view illustrating the example of the parity check matrix initial value table of the encoding rate of  $3/5$  and the code length of 64,800.

[FIG. 118] FIG. 118 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $1/4$  and a code length of 16,200.

[FIG. 119] FIG. 119 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $1/3$  and a code length of 16,200.

[FIG. 120] FIG. 120 is a view illustrating an example of a parity check matrix initial value table of an encoding

rate of  $2/5$  and a code length of 16,200.

[FIG. 121] FIG. 121 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $1/2$  and a code length of 16,200.

[FIG. 122] FIG. 122 is a view illustrating an example of a parity check matrix initial value table of an encoding rate of  $3/5$  and a code length of 16,200.

[FIG. 123] FIG. 123 is a view illustrating another example of the parity check matrix initial value table of the encoding rate of  $3/5$  and the code length of 16,200.

[FIG. 124] FIG. 124 is a view illustrating a method of determining a parity check matrix  $H$  from a parity check matrix initial table.

[FIG. 125] FIG. 125 is a view illustrating an example of replacement of code bits.

[FIG. 126] FIG. 126 is a view illustrating another example of replacement of code bits.

[FIG. 127] FIG. 127 is a view illustrating a further example of replacement of code bits.

[FIG. 128] FIG. 128 is a view illustrating a still further example of replacement of code bits.

[FIG. 129] FIG. 129 is a view illustrating a simulation result of the BER.

[FIG. 130] FIG. 130 is a view illustrating another

simulation result of the BER.

[FIG. 131] FIG. 131 is a view illustrating a further simulation result of the BER.

[FIG. 132] FIG. 132 is a view illustrating a still simulation result of the BER.

[FIG. 133] FIG. 133 is a view illustrating an example of replacement of code bits.

[FIG. 134] FIG. 134 is a view illustrating another example of replacement of code bits.

[FIG. 135] FIG. 135 is a view illustrating a further example of replacement of code bits.

[FIG. 136] FIG. 136 is a view illustrating a still further example of replacement of code bits.

[FIG. 137] FIG. 137 is a view illustrating a yet further example of replacement of code bits.

[FIG. 138] FIG. 138 is a view illustrating a yet further example of replacement of code bits.

[FIG. 139] FIG. 139 is a view illustrating a yet further example of replacement of code bits.

[FIG. 140] FIG. 140 is a view illustrating a yet further example of replacement of code bits.

[FIG. 141] FIG. 141 is a view illustrating a yet further example of replacement of code bits.

[FIG. 142] FIG. 142 is a view illustrating a yet further

example of replacement of code bits.

[FIG. 143] FIG. 143 is a view illustrating a yet further example of replacement of code bits.

[FIG. 144] FIG. 144 is a view illustrating a yet further example of replacement of code bits.

[FIG. 145] FIG. 145 is a view illustrating processing of a multiplexer 54 which composes a deinterleaver 53.

[FIG. 146] FIG. 146 is a view illustrating processing of a column twist deinterleaver 55.

[FIG. 147] FIG. 147 is a block diagram showing another example of a configuration of the reception apparatus 12.

[FIG. 148] FIG. 148 is a block diagram showing a first example of a configuration of a reception system which can be applied to the reception apparatus 12.

[FIG. 149] FIG. 149 is a block diagram showing a second example of the configuration of the reception system which can be applied to the reception apparatus 12.

[FIG. 150] FIG. 150 is a block diagram showing a third example of the configuration of the reception system which can be applied to the reception apparatus 12.

#### Explanation of Reference Symbols

[0054]

11 Transmission apparatus, 12 Reception apparatus,  
21 LDPC encoding section, 22 Bit interleaver, 23 Parity

interleaver, 24 Column twist interleaver, 25  
 Demultiplexer, 26 Mapping section, 27 Orthogonal  
 modulation section, 31 Memory, 32 Replacement section, 51  
 Orthogonal demodulation section, 52 Demapping section, 53  
 Deinterleaver, 54 Multiplexer, 55 Column twist  
 deinterleaver, 56 LDPC decoding section, 300 Edge data  
 storage memory, 301 Selector, 302 Check node calculation  
 section, 303 Cyclic shift circuit, 304 Edge data storage  
 memory, 305 Selector, 306 Reception data memory, 307  
 Variable node calculation section, 308 Cyclic shift  
 circuit, 309 Decoded word calculation section, 310  
 Reception data re-arrangement section, 311 Decoded data  
 re-arrangement section, 601 Encoding processing block,  
 602 Storage block, 611 Encoding rate setting portion, 612  
 Initial value table reading out portion, 613 Parity check  
 matrix production portion, 614 Information bit reading  
 out portion, 615 Encoding parity mathematical operation  
 portion, 616 Control portion, 701 Bus, 702 CPU, 703 ROM,  
 704 RAM, 705 Hard disk, 706 Outputting section, 707  
 Inputting section, 708 Communication section, 709 Drive,  
 710 Input/output interface, 711 Removable recording  
 medium, 1001 Reverse replacement section, 1002 Memory,  
 1011 Parity deinterleaver, 1021 LDPC decoding section,  
 1101 Acquisition section, 1101 Transmission line decoding

processing section, 1103 Information source decoding  
processing section, 1111 Outputting section, 1121  
Recording section

Best Mode for Carrying Out the Invention

[0055]

FIG. 7 shows an example of a configuration of an embodiment of a transmission system to which the present invention is applied (the term system signifies a logical aggregate of a plurality of apparatus irrespective of whether or not the individual component apparatus are included in the same housing).

[0056]

Referring to FIG. 7, the transmission system includes a transmission apparatus 11 and a reception apparatus 12.

[0057]

The transmission apparatus 11 carries out, for example, transmission (broadcast) (transfer) of a television broadcasting program. That is, the transmission apparatus 11, for example, encodes object data which are an object of transmission such as image data, sound data and so forth as a television broadcasting program into an LDPC code and transmits the resultant data through, for example, a communication path

13 such as a satellite channel, ground waves and CATV network.

[0058]

The reception apparatus 12 is, for example, a tuner, a television receiver or a STB (Set Top Box) for receiving a television broadcasting program or PC (Personal Computer) for receiving IPTV (Internet Protocol Television), and receives LDPC codes transmitted thereto from the transmission apparatus 11 through a communication path 13, decodes the LDPC codes into object data and outputs the object data.

[0059]

Here, it has been known that LDPC codes utilized in the transmission system in FIG. 7 exhibit a very high capacity in an AWGN (Additive White Gaussian Noise) communication path.

[0060]

However, in the communication path 13 such as ground waves, burst errors or erasure sometimes occurs. For example, in an OFDM (Orthogonal Frequency Division Multiplexing) system, in a multi-path environment wherein the D/U (Desired to Undesired Ratio) is 0 dB (power of Undesired = echo is equal to the power of Desired = main path), the power of a particular symbol becomes zero

(erasure) in response to a delay of an echo (paths other than the main path).

[0061]

Further, also in a flutter (communication path in which an echo whose delay is zero and to which a Doppler (dopper) frequency is applied is added), where the D/U is 0 dB, a case wherein the power of an entire OFDM symbol at a specific point of time is reduced to zero (erasure) by the Doppler frequency occurs.

[0062]

Further, from a situation of wiring lines on the reception apparatus 12 side from a reception section (not shown) such as an antenna or the like for receiving a signal from the transmission apparatus 11 to the reception apparatus 12 or from instability of the power supply to the reception apparatus 12, burst errors sometimes appear.

[0063]

Meanwhile, in decoding of LDPC codes, since variable node mathematical operation of the expression (1) wherein addition of (reception values  $u_{0i}$  of) code bits of an LDPC code as seen in FIG. 5 above described is carried out in a column of the parity check matrix  $H$  and hence a variable node corresponding to a code bit of the

LDPC code, if an error occurs with the code bit used for the variable node mathematical operation, then the accuracy of a message to be determined drops.

[0064]

Then, since, in decoding of the LDPC code, the message determined at the variable node connecting to the check node is used to carry out check node mathematical operation of the expression (7) at the check node, if the number of check nodes where (code bits of the LDPC code corresponding to) a plurality of variable nodes connected thereto exhibit an error (including erasure) at the same time becomes great, then the performance of the decoding deteriorates.

[0065]

For example, if two or more of the variable nodes connected to the check node suffer from erasure at the same time, then the check node returns a message that the probability that the value may be 0 and the probability that the value may be 1 are equal to each other to all variable nodes. In this instance, those check nodes to which the message of the equal probabilities does not contribute to one cycle of decoding processing (one set of variable node mathematical operation and check node mathematical operation), and as a result, an increased

number of times of repetition of decoding processing are required. Consequently, the performance of the decoding deteriorates. Further, the power consumption of a reception apparatus 12 which carries out decoding of the LDPC code increases.

[0066]

Accordingly, the transmission system shown in FIG. 7 is configured such that the tolerance to burst errors or erasure is improved while the performance in an AWGN communication path is maintained.

[0067]

FIG. 8 shows an example of a configuration of the transmission apparatus 11 of FIG. 7.

[0068]

Referring to FIG. 8, the transmission apparatus 11 includes an LDPC encoding section 21, a bit interleaver 22, a mapping section 26 and an orthogonal modulation section 27.

[0069]

To the LDPC encoding section 21, object data are supplied.

[0070]

The LDPC encoding section 21 carries out LDPC encoding of the object data supplied thereto in

accordance with a parity check matrix in which a parity matrix which is a portion corresponding to parity bits of an LDPC code has a staircase structure and outputs an LDPC code wherein the object data are information bits.

[0071]

In particular, the LDPC encoding section 21 carries out LDPC encoding of encoding the object data into an LDPC code prescribed, for example, in the DVB-S.2 or DVB-T.2 standards and outputs an LDPC code obtained as a result of the LDPC encoding.

[0072]

Here, in the DVB-T.2 standard, it is scheduled to adopt the LDPC codes prescribed in the DVB-S.2 standard. The LDPC code prescribed in the DVB-S.2 standard is an IRA (Irregular Repeat Accumulate) code, and the parity matrix in the parity check matrix of the LDPC code has a staircase structure. The parity matrix and the staircase structure are hereinafter described. Further, the IRA code is described, for example, in "Irregular Repeat-Accumulate Codes," H. Jin., A. Khandekar, and R. J. McEliece, in Proceedings of 2nd International Symposium on Turbo codes and Related Topics, pp.1-8, Sept. 2000.

[0073]

The LDPC code outputted from the LDPC encoding

section 21 is supplied to the bit interleaver 22.

[0074]

The bit interleaver 22 is a data processing apparatus for interleaving data and includes a parity interleaver 23, a column twist interleaver 24 and a demultiplexer (DEMUX) 25.

[0075]

The parity interleaver 23 carries out parity interleave of interleaving parity bits of the LDPC code from the LDPC encoding section 21 to positions of other parity bits and supplies the LDPC code after the parity interleave to the column twist interleaver 24.

[0076]

The column twist interleaver 24 carries out column twist interleave for the LDPC code from the parity interleaver 23 and supplies the LDPC code after the column twist interleave to the demultiplexer 25.

[0077]

In particular, the LDPC code is transmitted after two or more code bits thereof are mapped to signal points representing one symbol of orthogonal modulation by the mapping section 26 hereinafter described.

[0078]

The column twist interleaver 24 carries out, for

example, such column twist interleave as hereinafter described as a re-arranging process of re-arranging code bits of the LDPC code from the parity interleaver 23 such that a plurality of code bits of the LDPC code corresponding to the value 1 included in one arbitrary row of the parity check matrix used in the LDPC encoding section 21 are not included in one symbol.

[0079]

The demultiplexer 25 carries out a replacing process of replacing the positions of two or more code bits of the LDPC code (which are to be a symbol) from the column twist interleaver 24 to obtain an LDPC code whose tolerance to AWGN is reinforced. Then, the demultiplexer 25 supplies two or more code bits of an LDPC code obtained by the replacement process as a symbol to the mapping section 26.

[0080]

The mapping section 26 maps the symbol from the demultiplexer 25 to signal points determined by a modulation method of orthogonal modulation (multi-value modulation) carried out by the orthogonal modulation section 27.

[0081]

In particular, the mapping section 26 maps the LDPC

code from the demultiplexer 25 into a signal point determined by the modulation system, on an IQ plane (IQ constellation) defined by an I axis representative of an I component which is in phase with a carrier and a Q axis representative of a Q component which is orthogonal to the carrier wave.

[0082]

Here, as the modulation method of orthogonal modulation carried out by the orthogonal modulation section 27, modulation methods including, for example, a modulation method defined in the DVB-T standards, that is, for example, QPSK (Quadrature Phase Shift Keying), 16QAM (Quadrature Amplitude Modulation), 64QAM, 256QAM, 1024QAM, 4096QAM and so forth are available. What modulation method should be used for orthogonal modulation to be carried out by the orthogonal modulation section 27 is set in advance, for example, in accordance with an operation of the transmission apparatus 11 by an operator. It is to be noted that the orthogonal modulation section 27 can carry out some other orthogonal modulation such as, for example, 4PAM (Pulse Amplitude Modulation).

[0083]

The symbol mapped to a signal point by the mapping section 26 is supplied to the orthogonal modulation

section 27.

[0084]

The orthogonal modulation section 27 carries out orthogonal modulation of a carrier in accordance with (the symbol mapped to) the signal point from the mapping section 26 and transmits a modulation signal obtained by the orthogonal modulation through the communication path 13 (FIG. 7).

[0085]

Now, FIG. 9 illustrates a parity check matrix  $H$  used in LDPC encoding by the LDPC encoding section 21 of FIG. 8.

[0086]

The parity check matrix  $H$  has an LDGM (Low-Density Generation Matrix) structure and can be represented by an expression  $H = [H_A | H_T]$  from an information matrix  $H_A$  of a portion corresponding to information bits and a parity matrix  $H_T$  corresponding to parity bits from among code bits of the LDPC code (matrix in which elements of the information matrix  $H_A$  are elements on the left side and elements of the parity matrix  $H_T$  are elements on the right side).

[0087]

Here, the bit number of information bits and the

bit number of parity bits from among code bits of one LDPC code (one codeword) are referred to as information length  $K$  and parity length  $M$ , and the bit number of code bits of one LDPC code is referred to as code length  $N$  ( $= K + M$ ).

[0088]

The information length  $K$  and the parity length  $M$  regarding an LDPC code of a certain code length  $N$  depend upon the encoding rate. Meanwhile, the parity check matrix  $H$  is a matrix whose rows  $\times$  columns are  $M \times N$ . Then, the information matrix  $H_A$  is an  $M \times K$  matrix and the parity matrix  $H_T$  is an  $M \times M$  matrix.

[0089]

FIG. 10 illustrates the parity matrix  $H_T$  of the parity check matrix  $H$  of an LDPC code prescribed in the DVB-S.2 (and DVB-T.2) standard.

[0090]

The parity matrix  $H_T$  of the parity check matrix  $H$  of the LDPC code prescribed in the DVB-S.2 standard has a staircase structure wherein elements of the value 1 are arranged like a staircase as seen in FIG. 10. The row weight of the parity matrix  $H_T$  is 1 with regard to the first row but is 2 with regard to all of the remaining rows. Meanwhile, the column weight is 1 with regard to

the last column but is 2 with regard to all of the remaining columns.

[0091]

As described above, the LDPC code of the parity check matrix  $H$  wherein the parity matrix  $H_T$  has a staircase structure can be produced readily using the parity check matrix  $H$ .

[0092]

In particular, an LDPC code (one codeword) is represented by a row vector  $c$  and a column vector obtained by transposing the row vector is represented by  $c^T$ . Further, a portion of information bits from within the row vector  $c$  which is an LDPC code is represented by an row vector  $A$  and a portion of parity bits is represented by a row vector  $T$ .

[0093]

Here, in this instance, the row vector  $c$  can be presented by an expression  $c = [A|T]$  from the row vector  $A$  as information bits and the row vector  $T$  as parity bits (row vector wherein the elements of the row vector  $A$  are elements on the left side and the elements of the row vector  $T$  are elements on the right side).

[0094]

It is necessary for the parity check matrix  $H$  and

the row vector  $c = [A|T]$  as the LDPC code to satisfy an expression  $Hc^T = 0$ , and where the parity matrix  $H_T$  of the parity check matrix  $H = [H_A|H_T]$  has such a staircase structure as shown in FIG. 10, the row vector  $T$  as parity bits which forms the row vector  $c = [A|T]$  which satisfies the expression  $Hc^T = 0$  can be determined sequentially by successively setting the elements in the rows beginning with the elements in the first row of the column vector  $Hc^T$  in the expression  $Hc^T = 0$  to zero.

[0095]

FIG. 11 illustrates the parity check matrix  $H$  of an LDPC code and column weights defined in the DVB-S.2 (and DVB-T.2) standard.

[0096]

In particular, FIG. 11A illustrates the parity check matrix  $H$  of an LDPC code defined in the DVB-S.2 standard.

[0097]

With regard to  $KX$  columns from the first column of the parity check matrix  $H$ , the column weight is  $X$ ; with regard to succeeding  $K3$  columns, the column weight is 3; with regard to succeeding  $M-1$  rows, the column weight is 2; and with regard to the last one column, the column weight is 1.

[0098]

Here,  $KX + K3 + M - 1 + 1$  is equal to the code length  $N$ .

[0099]

In the DVB-S.2 standard, the column numbers  $KX$ ,  $K3$  and  $M$  (parity length) as well as the column weight  $X$  are prescribed in such a manner as seen in FIG. 11B.

[0100]

In particular, FIG. 11B illustrates the column numbers  $KX$ ,  $K3$  and  $M$  as well as the column weight  $X$  regarding different encoding rates of LDPC codes prescribed in the DVB-S.2 standard.

[0101]

In the DVB-S.2 standard, LDPC codes of the code lengths  $N$  of 64,800 bits and 16,200 bits are prescribed.

[0102]

And as seen in FIG. 11B, for the LDPC code whose code length  $N$  is 64,800 bits, 11 encoding rates (nominal rates)  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$ ,  $8/9$  and  $9/10$  are prescribed, and for the LDPC code whose code length  $N$  is 16,200 bits, 10 encoding rates  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$  and  $8/9$  are prescribed.

[0103]

Regarding LDPC codes, it is known that code bits

corresponding to a column of the parity check matrix  $H$  which has a higher column weight exhibits a lower error rate.

[0104]

The parity check matrix  $H$  prescribed in the DVB-S.2 standard and illustrated in FIG. 11 has a tendency that a column nearer to the head side (left side) has a higher column weight. Accordingly, the LDPC code corresponding to the parity check matrix  $H$  has a tendency that a code bit nearer to the head is higher in tolerance to an error (has a higher tolerance to an error) and a code bit nearer to the tail is lower in tolerance to an error.

[0105]

FIG. 12 illustrates an arrangement of (signal points corresponding to) 16 symbols on the IQ plane where 16QAM is carried out by the orthogonal modulation section 27 of FIG. 8.

[0106]

In particular, FIG. 12A illustrates symbols of 16QAM.

[0107]

In 16QAM, one symbol represents 4 bits, and 16 ( $= 2^4$ ) symbols exist. Then, the 16 symbols are disposed such that they form a square shape of  $4 \times 4$  symbols in the I

direction  $\times$  Q direction centered at the origin of the IQ plane.

[0108]

Now, if the  $i+1$ th bit from the most significant bit of the bit string represented by one symbol is represented as bit  $y_i$ , then 4 bits represented by one symbol of 16QAM can be represented as bits  $y_0$ ,  $y_1$ ,  $y_2$  and  $y_3$  in order beginning with the most significant bit. Where the modulation method is 16QAM, 4 code bits of the LDPC code are set (symbolized) as a symbol (symbol value) of the 4 bits  $y_0$  to  $y_3$ .

[0109]

FIG. 12B indicates bit boundaries regarding the 4 bits (hereinafter, bit is also referred to as symbol bit)  $y_0$  to  $y_3$  represented by the symbol of the 16QAM.

[0110]

Here, a bit boundary regarding a symbol bit  $y_i$  (in FIG. 12,  $i = 0, 1, 2, 3$ ) signifies a boundary between a symbol whose bit  $y_i$  is 0 and another symbol whose bit  $y_i$  is 1.

[0111]

As seen in FIG. 12B, as regards the most significant symbol bit  $y_0$  from among the 4 symbol bits  $y_0$  to  $y_3$  represented by the symbol of 16QAM, only one

location of the Q axis on the IQ plane makes a bit boundary, and as regards the second symbol bit  $y_1$  (second from the most significant bit), only one location of the I axis on the IQ plane makes a bit boundary.

[0112]

Further, as regards the third symbol bit  $y_3$ , each of two locations between the first and second columns and between the third and fourth columns from the left of the  $4 \times 4$  symbols makes a boundary.

[0113]

Furthermore, as regards the fourth symbol bit  $y_3$ , each of two locations between the first and second rows and between the third and fourth rows of the  $4 \times 4$  symbols makes a boundary.

[0114]

The symbol bit  $y_1$  represented by a symbol is less likely to become erroneous and becomes lower in error probability as the number of symbols spaced away from a bit boundary increases but is more likely to become erroneous and becomes higher in error probability as the number of symbols positioned nearer to a bit boundary increases.

[0115]

If a bit which is less likely to become erroneous

(is tolerant to an error) is referred to as "strong bit" but a bit which is more likely to become erroneous (is less tolerant to an error) is referred to as "weak bit," then as regards the 4 symbol bits  $y_0$  to  $y_3$  represented by symbols of 16QAM, the most significant symbol bit  $y_0$  and the second symbol bit  $y_1$  are strong bits and the third symbol bit  $y_2$  and the fourth symbol bit  $y_3$  are weak bits.

[0116]

FIGS. 13 to 15 illustrate arrangements of (signal points corresponding to) 64 symbols on the IQ plane where 64QAM is carried out by the orthogonal modulation section 27 of FIG. 8.

[0117]

In 64QAM, one symbol represents 6 bits, and 64 ( $= 2^6$ ) symbols exist. Then, the 64 symbols are arranged such that they make a square of  $8 \times 8$  symbols in the I direction  $\times$  Q direction centered at the origin of the IQ plane.

[0118]

The symbol bits represented by one symbol of 64QAM can be represented as bits  $y_0, y_1, y_2, y_3, y_4,$  and  $y_5$  in order beginning with the most significant bit. Where the modulation method is 64QAM, 6 code bits of the LDPC code are set (symbolized) as a symbol (symbol value) of the 6

bits  $y_0$  to  $y_5$ .

[0119]

Here, FIG. 13 indicates bit boundaries regarding the most significant symbol bit  $y_0$  and the second symbol bit  $y_1$  from among the symbol bits  $y_0$  to  $y_5$  of symbols of 64QAM; FIG. 14 indicates bit boundaries regarding the third symbol bit  $y_2$  and the fourth symbol bit  $y_3$ ; and FIG. 15 indicates bit boundaries regarding the fifth symbol bit  $y_4$  and the sixth symbol bit  $y_5$ .

[0120]

As seen in FIG. 13, the number of bit boundaries with regard to each of the most significant symbol bit  $y_0$  and the second symbol bit  $y_1$  is one. Meanwhile, as seen in FIG. 14, the number of bit boundaries with regard to each of the third symbol bit  $y_2$  and the fourth symbol bit  $y_3$  is two, and as seen in FIG. 15, the number of bit boundaries with regard to each of the fifth symbol bit  $y_4$  and the sixth symbol bit  $y_5$  is four.

[0121]

Accordingly, among the symbol bits  $y_0$  to  $y_5$  of symbols of 64QAM, the most significant symbol bit  $y_0$  and the second symbol bit  $y_1$  are the strongest bits, and the third symbol bit  $y_2$  and the fourth symbol bit  $y_3$  are the second strongest bits. Then, the fifth symbol bit  $y_4$  and

the sixth symbol bit  $y_5$  are the weakest bits.

[0122]

From FIG. 12 and further from FIGS. 13 to 15, it can be seen that, as regards symbol bits of symbols of orthogonal modulation, there is a tendency that a high-order bit is a strong bit and a low-order bit is a weak bit.

[0123]

Here, as described hereinabove with reference to FIG. 11, an LDPC code outputted from the LDPC encoding section 21 (FIG. 8) includes code bits which are tolerant to errors and code bits which are less tolerant to errors.

[0124]

Meanwhile, as described hereinabove with reference to FIGS. 12 to 15, symbol bits of symbols of orthogonal modulation carried out by the orthogonal modulation section 27 include strong bits and weak bits.

[0125]

Accordingly, if a code bit of the LDPC code which is low in tolerance to an error is allocated to a weak symbol bit of a symbol of orthogonal modulation, then the tolerance to an error drops as a whole.

[0126]

Therefore, an interleaver has been proposed which

interleaves code bits of an LDPC code such that code bits of the LDPC code which are low in tolerance to an error are allocated to strong bits (symbol bits) of a symbol of orthogonal modulation.

[0127]

The demultiplexer 25 of FIG. 8 carries out processing of the interleaver.

[0128]

FIG. 16 is a view illustrating processing of the demultiplexer 25 of FIG. 8.

[0129]

In particular, FIG. 16A shows an example of a functional configuration of the demultiplexer 25.

[0130]

The demultiplexer 25 includes a memory 31 and a replacement section 32.

[0131]

To the memory 31, an LDPC code from the LDPC encoding section 21 is supplied.

[0132]

The memory 31 has a storage capacity for storing  $mb$  bits in the (horizontal) direction of a row and storing  $N/(mb)$  bits in the (vertical) direction of a column. The memory 31 writes code bits of the LDPC code supplied

thereto into the column direction and reads out the code bits in the row direction and then supplies the read out code bits to the replacement section 32.

[0133]

Here,  $N$  (= information length  $K$  + parity length  $M$ ) represents the code length of the LDPC code as described hereinabove.

[0134]

In addition,  $m$  represents the bit number of code bits of an LDPC code to be one symbol, and  $b$  is a predetermined positive integer and is a multiple to be used for multiplying  $m$  by the integer. The multiplexer 25 converts (symbolizes) the code bits of the LDPC code into symbols as described above, and the multiple  $b$  represents the number of symbols obtained in a way by single time symbolization by the multiplexer 25.

[0135]

FIG. 16A shows an example of a configuration of the demultiplexer 25 where the modulation system is 64QAM, and accordingly, the bit number  $m$  of code bits of the LDPC code to be one symbol is 6 bits.

[0136]

Further, in FIG. 16A, the multiple  $b$  is 1, and accordingly, the memory 31 has a storage capacity of  $N/(6$

$\times 1) \times (6 \times 1)$  bits in the column direction  $\times$  row direction.

[0137]

Here, a storage region of the memory 31 which extends in the column direction and includes one bit in the row direction is hereinafter referred to suitably as column. In FIG. 16A, the memory 31 includes six ( $= 6 \times 1$ ) columns.

[0138]

The demultiplexer 25 carries out writing of the code bits of the LDPC code in a downward direction from above of a column which forms the memory 31 (in a column direction) beginning with a left side column toward a right side column.

[0139]

Then, if the writing of the code bits ends with the lowermost bit in the rightmost column, then the code bits are read out and supplied to the replacement section 32 in a unit of 6 bits (mb bits) in the row direction beginning with the first row of all of the columns which form the memory 31.

[0140]

The replacement section 32 carries out a replacement process of replacing the position of code

bits of 6 bits from the memory 31 and outputs the 6 bits obtained by the replacement as 6 symbol bits  $y_0, y_1, y_2, y_3, y_4$  and  $y_5$  representative of one symbol of 64QAM.

[0141]

In particular, while mb code bits (here, 6 bits) are read out in the row direction from the memory 31, if the  $i$ th bit ( $i = 0, 1, \dots, mb-1$ ) from the most significant bit from among the mb code bits read out from the memory 31 is represented by bit  $b_i$ , then the 6 code bits read out in the row direction from the memory 31 can be represented as bits  $b_0, b_1, b_2, b_3, b_4$  and  $b_5$  in order beginning with the most significant bit.

[0142]

A relationship of the column weight described hereinabove with reference to FIG. 11 leads that the code bit positioned in the direction of the bit  $b_0$  is a code bit high in tolerance to an error while the code bit in the direction of the bit  $b_5$  is a code bit low in tolerance to an error.

[0143]

The replacement section 32 carries out a replacement process of replacing the position of the 6 code bits  $b_0$  to  $b_5$  from the memory 31 such that a code bit which is low in tolerance to an error from among the 6

code bits  $b_0$  to  $b_5$  from the memory 31 may be allocated to a bit which is high in tolerance from among the symbol bits  $y_0$  to  $y_5$  of one symbol of 64QAM.

[0144]

Here, for a replacement method for replacing the 6 code bits  $b_0$  to  $b_5$  from the memory 31 so as to be allocated to the 6 symbol bits  $y_0$  to  $y_5$  representative of one symbol of 64QAM, various systems have been proposed.

[0145]

FIG. 16B illustrates a first replacement method; FIG. 16C illustrates a second replacement method; and FIG. 16D illustrates a third replacement method.

[0146]

In FIG. 16B to FIG. 16D (similarly also in FIG. 17 hereinafter described), a line segment interconnecting the bits  $b_i$  and  $y_j$  signifies that the code bit  $b_i$  is allocated to the symbol bit  $y_j$  of the symbol (is replaced into the position of the symbol bit  $y_j$ ).

[0147]

As the first replacement method, it is proposed to adopt one of three kinds of replacement methods in FIG. 16B, and as the second replacement method, it is proposed to adopt one of two kinds of replacement methods in FIG. 16C.

[0148]

As the third replacement method, it is proposed to select and use six kinds of replacement methods in FIG. 16D in order.

[0149]

FIG. 17 illustrates an example of a configuration of the demultiplexer 25 in a case wherein the modulation method is 64QAM (accordingly, the bit number  $m$  of code bits of an LDPC code mapped to one symbol is 6 similarly as in FIG. 16) and the multiple  $b$  is 2, and a fourth replacement method.

[0150]

Where the multiple  $b$  is 2, the memory 31 has a storage capacity of  $N/(6 \times 2) \times (6 \times 2)$  bits in the column direction  $\times$  row direction and includes 12 ( $= 6 \times 2$ ) columns.

[0151]

FIG. 17A illustrates a writing order of an LDPC code into the memory 31.

[0152]

The demultiplexer 25 carries out writing of code bits of an LDPC code in a downward direction from above of a column which forms the memory 31 (in the column direction) beginning with a left side column toward a

right side column as described hereinabove with reference to FIG. 16.

[0153]

Then, if the writing of code bits ends with the lowermost bit in the rightmost column, then the code bits are read out and supplied to the replacement section 32 in a unit of 12 bits (mb bits) in the row direction beginning with the first row of all of the columns which form the memory 31.

[0154]

The replacement section 32 carries out a replacement process of replacing the position of 12 code bits from the memory 31 in accordance with the fourth replacement method and outputs the 12 bits obtained by the replacement as 12 bits representative of two symbols (b symbols) of 64QAM, in particular, as 6 symbol bits  $y_0$ ,  $y_1$ ,  $y_2$ ,  $y_3$ ,  $y_4$  and  $y_5$  representative of one symbol of 64QAM and 6 symbol bits  $y_0$ ,  $y_1$ ,  $y_2$ ,  $y_3$ ,  $y_4$  and  $y_5$  representative of a next one symbol.

[0155]

Here, FIG. 17B illustrates the fourth replacement method of the replacement process by the replacement section 32 of FIG. 17A.

[0156]

It is to be noted that, where the multiple  $b$  is 2 (similarly also where the multiple  $b$  is equal to or higher than 3), in the replacement process,  $mb$  code bits are allocated to  $mb$  symbol bits of  $b$  successive symbols. In the following description including description given with reference to FIG. 17, the  $i+1$ th bit from the most significant bit from among the  $mb$  symbol bits of the  $b$  successive symbols is represented as bit (symbol bit)  $y_i$  for the convenience of description.

[0157]

Moreover, which replacement method is optimum, that is, which replacement method provides improved error rate in an AWGN communication path, differs depends upon the encoding rate, code length and modulation method of LDPC code and so forth.

[0158]

Now, parity interleave by the parity interleaver 23 of FIG. 8 is described with reference to FIGS. 18 to 20.

[0159]

FIG. 18 shows (part of) a Tanner graph of the parity check matrix of the LDPC code.

[0160]

If a plurality of (code bits corresponding to) variable nodes connecting to a check node such as two

variable nodes suffer from an error such as erasure at the same time as shown in FIG. 18, then the check node returns a message of an equal probability representing that the probability that the value may be 0 and the probability that the value may be 1 are equal to each other to all variable nodes connecting to the check node. Therefore, if a plurality of variable nodes connecting to the same check node are placed into an erasure state or the like at the same time, then the performance in decoding is deteriorated.

[0161]

Incidentally, an LDPC code outputted from the LDPC encoding section 21 of FIG. 8 and prescribed in the DVB-S.2 standard is an IRA code, and the parity matrix  $H_T$  of the parity check matrix  $H$  has a staircase structure as shown in FIG. 10.

[0162]

FIG. 19 illustrates a parity matrix  $H_T$  having a staircase structure and a Tanner graph corresponding to the parity matrix  $H_T$ .

[0163]

In particular, FIG. 19A illustrates a parity matrix  $H_T$  having a staircase structure and FIG. 19B shows a Tanner graph corresponding to the parity matrix  $H_T$  of FIG.

19A.

[0164]

Where the parity matrix  $H_T$  has a staircase structure, in the Tanner graph of the parity matrix  $H_T$ , variable nodes of the LDPC code which correspond to a column of an element of the parity matrix  $H_T$  having the value of 1 and whose message is determined using adjacent code bits (parity bits) are connected to the same check node.

[0165]

Accordingly, if the adjacent parity bits described above are placed into an error state by burst errors, erasure or the like, then since a check node connecting to a plurality of variable nodes corresponding to the plural parity bits which have become an error (variable nodes whose message are to be determined using parity bits) returns a message of an equal probability representing that the probability that the value may be 0 and the probability that the value is 1 may be equal to each other to the variable nodes connecting to the check node, the performance of the decoding deteriorates. Then, where the burst length (number of bits which are made an error by a burst) is great, the performance of the decoding further deteriorates.

[0166]

Therefore, in order to prevent the deterioration in performance of decoding described above, the parity interleaver 23 (FIG. 8) carries out interleave of interleaving parity bits of the LDPC code from the LDPC encoding section 21 to positions of other parity bits.

[0167]

FIG. 20 illustrates a parity matrix  $H_T$  of a parity check matrix  $H$  corresponding to the LDPC code after the parity interleave carried out by the parity interleaver 23 of FIG. 8.

[0168]

Here, the information matrix  $H_A$  of the parity check matrix  $H$  corresponding to the LDPC code prescribed in the DVB-S.2 standard and outputted from the LDPC encoding section 21 has a cyclic structure.

[0169]

The cyclic structure signifies a structure wherein a certain column coincides with another column in a cyclically operated state (rotation) and includes, for example, a structure wherein, for every  $P$  columns, the positions of the value 1 in the rows of the  $P$  columns coincide with positions to which the first one of the  $P$  columns is cyclically shifted in the column direction by

a value which increases in proportion to a value  $q$  obtained by dividing the parity length  $M$ . In the following, the number of  $P$  columns in a cyclic structure is hereinafter referred to suitably as a unit column number of the cyclic structure.

[0170]

As an LDPC code prescribed in the DVB-S.2 standard and outputted from the LDPC encoding section 21, two LDPC codes are available including those whose code length  $N$  is 64,800 bits and 16,200 bits as described hereinabove with reference to FIG. 11.

[0171]

Now, if attention is paid to the LDPC code whose code length  $N$  is 64,800 bits from the two different LDPC codes whose code length  $N$  is 64,800 bits and 16,200 bits, then eleven different encoding rates are available as the encoding rate of the LDPC code whose code length  $N$  is 64,800 bits as described hereinabove with reference to FIG. 11.

[0172]

With regard to LDPC codes whose code length  $N$  is 64,800 bits and which have the eleven different encoding rates, it is prescribed in the DVB-S.2 standard that the column number  $P$  of the cyclic structure is prescribed to

360 which is one of divisors of the parity length  $M$  except 1 and  $M$ .

[0173]

Further, with regard to LDPC codes whose code length  $N$  is 64,800 bits and which have the eleven different encoding rates, the parity length  $M$  has a value other than prime numbers and represented by an expression  $M = q \times P = q \times 360$  using the value  $q$  which is different depending upon the encoding rate. Accordingly, also the value  $q$  is one of the divisors of the parity length  $M$  except 1 and  $M$  similarly to the column number  $P$  of the cyclic structure and is obtained by dividing the parity length  $M$  by the column number  $P$  of the cyclic structure (the product of  $P$  and  $q$  which are divisors of the parity length  $M$  is the parity length  $M$ ).

[0174]

Where the information length is represented by  $K$  and an integer higher than 0 but lower than  $P$  is represented by  $x$  while an integer higher than 0 but lower than  $q$  is represented by  $y$ , the parity interleaver 23 interleaves, as parity interleave, the  $K+qx+y+1$ th code bit from among parity bits which are  $K+1$ th to  $K+M$ th ( $K + M = N$ ) bits of the LDPC code from the LDPC encoding section 21 to the position of the  $K+Py+x+1$ th code bit.

[0175]

According to such parity interleave, since the (parity bits corresponding to) variable nodes connecting to the same check node are spaced by a distance corresponding to the column number  $P$  of the cyclic structure, here, by 360 bits, where the burst length is smaller than 360 bits, such a situation that a plurality of variable nodes connecting to the same check node are rendered erroneous at the same time can be prevented. As a result, the tolerance to a burst error can be improved.

[0176]

It is to be noted that the LDPC code after the parity interleave by which the  $K+qx+y+1$ th code bit is interleaved to the position of the  $K+Py+x+1$ th code bit coincides with the LDPC code of a parity check matrix (hereinafter referred to also as conversion parity check matrix) obtained by column replacement of replacing the  $K+qx+y+1$ th column of the original parity check matrix  $H$  into the  $K+Py+x+1$ th column.

[0177]

Further, in the parity matrix of the conversion parity check matrix, a pseudo cyclic structure whose unit is  $P$  columns (in FIG. 20, 360 columns) appears as seen in FIG. 20.

[0178]

Here, the pseudo cyclic structure signifies a structure which has a portion having a cyclic structure except part thereof. In a conversion parity check column obtained by applying column replacement corresponding to parity interleave to the parity check matrix of the LDPC code prescribed in the DVB-S.2 standard, a portion of 360 rows  $\times$  360 columns (shift matrix hereinafter described) at a right corner portion is short of one element of 1 (which has the value of 0). Therefore, the conversion parity check matrix does not have a (complete) cyclic structure but has a pseudo cyclic structure.

[0179]

It is to be noted that the conversion parity check matrix of FIG. 20 is a matrix to which also replacement of rows (row replacement) for configuring the conversion parity check matrix from a configuration matrix hereinafter described is applied to the original parity check matrix H in addition to the column replacement which corresponds to parity interleave.

[0180]

Now, column twist interleave as a re-arrangement process by the column twist interleaver 24 of FIG. 8 is described with reference to FIGS. 21 to 24.

[0181]

In the transmission apparatus 11 of FIG. 8, two or more of the code bits of the LDPC code are transmitted as one symbol as described hereinabove in order to improve the utilization efficiency of frequencies. In particular, for example, where 2 bits of the code bits are used to form one symbol, for example, QPSK is used as the modulation method, but where 4 bits of the code bits are used to form one symbol, for example, 16QAM is used as the modulation method.

[0182]

Where two or more ones of the code bits are transmitted as one symbol in this manner, if erasure or the like occurs with a certain symbol, the all of the code bits (allocated to the symbol bits) of the symbol become an error (erasure).

[0183]

Accordingly, in order to lower the probability that a plurality of (code bits corresponding to) variable nodes connecting to the same check node may suffer from erasure at the same time to improve the performance in decoding, it is necessary to avoid the variable nodes corresponding to code bits of one symbol from connecting to the same check node.

[0184]

Meanwhile, in the parity check matrix  $H$  of an LDPC code prescribed in the DVB-S.2 standard and outputted from the LDPC encoding section 21, the information matrix  $H_A$  has a cyclic structure and the parity matrix  $H_T$  has a staircase structure as described hereinabove. Then, in a conversion parity check matrix which is a parity check matrix of the LDPC code after parity interleave, a cyclic structure (accurately, a pseudo cyclic structure as described hereinabove) appears also in the parity matrix as described in FIG. 20.

[0185]

FIG. 21 shows a conversion parity check matrix.

[0186]

In particular, FIG. 21A illustrates a conversion parity check matrix of a parity check matrix  $H$  which has a code length  $N$  of 64,800 bits and an encoding rate ( $r$ ) of  $3/4$ .

[0187]

In FIG. 21A, the position of an element having the value of 1 in the conversion parity check matrix is indicated by a dot ( $\cdot$ ).

[0188]

In FIG. 21B, a process carried out by the

demultiplexer 25 (FIG. 8) for the LDPC code of the conversion parity check matrix of FIG. 21A, that is, the LDPC code after the parity interleave.

[0189]

In FIG. 21B, the code bits of the LDPC code after the parity interleave are written in the column direction in four columns which form the memory 31 of the demultiplexer 25 using 16QAM as the modulation method.

[0190]

The code bits written in the column direction in the four columns which form the memory 31 are read out in the row direction in a unit of 4 bits which make one symbol.

[0191]

In this instance, the 4 code bits  $B_0$ ,  $B_1$ ,  $B_2$  and  $B_3$  which make one symbol sometimes make code bits corresponding to 1 and included in one arbitrary row of the parity check matrix after the conversion of FIG. 21A, and in this instance, variable nodes corresponding to the code bits  $B_0$ ,  $B_1$ ,  $B_2$  and  $B_3$  are connected to the same check node.

[0192]

Accordingly, where the 4 code bits  $B_0$ ,  $B_1$ ,  $B_2$  and  $B_3$  of one symbol become code bits corresponding to 1 and

included in one arbitrary row of the conversion parity check matrix, if erasure occurs with the symbol, then the same check node to which the variable nodes corresponding to the code bits  $B_0$ ,  $B_1$ ,  $B_2$  and  $B_3$  are connected cannot determine an appropriate message. As a result, the performance in decoding deteriorates.

[0193]

Also with regard to the encoding rates other than the encoding rate of  $3/4$ , a plurality of code bits corresponding to a plurality of variable nodes connecting to the same check node sometimes make one symbol of 16QAM similarly.

[0194]

Therefore, the column twist interleaver 24 carries out column twist interleave wherein the code bits of the LDPC code after the parity interleave from the parity interleaver 23 are interleaved such that a plurality of code bits corresponding to 1 and included in one arbitrary row of the conversion parity check matrix are not included to one symbol.

[0195]

FIG. 22 is a view illustrating the column twist interleave.

[0196]

In particular, FIG. 22 illustrates the memory 31 (FIGS. 16 and 17) of the demultiplexer 25.

[0197]

The memory 31 has a storage capacity for storing  $mb$  bits in the column (vertical) direction and stores  $N/(mb)$  bits in the row (horizontal) direction and includes  $mb$  columns as described in FIG. 16. Then, the column twist interleaver 24 writes the code bits of the LDPC code in the column direction into the memory 31 and controls the writing starting position when the code bits are read out in the row direction to carry out column twist interleave.

[0198]

In particular, the column twist interleaver 24 suitably changes the writing starting position at which writing of code bits is to be started for each of a plurality of columns so that a plurality of code bits read out in the row direction and used to make one symbol may not become code bits corresponding to 1 and included in one arbitrary row of the conversion parity check matrix (re-arranges the code bits of the LDPC code such that a plurality of code bits corresponding to 1 and included in one arbitrary row of the parity check matrix may not be included in the same symbol).

[0199]

Here, FIG. 22 shows an example of a configuration of the memory 31 where the modulation method is 16QAM and besides the multiple  $b$  described hereinabove with reference to FIG. 16 is 1. Accordingly, the bit number  $m$  of code bits of an LDPC code to be one symbol is 4 bits, and the memory 31 is formed from four ( $= mb$ ) columns.

[0200]

The column twist interleaver 24 (instead of the demultiplexer 25 shown in FIG. 16) carries out writing of the code bits of the LDPC code in a downward direction (column direction) from above into the four columns which form the memory 31 beginning with a left side column towards a right side column.

[0201]

Then, when the writing of code bits ends to the rightmost column, the column twist interleaver 24 reads out the code bits in a unit of 4 bits ( $mb$  bits) in the row direction beginning with the first row of all columns which form the memory 31 and outputs the code bits as an LDPC code after the column twist interleave to the replacement section 32 (FIGS. 16 and 17) of the demultiplexer 25.

[0202]

However, if the address of the head (uppermost)

position of each column is represented by 0 and the addresses of the positions in the column direction are represented by integers of an ascending order, then the column twist interleaver 24 sets, for the leftmost column, the writing starting position to the position whose address is 0; sets, for the second column (from the left), the writing starting position to the position whose address is 2; sets, for the third column, the writing starting position to the position whose address is 4; and sets, for the fourth column, the writing starting position to the position whose address is 7.

[0203]

It is to be noted that, with regard to the columns for which the writing starting position is any other position than the position whose address is 0, after the code bits are written down to the lowermost position, the writing position returns to the top (position whose address is 0) and writing down to a position immediately preceding to the writing starting position is carried out. Thereafter, writing into the next (right) column is carried out.

[0204]

By carrying out such column twist interleave as described above, such a situation that a plurality of

code bits corresponding to a plurality of variable nodes connecting to the same check node are made one symbol of 16QAM (included into the same symbol) with regard to LDPC codes of all encoding rates whose code length  $N$  is 64,800 as prescribed in the DVB-S.2 standard can be prevented, and as a result, the performance in decoding in a communication path which provides erasure can be improved.

[0205]

FIG. 23 illustrates the number of columns of the memory 31 necessary for column twist interleave and the address of the writing starting position for each modulation method with regard to LDPC codes of the eleven different encoding rates having the code length  $N$  of 64,800 as prescribed in the DVB-S.2 standard.

[0206]

Where the multiple  $b$  is 1 and besides, since, for example, QPSK is adopted as the modulation method, the bit number  $m$  of one symbol is 2 bits, according to FIG. 23, the memory 31 has two columns for storing  $2 \times 1$  ( $= mb$ ) bits in the row direction and stores  $64,800 / (2 \times 1)$  bits in the column direction.

[0207]

Then, the writing starting position for the first one of the two columns of the memory 31 is set to the

position whose address is 0, and the writing starting position for the second column is set to the position whose address is 2.

[0208]

It is to be noted that the multiple  $b$  is 1, for example, where one of the first to third replacement methods of FIG. 16 is adopted as the replacement method of the replacement process of the demultiplexer 25 (FIG. 8) or in a like case.

[0209]

Where the multiple  $b$  is 2 and besides, since, for example, QPSK is adopted as the modulation method, the bit number  $m$  of one symbol is 2 bits, according to FIG. 23, the memory 31 has four columns for storing  $2 \times 2$  bits in the row direction and stores  $64,800/(2 \times 2)$  bits in the column direction.

[0210]

Then, the writing starting position for the first one of the four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 4, and the writing starting position for the fourth column

is set to the position whose address is 7.

[0211]

It is to be noted that the multiple  $b$  is 2, for example, where fourth replacement method of FIG. 17 is adopted as the replacement method of the replacement process of the demultiplexer 25 (FIG. 8).

[0212]

Where the multiple  $b$  is 1 and besides, since, for example, 16QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 4 bits, according to FIG. 23, the memory 31 has four columns for storing  $4 \times 1$  bits in the row direction and stores  $64,800/(4 \times 1)$  bits in the column direction.

[0213]

Then, the writing starting position for the first one of the four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 4, and the writing starting position for the fourth column is set to the position whose address is 7.

[0214]

Where the multiple  $b$  is 2 and besides, since, for

example, 16QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 4 bits, according to FIG. 23, the memory 31 has eight columns for storing  $4 \times 2$  bits in the row direction and stores  $64,800/(4 \times 2)$  bits in the column direction.

[0215]

Then, the writing starting position for the first one of the eight columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 4, the writing starting position for the fifth column is set to the position whose address is 4, the writing starting position for the sixth column is set to the position whose address is 5, the writing starting position for the seventh column is set to the position whose address is 7, and the writing starting position for the eighth column is set to the position whose address is 7.

[0216]

Where the multiple  $b$  is 1 and besides, since, for example, 64QAM is adopted as the modulation method, the

bit number  $m$  of one symbol is 6 bits, according to FIG. 23, the memory 31 has six columns for storing  $6 \times 1$  bits in the row direction and stores  $64,800/(6 \times 1)$  bits in the column direction.

[0217]

Then, the writing starting position for the first one of the six columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 5, the writing starting position for the fourth column is set to the position whose address is 9, the writing starting position for the fifth column is set to the position whose address is 10, and the writing starting position for the sixth column is set to the position whose address is 13.

[0218]

Where the multiple  $b$  is 2 and besides, since, for example, 64QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 6 bits, according to FIG. 23, the memory 31 has twelve columns for storing  $6 \times 2$  bits in the row direction and stores  $64,800/(6 \times 2)$  bits in the column direction.

[0219]

Then, the writing starting position for the first one of the twelve columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 3, the writing starting position for the sixth column is set to the position whose address is 4, the writing starting position for the seventh column is set to the position whose address is 4, the writing starting position for the eighth column is set to the position whose address is 5, the writing starting position for the ninth column is set to the position whose address is 5, the writing starting position for the tenth column is set to the position whose address is 7, the writing starting position for the eleventh column is set to the position whose address is 8, and the writing starting position for the twelfth column is set to the position whose address is 9.

[0220]

Where the multiple  $b$  is 1 and besides, since, for example, 256QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 8 bits, according to FIG. 23, the memory 31 has eight columns for storing  $8 \times 1$  bits in the row direction and stores  $64,800/(8 \times 1)$  bits in the column direction.

[0221]

Then, the writing starting position for the first one of the eight columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 4, the writing starting position for the fifth column is set to the position whose address is 4, the writing starting position for the sixth column is set to the position whose address is 5, the writing starting position for the seventh column is set to the position whose address is 7, and the writing starting position for the eighth column is set to the position whose address is 7.

[0222]

Where the multiple  $b$  is 2 and besides, since, for

example, 256QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 8 bits, according to FIG. 23, the memory 31 has sixteen columns for storing  $8 \times 2$  bits in the row direction and stores  $64,800/(8 \times 2)$  bits in the column direction.

[0223]

Then, the writing starting position for the first one of the sixteen columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 2, the writing starting position for the sixth column is set to the position whose address is 3, the writing starting position for the seventh column is set to the position whose address is 7, the writing starting position for the eighth column is set to the position whose address is 15, the writing starting position for the ninth column is set to the position whose address is 16, the writing starting position for the tenth column is set to the position

whose address is 20, the writing starting position for the eleventh column is set to the position whose address is 22, the writing starting position for the twelfth column is set to the position whose address is 22, the writing starting position for the thirteenth column is set to the position whose address is 27, the writing starting position for the fourteenth column is set to the position whose address is 27, the writing starting position for the fifteenth column is set to the position whose address is 28, and the writing starting position for the sixteenth column is set to the position whose address is 32.

[0224]

Where the multiple  $b$  is 1 and besides, since, for example, 1024QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 10 bits, according to FIG. 23, the memory 31 has ten columns for storing  $10 \times 1$  bits in the row direction and stores  $64,800 / (10 \times 1)$  bits in the column direction.

[0225]

Then, the writing starting position for the first one of the ten columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position

whose address is 3, the writing starting position for the third column is set to the position whose address is 6, the writing starting position for the fourth column is set to the position whose address is 8, the writing starting position for the fifth column is set to the position whose address is 11, the writing starting position for the sixth column is set to the position whose address is 13, the writing starting position for the seventh column is set to the position whose address is 15, the writing starting position for the eighth column is set to the position whose address is 17, the writing starting position for the ninth column is set to the position whose address is 18, and the writing starting position for the tenth column is set to the position whose address is 20.

[0226]

Where the multiple  $b$  is 2 and besides, since, for example, 1024QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 10 bits, according to FIG. 23, the memory 31 has twenty columns for storing  $10 \times 2$  bits in the row direction and stores  $64,800 / (10 \times 2)$  bits in the column direction.

[0227]

Then, the writing starting position for the first

one of the twenty columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 1, the writing starting position for the third column is set to the position whose address is 3, the writing starting position for the fourth column is set to the position whose address is 4, the writing starting position for the fifth column is set to the position whose address is 5, the writing starting position for the sixth column is set to the position whose address is 6, the writing starting position for the seventh column is set to the position whose address is 6, the writing starting position for the eighth column is set to the position whose address is 9, the writing starting position for the ninth column is set to the position whose address is 13, the writing starting position for the tenth column is set to the position whose address is 14, the writing starting position for the eleventh column is set to the position whose address is 14, the writing starting position for the twelfth column is set to the position whose address is 16, the writing starting position for the thirteenth column is set to the position whose address is 21, the writing starting position for the fourteenth column is set to the

position whose address is 21, the writing starting position for the fifteenth column is set to the position whose address is 23, the writing starting position for the sixteenth column is set to the position whose address is 25, the writing starting position for the seventeenth column is set to the position whose address is 25, the writing starting position for the eighteenth column is set to the position whose address is 26, the writing starting position for the nineteenth column is set to the position whose address is 28, and the writing starting position for the twentieth column is set to the position whose address is 30.

[0228]

Where the multiple  $b$  is 1 and besides, since, for example, 4096QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 12 bits, according to FIG. 23, the memory 31 has twelve columns for storing  $12 \times 1$  bits in the row direction and stores  $64,800/(12 \times 1)$  bits in the column direction.

[0229]

Then, the writing starting position for the first one of the twelve columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position

whose address is 0, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 3, the writing starting position for the sixth column is set to the position whose address is 4, the writing starting position for the seventh column is set to the position whose address is 4, the writing starting position for the eighth column is set to the position whose address is 5, the writing starting position for the ninth column is set to the position whose address is 5, the writing starting position for the tenth column is set to the position whose address is 7, the writing starting position for the eleventh column is set to the position whose address is 8, and the writing starting position for the twelfth column is set to the position whose address is 9.

[0230]

Where the multiple  $b$  is 2 and besides, since, for example, 4096QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 12 bits, according to FIG. 23, the memory 31 has twenty-four columns for storing  $12 \times 2$  bits in the row direction and stores

64,800/(12 × 2) bits in the column direction.

[0231]

Then, the writing starting position for the first one of the twenty-four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 5, the writing starting position for the third column is set to the position whose address is 8, the writing starting position for the fourth column is set to the position whose address is 8, the writing starting position for the fifth column is set to the position whose address is 8, the writing starting position for the sixth column is set to the position whose address is 8, the writing starting position for the seventh column is set to the position whose address is 10, the writing starting position for the eighth column is set to the position whose address is 10, the writing starting position for the ninth column is set to the position whose address is 10, the writing starting position for the tenth column is set to the position whose address is 12, the writing starting position for the eleventh column is set to the position whose address is 13, the writing starting position for the twelfth column is set to the position whose address is 16, the

writing starting position for the thirteenth column is set to the position whose address is 17, the writing starting position for the fourteenth column is set to the position whose address is 19, the writing starting position for the fifteenth column is set to the position whose address is 21, the writing starting position for the sixteenth column is set to the position whose address is 22, the writing starting position for the seventeenth column is set to the position whose address is 23, the writing starting position for the eighteenth column is set to the position whose address is 26, the writing starting position for the nineteenth column is set to the position whose address is 37, the writing starting position for the twentieth column is set to the position whose address is 39, the writing starting position for the twenty-first column is set to the position whose address is 40, the writing starting position for the twenty-second column is set to the position whose address is 41, the writing starting position for the twenty-third column is set to the position whose address is 41, and the writing starting position for the twenty-fourth column is set to the position whose address is 41.

[0232]

FIG. 24 indicates the number of columns of the

memory 31 necessary for column twist interleave and the address of the writing starting position for each modulation method with regard to the LDPC codes of the 10 different encoding rates having the code length  $N$  of 16,200 as prescribed in the DVB-S.2 standard.

[0233]

Where the multiple  $b$  is 1 and besides, since, for example, QPSK is adopted as the modulation method, the bit number  $m$  of one symbol is 2 bits, according to FIG. 24, the memory 31 has two columns for storing  $2 \times 1$  bits in the row direction and stores  $16,200/(2 \times 1)$  bits in the column direction.

[0234]

Then, the writing starting position for the first one of the two columns of the memory 31 is set to the position whose address is 0, and the writing starting position for the second column is set to the position whose address is 0.

[0235]

Where the multiple  $b$  is 2 and besides, since, for example, QPSK is adopted as the modulation method, the bit number  $m$  of one symbol is 2 bits, according to FIG. 24, the memory 31 has four columns for storing  $2 \times 2$  bits in the row direction and stores  $16,200/(2 \times 2)$  bits

in the column direction.

[0236]

Then, the writing starting position for the first one of the four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 3, and the writing starting position for the fourth column is set to the position whose address is 3.

[0237]

Where the multiple  $b$  is 1 and besides, since, for example, 16QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 4 bits, according to FIG. 24, the memory 31 has four columns for storing  $4 \times 1$  bits in the row direction and stores  $16,200/(4 \times 1)$  bits in the column direction.

[0238]

Then, the writing starting position for the first one of the four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 2, the writing starting position for the third column is set to the position whose address is 3,

and the writing starting position for the fourth column is set to the position whose address is 3.

[0239]

Where the multiple  $b$  is 2 and besides, since, for example, 16QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 4 bits, according to FIG. 24, the memory 31 has eight columns for storing  $4 \times 2$  bits in the row direction and stores  $16,200 / (4 \times 2)$  bits in the column direction.

[0240]

Then, the writing starting position for the first one of the eight columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 1, the writing starting position for the fifth column is set to the position whose address is 7, the writing starting position for the sixth column is set to the position whose address is 20, the writing starting position for the seventh column is set to the position whose address is 20, and the writing starting position for the eighth

column is set to the position whose address is 21.

[0241]

Where the multiple  $b$  is 1 and besides, since, for example, 64QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 6 bits, according to FIG. 24, the memory 31 has six columns for storing  $6 \times 1$  bits in the row direction and stores  $16,200/(6 \times 1)$  bits in the column direction.

[0242]

Then, the writing starting position for the first one of the six columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 3, the writing starting position for the fifth column is set to the position whose address is 7, and the writing starting position for the sixth column is set to the position whose address is 7.

[0243]

Where the multiple  $b$  is 2 and besides, since, for example, 64QAM is adopted as the modulation method, the

bit number  $m$  of one symbol is 6 bits, according to FIG. 24, the memory 31 has twelve columns for storing  $6 \times 2$  bits in the row direction and stores  $16,200/(6 \times 2)$  bits in the column direction.

[0244]

Then, the writing starting position for the first one of the twelve columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 2, the writing starting position for the sixth column is set to the position whose address is 2, the writing starting position for the seventh column is set to the position whose address is 3, the writing starting position for the eighth column is set to the position whose address is 3, the writing starting position for the ninth column is set to the position whose address is 3, the writing starting position for the tenth column is set to the position whose address is 6, the writing starting position for the

eleventh column is set to the position whose address is 7, and the writing starting position for the twelfth column is set to the position whose address is 7.

[0245]

Where the multiple  $b$  is 1 and besides, since, for example, 256QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 8 bits, according to FIG. 24, the memory 31 has eight columns for storing  $8 \times 1$  bits in the row direction and stores  $16,200/(8 \times 1)$  bits in the column direction.

[0246]

Then, the writing starting position for the first one of the eight columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 1, the writing starting position for the fifth column is set to the position whose address is 7, the writing starting position for the sixth column is set to the position whose address is 20, the writing starting position for the seventh column is set to the position whose address

is 20, and the writing starting position for the eighth column is set to the position whose address is 21.

[0247]

Where the multiple  $b$  is 1 and besides, since, for example, 1024QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 10 bits, according to FIG. 24, the memory 31 has ten columns for storing  $10 \times 1$  bits in the row direction and stores  $16,200/(10 \times 1)$  bits in the column direction.

[0248]

Then, the writing starting position for the first one of the ten columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 1, the writing starting position for the third column is set to the position whose address is 2, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 3, the writing starting position for the sixth column is set to the position whose address is 3, the writing starting position for the seventh column is set to the position whose address is 4, the writing starting position for the eighth column is

set to the position whose address is 4, the writing starting position for the ninth column is set to the position whose address is 5, and the writing starting position for the tenth column is set to the position whose address is 7.

[0249]

Where the multiple  $b$  is 2 and besides, since, for example, 1024QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 10 bits, according to FIG. 24, the memory 31 has twenty columns for storing  $10 \times 2$  bits in the row direction and stores  $16,200 / (10 \times 2)$  bits in the column direction.

[0250]

Then, the writing starting position for the first one of the twenty columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 2, the writing starting position for the sixth column is set to the position

whose address is 2, the writing starting position for the seventh column is set to the position whose address is 2, the writing starting position for the eighth column is set to the position whose address is 2, the writing starting position for the ninth column is set to the position whose address is 5, the writing starting position for the tenth column is set to the position whose address is 5, the writing starting position for the eleventh column is set to the position whose address is 5, the writing starting position for the twelfth column is set to the position whose address is 5, the writing starting position for the thirteenth column is set to the position whose address is 5, the writing starting position for the fourteenth column is set to the position whose address is 7, the writing starting position for the fifteenth column is set to the position whose address is 7, the writing starting position for the sixteenth column is set to the position whose address is 7, the writing starting position for the seventeenth column is set to the position whose address is 7, the writing starting position for the eighteenth column is set to the position whose address is 8, the writing starting position for the nineteenth column is set to the position whose address is 8, and the writing starting position for the twentieth

column is set to the position whose address is 10.

[0251]

Where the multiple  $b$  is 1 and besides, since, for example, 4096QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 12 bits, according to FIG. 24, the memory 31 has twelve columns for storing  $12 \times 1$  bits in the row direction and stores  $16,200/(12 \times 1)$  bits in the column direction.

[0252]

Then, the writing starting position for the first one of the twelve columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 2, the writing starting position for the fifth column is set to the position whose address is 2, the writing starting position for the sixth column is set to the position whose address is 2, the writing starting position for the seventh column is set to the position whose address is 3, the writing starting position for the eighth column is set to the position whose address is 3, the writing

starting position for the ninth column is set to the position whose address is 3, the writing starting position for the tenth column is set to the position whose address is 6, the writing starting position for the eleventh column is set to the position whose address is 7, and the writing starting position for the twelfth column is set to the position whose address is 7.

[0253]

Where the multiple  $b$  is 2 and besides, since, for example, 4096QAM is adopted as the modulation method, the bit number  $m$  of one symbol is 12 bits, according to FIG. 24, the memory 31 has twenty-four columns for storing  $12 \times 2$  bits in the row direction and stores  $16,200/(12 \times 2)$  bits in the column direction.

[0254]

Then, the writing starting position for the first one of the twenty-four columns of the memory 31 is set to the position whose address is 0, the writing starting position for the second column is set to the position whose address is 0, the writing starting position for the third column is set to the position whose address is 0, the writing starting position for the fourth column is set to the position whose address is 0, the writing starting position for the fifth column is set to the

position whose address is 0, the writing starting position for the sixth column is set to the position whose address is 0, the writing starting position for the seventh column is set to the position whose address is 0, the writing starting position for the eighth column is set to the position whose address is 1, the writing starting position for the ninth column is set to the position whose address is 1, the writing starting position for the tenth column is set to the position whose address is 1, the writing starting position for the eleventh column is set to the position whose address is 2, the writing starting position for the twelfth column is set to the position whose address is 2, the writing starting position for the thirteenth column is set to the position whose address is 2, the writing starting position for the fourteenth column is set to the position whose address is 3, the writing starting position for the fifteenth column is set to the position whose address is 7, the writing starting position for the sixteenth column is set to the position whose address is 9, the writing starting position for the seventeenth column is set to the position whose address is 9, the writing starting position for the eighteenth column is set to the position whose address is 9, the writing starting position for the

nineteenth column is set to the position whose address is 10, the writing starting position for the twentieth column is set to the position whose address is 10, the writing starting position for the twenty-first column is set to the position whose address is 10, the writing starting position for the twenty-second column is set to the position whose address is 10, the writing starting position for the twenty-third column is set to the position whose address is 10, and the writing starting position for the twenty-fourth column is set to the position whose address is 11.

[0255]

Now, a transmission process carried out by the transmission apparatus 11 of FIG. 8 is described with reference to a flow chart of FIG. 25.

[0256]

The LDPC encoding section 21 waits that object data are supplied thereto and, at step S101, encodes the object data into LDPC codes and supplies the LDPC codes to the bit interleaver 22. Thereafter, the processing advances to step S102.

[0257]

At step S102, the bit interleaver 22 carries out bit interleave for the LDPC codes from the LDPC encoding

section 21 and supplies to the mapping section 26 a symbol in which the LDPC codes after the interleave are symbolized. Thereafter, the processing advances to step S103.

[0258]

In particular, at step S102, the parity interleaver 23 in the bit interleaver 22 carries out parity interleave for the LDPC codes from the LDPC encoding section 21 and supplies the LDPC codes after the parity interleave to the column twist interleaver 24.

[0259]

The column twist interleaver 24 carries out column twist interleave for the LDPC code from the parity interleaver 23 and supplies a result of the column twist interleave to the demultiplexer 25.

[0260]

The demultiplexer 25 carries out a replacement process of replacing the code bits of the LDPC code after the column twist interleave by the column twist interleaver 24 and converting the code bits after the replacement into symbol bits (bits representative of symbols) of symbols.

[0261]

Here, the replacement process by the demultiplexer

25 can be carried out in accordance with the first to fourth replacement methods described hereinabove with reference to FIGS. 16 and 17 and besides can be carried out in accordance with an allocation rule. The allocation rule is a rule for allocating code bits of an LDPC code to symbol bits representative of symbols, and details of the allocation rule are hereinafter described.

[0262]

The symbols obtained by the replacement process by the demultiplexer 25 are supplied from the demultiplexer 25 to the mapping section 26.

[0263]

At step S103, the mapping section 26 maps the symbol from the demultiplexer 25 to signal points defined by the modulation method of orthogonal modulation carried out by the orthogonal modulation section 27 and supplies the mapped symbol to the orthogonal modulation section 27. Then, the processing advances to step S104.

[0264]

At step S104, the orthogonal modulation section 27 carries out orthogonal modulation of a carrier in accordance with the signal points from the mapping section 26. Then, the processing advances to step S105, at which the modulation signal obtained as a result of

the orthogonal modulation is transmitted, whereafter the processing is ended.

[0265]

It is to be noted that the transmission process of FIG. 25 is carried out by pipeline repetitively.

[0266]

By carrying out the parity interleave and the column twist interleave as described above, the tolerance to erasure or burst errors where a plurality of code bits of an LDPC codes are transmitted as one symbol can be improved.

[0267]

Here, while, in FIG. 8, the parity interleaver 23 which is a block for carrying out parity interleave and the column twist interleaver 24 which is a block for carrying out column twist interleave are configured separately from each other for the convenience of description, the parity interleaver 23 and the column twist interleaver 24 may otherwise be configured integrally with each other.

[0268]

In particular, both of the parity interleave and the column twist interleave can be carried out by writing and reading out of code bits into and from a memory and

can be represented by a matrix for converting addresses (write addresses) into which writing of code bits is to be carried out into addresses (readout addresses) from which reading out of code bits is to be carried out.

[0269]

Accordingly, if a matrix obtained by multiplying a matrix representative of the parity interleave and a matrix representative of the column twist interleave is determined in advance, then if the matrix is used to convert code bits, then a result when parity interleave is carried out and then LDPC codes after the parity interleave are column twist interleaved can be obtained.

[0270]

Further, in addition to the parity interleaver 23 and the column twist interleaver 24, also the demultiplexer 25 may be configured integrally.

[0271]

In particular, also the replacement process carried out by the demultiplexer 25 can be represented by a matrix for converting a write address of the memory 31 for storing an LDPC code into a read address.

[0272]

Accordingly, if a matrix obtained by multiplication of a matrix representative of the parity interleave,

another matrix representative of the column twist interleave and a further matrix representative of the replacement process is determined in advance, then the parity interleave, column twist interleave and replacement process can be carried out collectively by the determined matrix.

[0273]

It is to be noted that it is possible to carry out only one of or no one of the parity interleave and the column twist interleave.

[0274]

Now, a simulation carried out with regard to the transmission apparatus 11 of FIG. 8 for measuring the error rate (bit error rate) is described with reference to FIGS. 26 to 28.

[0275]

The simulation was carried out adopting a communication path which has a flutter whose D/U is 0 dB.

[0276]

FIG. 26 shows a model of the communication path adopted in the simulation.

[0277]

In particular, FIG. 26A shows a model of the flutter adopted in the simulation.

[0278]

Meanwhile, FIG. 26B shows a model of a communication path which has the flutter represented by the model of FIG. 26A.

[0279]

It is to be noted that, in FIG. 26B, H represents the model of the flutter of FIG. 26A. Further, in FIG. 26B, N represents ICI (Inter Carrier Interference), and in the simulation, an expected value  $E[N^2]$  of the power was approximated by AWGN.

[0280]

FIGS. 27 and 28 illustrate relationships between the error rate obtained by the simulation and the Doppler frequency  $f_d$  of the flutter.

[0281]

It is to be noted that FIG. 27 illustrates a relationship between the error rate and the Doppler frequency  $f_d$  where the modulation method is 16QAM and the encoding rate (r) is (3/4) and besides the replacement method is the first replacement method. Meanwhile, FIG. 28 illustrates the relationship between the error rate and the Doppler frequency  $f_d$  where the modulation method is 64QAM and the encoding rate (r) is (5/6) and besides the replacement method is the first replacement method.

[0282]

Further, in FIGS. 27 and 28, a thick line curve indicates the relationship between the error rate and the Doppler frequency  $f_d$  where all of the parity interleave, column twist interleave and replacement process were carried out, and a thin line curve indicates the relationship between the error rate and the Doppler frequency  $f_d$  where only the replacement process from among the parity interleave, column twist interleave and replacement process was carried out.

[0283]

In both of FIGS. 27 and 28, it can be recognized that the error rate improves (decreases) where all of the parity interleave, column twist interleave and replacement process are carried out rather than where only the replacement process is carried out.

[0284]

Now, the LDPC encoding section 21 of FIG. 8 is described furthermore.

[0285]

As described referring to FIG. 11, in the DVB-S.2 standard, LDPC encoding of the two different code lengths  $N$  of 64,800 bits and 16,200 bits are prescribed.

[0286]

And, for the LDPC code whose code length  $N$  is 64,800 bits, the 11 encoding rates  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$ ,  $8/9$  and  $9/10$  are prescribed, and for the LDPC code whose code length  $N$  is 16,200 bits, the 10 encoding rates  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$  and  $8/9$  are prescribed (FIG. 11B).

[0287]

The LDPC encoding section 21 carries out encoding (error correction encoding) into LDPC codes of the different encoding rates whose code length  $N$  is 64,800 bits or 16,200 bits in accordance with a parity check matrix  $H$  prepared for each code length  $N$  and for each encoding rate.

[0288]

FIG. 29 shows an example of a configuration of the LDPC encoding section 21 of FIG. 8.

[0289]

The LDPC encoding section 21 includes an encoding processing block 601 and a storage block 602.

[0290]

The encoding processing block 601 includes an encoding rate setting portion 611, an initial value table reading out portion 612, a parity check matrix production portion 613, an information bit reading out portion 614,

an encoding parity mathematical operation portion 615, and a control portion 616, and carries out LDPC encoding of object data supplied to the LDPC encoding section 21 and supplies an LDPC code obtained as a result of the LDPC encoding to the bit interleaver 22 (FIG. 8).

[0291]

In particular, the encoding rate setting portion 611 sets a code length  $N$  and an encoding rate for LDPC codes, for example, in response to an operation of an operator.

[0292]

The initial value table reading out portion 612 reads out a parity check matrix initial value table hereinafter described which corresponds to the code length  $N$  and the encoding rate set by the encoding rate setting portion 611 from the storage block 602.

[0293]

The parity check matrix production portion 613 places, based on the parity check matrix initial value table read out by the initial value table reading out portion 612, elements of the value 1 of an information matrix  $H_A$  corresponding to an information length  $K$  ( $=$  code length  $N$  - parity length  $M$ ) corresponding to the code length  $N$  and the encoding rate set by the encoding rate

setting portion 611 in a period of 360 columns (unit column number P of the cyclic structure) in the column direction to produce a parity check matrix H, and stores the parity check matrix H into the storage block 602.

[0294]

The information bit reading out portion 614 reads out (extracts) information bits for the information length K from the object data supplied to the LDPC encoding section 21.

[0295]

The encoding parity mathematical operation portion 615 reads out the parity check matrix H produced by the parity check matrix production portion 613 from the storage block 602 and calculates parity bits corresponding to the information bits read out by the information bit reading out portion 614 in accordance with a predetermined expression to produce a codeword (LDPC code).

[0296]

The control portion 616 controls the blocks which compose the encoding processing block 601.

[0297]

In the storage block 602, a plurality of parity check matrix initial value tables and so forth

individually corresponding to the plural encoding rates illustrated in FIG. 11 in regard to individual ones of the two code lengths  $N$  of 64,800 bits and 16,200 bits are stored. Further, the storage block 602 temporarily stores data necessary for processing of the encoding processing block 601.

[0298]

FIG. 30 is a flow chart illustrating a reception process carried out by the reception apparatus 12 of FIG. 29.

[0299]

At step S201, the encoding rate setting portion 611 determines (sets) a code length  $N$  and an encoding rate  $r$  used for carrying out LDPC encoding.

[0300]

At step S202, the initial value table reading out portion 612 reads out from the storage block 602 a predetermined parity check matrix initial value table corresponding to the code length  $N$  and the encoding rate  $r$  determined by the encoding rate setting portion 611.

[0301]

At step S203, the parity check matrix production portion 613 determines (produces) a parity check matrix  $H$  for an LDPC code having the code length  $N$  and the

encoding rate  $r$  determined by the encoding rate setting portion 611 using the parity check matrix initial value table read out from the storage block 602 by the initial value table reading out portion 612, and supplies the parity check matrix  $H$  to the storage block 602 so as to be stored.

[0302]

At step S204, the information bit reading out portion 614 reads out information bits of the information length  $K (= N \times r)$  corresponding to the code length  $N$  and the encoding rate  $r$  determined by the encoding rate setting portion 611 from among the object data supplied to the LDPC encoding section 21 and reads out the parity check matrix  $H$  determined by the parity check matrix production portion 613 from the storage block 602, and supplies the information bits and the parity check matrix  $H$  to the encoding parity mathematical operation portion 615.

[0303]

At step S205, the encoding parity mathematical operation portion 615 successively mathematically operates a parity bit of a codeword  $c$  which satisfies an expression (8).

[0304]

$$Hc^T = 0 \quad \dots (8)$$

[0305]

In the expression (8),  $c$  indicates a row vector as the codeword (LDPC code), and  $c^T$  indicates inversion of the row vector  $c$ .

[0306]

Here, as above described, where, from within the row vector  $c$  as an LDPC code (one codeword), a portion corresponding to the information bits is represented by a row vector  $A$  and a portion corresponding to the parity bits is represented by a row vector  $T$ , the row vector  $c$  can be represented by an expression  $c = [A|T]$  from the row vector  $A$  as the information bits and the row vector  $T$  as the parity bits.

[0307]

It is necessary for the parity check matrix  $H$  and the row vector  $c = [A|T]$  as an LDPC code to satisfy the expression  $Hc^T = 0$ , and where the parity matrix  $H_T$  of the parity check matrix  $H = [H_A|H_T]$  has a staircase structure shown in FIG. 10, the row vector  $T$  as parity bits which configures the row vector  $c = [A|T]$  which satisfies the expression  $Hc^T = 0$  can be determined sequentially by setting the elements of each row to zero in order beginning with the elements in the first row of the

column vector  $Hc^T$  in the expression  $Hc^T = 0$ .

[0308]

If the encoding parity mathematical operation portion 615 determines a parity bit T for an information bit A, then it outputs a codeword  $c = [A|T]$  represented by the information bit A and the parity bit T as an LDPC encoding result of the information bit A.

[0309]

It is to be noted that the codeword c has 64,800 bits or 16,200 bits.

[0310]

Thereafter, at step S206, the control portion 616 decides whether or not the LDPC encoding should be ended. If it is decided at step S206 that the LDPC encoding should not be ended, that is, for example, if there remain object data to be LDPC encoded, then the processing returns to step S201, and thereafter, the processes at steps S201 to S206 are repeated.

[0311]

On the other hand, if it is decided at step S206 that the LDPC encoding should be ended, that is, for example, if there remains no object data to be LDPC encoded, the LDPC encoding section 21 ends the processing.

[0312]

As described above, the parity check matrix initial value tables corresponding to the code lengths  $N$  and the encoding rates  $r$  are prepared, and the LDPC encoding section 21 carries out LDPC encoding for a predetermined code length  $N$  and a predetermined encoding rate  $r$  using a parity check matrix  $H$  produced from a parity check matrix initial value table corresponding to the predetermined code length  $N$  and the predetermined encoding rate  $r$ .

[0313]

Each parity check matrix initial value table is a table which represents the position of elements of the value 1 of the information matrix  $H_A$  corresponding to the information length  $K$  corresponding to the code length  $N$  and the encoding rate  $r$  of the LDPC code of the parity check matrix  $H$  (LDPC code defined by the parity check matrix  $H$ ) for every 360 rows (unit column number  $P$  of the periodic structure), and is produced in advance for a parity check matrix  $H$  for each code length  $N$  and each encoding rate  $r$ .

[0314]

FIGS. 31 to 58 illustrate some of the parity check matrix initial value tables prescribed in the DVB-S.2 standard.

[0315]

In particular, FIG. 31 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $2/3$ .

[0316]

FIGS. 32 to 34 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $2/3$ .

[0317]

It is to be noted that FIG. 33 is a view continuing from FIG. 32 and FIG. 34 is a view continuing from FIG. 33.

[0318]

FIG. 35 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $3/4$ .

[0319]

FIGS. 36 to 39 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $3/4$ .

[0320]

It is to be noted that FIG. 37 is a view continuing from FIG. 36 and FIG. 38 is a view continuing from FIG. 37. Further, FIG. 39 is a view continuing from FIG. 38.

[0321]

FIG. 40 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $4/5$ .

[0322]

FIGS. 41 to 44 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $4/5$ .

[0323]

It is to be noted that FIG. 42 is a view continuing from FIG. 41 and FIG. 43 is a view continuing from FIG. 42. Further, FIG. 44 is a view continuing from FIG. 43.

[0324]

FIG. 45 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $5/6$ .

[0325]

FIGS. 46 to 49 show the parity check matrix initial

value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $5/6$ .

[0326]

It is to be noted that FIG. 47 is a view continuing from FIG. 46 and FIG. 48 is a view continuing from FIG. 47. Further, FIG. 49 is a view continuing from FIG. 48.

[0327]

FIG. 50 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $8/9$ .

[0328]

FIGS. 51 to 54 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $8/9$ .

[0329]

It is to be noted that FIG. 52 is a view continuing from FIG. 51 and FIG. 53 is a view continuing from FIG. 52. Further, FIG. 54 is a view continuing from FIG. 53.

[0330]

FIGS. 55 to 58 show the parity check matrix initial

value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $9/10$ .

[0331]

It is to be noted that FIG. 56 is a view continuing from FIG. 55 and FIG. 57 is a view continuing from FIG. 56. Further, FIG. 58 is a view continuing from FIG. 57.

[0332]

The parity check matrix production portion 613 (FIG. 29) determines a parity check matrix  $H$  in the following manner using the parity check matrix initial value tables.

[0333]

In particular, FIG. 59 illustrates a method for determining a parity check matrix  $H$  from a parity check matrix initial value table.

[0334]

It is to be noted that the parity check matrix initial value table of FIG. 59 indicates the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $2/3$  shown in FIG. 31.

[0335]

As described above, the parity check matrix initial value table is a table which represents the position of elements of the value 1 of a information matrix  $H_A$  (FIG. 9) corresponding to the information length  $K$  corresponding to the code length  $N$  and the encoding rate  $r$  of the LDPC code for every 360 columns (for every unit column number  $P$  of the cyclic structure), and in the first row of the parity check matrix initial value table, a number of row numbers of elements of the value 1 in the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  (row numbers where the row number of the first row of the parity check matrix  $H$  is 0) equal to the number of column weights which the  $1+360 \times (i-1)$ th column has.

[0336]

Here, since the parity matrix  $H_T$  (FIG. 9) of the parity check matrix  $H$  which corresponds to the parity length  $M$  is determined as illustrated in FIG. 19, according to the parity check matrix initial value table, the information matrix  $H_A$  (FIG. 9) of the parity check matrix  $H$  corresponding to the information length  $K$  is determined.

[0337]

The row number  $k+1$  of the parity check matrix initial value table differs depending upon the

information length K.

[0338]

The information length K and the row number k+1 of the parity check matrix initial value table satisfy a relationship given by an expression (9).

[0339]

$$K = (k + 1) \times 360 \quad \dots (9)$$

[0340]

Here, 360 in the expression (9) is the unit column number P of the cyclic structure described referring to FIG. 20.

[0341]

In the parity check matrix initial value table of FIG. 59, 13 numerical values are listed in the first to third rows, and three numerical values are listed in the fourth to k+1th (in FIG. 59, 30th) rows.

[0342]

Accordingly, the number of column weights in the parity check matrix H determined from the parity check matrix initial value table of FIG. 59 is 13 in the first to  $1+360 \times (3-1)-1$ th rows but is 3 in the  $1+360 \times (3-1)$ th to Kth rows.

[0343]

The first row of the parity check matrix initial

value table of FIG. 59 includes 0, 2084, 1613, 1548, 1286, 1460, 3196, 4297, 2481, 3369, 3451, 4620 and 2622, and this indicates that, in the first column of the parity check matrix  $H$ , the elements in rows of the row numbers of 0, 2084, 1613, 1548, 1286, 1460, 3196, 4297, 2481, 3369, 3451, 4620 and 2622 have the value 1 (and besides the other elements have the value 0).

[0344]

Meanwhile, the second row of the parity check matrix initial value table of FIG. 59 includes 1, 122, 1516, 3448, 2880, 1407, 1847, 3799, 3529, 373, 971, 4358 and 3108, and this indicates that, in the 361st (=  $1+360 \times (2-1)$ th) column of the parity check matrix  $H$ , the elements in rows of the row numbers of 1, 122, 1546, 3448, 2880, 1407, 1847, 3799, 3529, 373, 971, 4358 and 3108 have the value 1.

[0345]

As given above, the parity check matrix initial value table represents the position of elements of the value 1 of the information matrix  $H_A$  of the parity check matrix  $H$  for every 360 columns.

[0346]

Each of the columns of the parity check matrix  $H$  other than the  $1+360 \times (i-1)$ th column, that is, each of the

columns from  $2+360 \times (i-1)$ th to  $360 \times i$ th columns, includes elements of the value of 1 obtained by cyclically shifting the elements of the value of 1 of the  $1+360 \times (i-1)$ th column which depend upon the parity check matrix initial value table periodically in the downward direction (in the downward direction of the column) in accordance with the parity length  $M$ .

[0347]

In particular, for example, the  $2+360 \times (i-1)$ th column is a column obtained by cyclically shifting the  $1+360 \times (i-1)$ th column in the downward direction by  $M/360$  ( $= q$ ), and the next  $3+360 \times (i-1)$ th is a column obtained by cyclically shifting the  $1+360 \times (i-1)$ th column in the downward direction by  $2 \times M/360$  ( $= 2 \times q$ ) and then cyclically shifting the cyclically shifted column ( $2+360 \times (i-1)$ th column) in the downward direction by  $M/360$  ( $= q$ ).

[0348]

Now, if it is assumed that the numeral value in the  $j$ th column ( $j$ th from the left) in the  $i$ th row ( $i$ th row from above) of the parity check matrix initial value table is represented by  $b_{i,j}$  and the row number of the  $j$ th element of the value 1 in the  $w$ th column of the parity check matrix  $H$  is represented by  $H_{w-j}$ , then the row number

$H_{w-j}$  of the element of the value 1 in the  $w$ th column which is a column other than the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  can be determined in accordance with an expression (10).

[0349]

$$H_{w-j} = \text{mod}\{h_{i,j} + \text{mod}((w-1), P) \times q, M\} \dots (10)$$

[0350]

Here,  $\text{mod}(x, y)$  signifies a remainder when  $x$  is divided by  $y$ .

[0351]

Meanwhile,  $P$  is a unit number of columns of the cyclic structure described hereinabove and is, for example, in the DVB-S.2 standard, as described above, 360. Further,  $q$  is a value  $M/360$  obtained by dividing the parity length  $M$  by the unit column number  $P$  ( $= 360$ ) of the cyclic structure.

[0352]

The parity check matrix production portion 613 (FIG. 29) specifies the row number of the elements of the value 1 in the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  from the parity check matrix initial value table.

[0353]

Further, the parity check matrix production portion 613 (FIG. 29) determines the row number  $H_{w-j}$  of the

element of the value 1 in the  $w$ th column which is a column other than the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  in accordance with the expression (10) and produces a parity check matrix  $H$  in which the elements of the row numbers obtained by the foregoing have the value 1.

[0354]

Incidentally, it is known that the LDPC code having an encoding rate of  $2/3$  prescribed in the DVB-S.2 standard is inferior (higher) in the error floor thereof in comparison with the LDPC codes of the other encoding rates.

[0355]

Here, a phenomenon (error floor phenomenon) that, as the  $S/N$  ( $E_s/N_0$ ) becomes higher, the drop of the error rate (BER) becomes duller and the error rate stops its drop occurs, and the error rate when the drop stops is an error floor.

[0356]

If the error floor becomes higher, then generally the tolerance to errors in the communication path 13 (FIG. 7) drops, and therefore, it is desirable to take a countermeasure for improving the tolerance to errors.

[0357]

As a countermeasure for improving the tolerance to errors, for example, a replacement process which is carried out by the demultiplexer 25 (FIG. 8) is available.

[0358]

In the replacement process, as a replacement method for replacing code bits of an LDPC code, for example, the first to fourth replacement methods described hereinabove are available. However, it is demanded to propose a method which has a further improved tolerance to errors in comparison with methods proposed already including the first to fourth replacement methods.

[0359]

Thus, the demultiplexer 25 (FIG. 8) is configured such that it can carry out a replacement process in accordance with an allocation rule as described hereinabove with reference to FIG. 25.

[0360]

In the following, before a replacement process in accordance with an allocation rule is described, a replacement process by replacement methods (hereinafter referred to existing methods) proposed already is described.

[0361]

A replacement process where it is assumed that the

replacement process is carried out in accordance with the existing methods by the demultiplexer 25 is described with reference to FIGS. 60 and 61.

[0362]

FIG. 60 shows an example of the replacement process of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $3/5$ .

[0363]

In particular, FIG. 60A illustrates an example of the replacement method of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2.

[0364]

Where the modulation method is 16QAM, 4 ( $= m$ ) bits from among the code bits are mapped as one symbol to some of 16 signal points prescribed by 16QAM.

[0365]

Further, where the code length  $N$  is 64,800 bits and the multiple  $b$  is 2, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has eight columns for storing  $4 \times 2$  ( $= mb$ ) bits in the row direction and stores  $64,800 / (4 \times 2)$  bits in the column direction.

[0366]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 64,800 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $4 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32 (FIGS. 16 and 17).

[0367]

The replacement section 32 replaces, for example, the  $4 \times 2$  (= mb) code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6$  and  $b_7$  read out from the memory 31 such that, as seen in FIG. 60A, the  $4 \times 2$  (= mb) code bits  $b_0$  to  $b_7$  are allocated to  $4 \times 2$  (= mb) symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6$  and  $y_7$  of successive two (= b) symbols.

[0368]

In particular, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_7$ ,

the code bit  $b_1$  to the symbol bit  $y_1$ ,

the code bit  $b_2$  to the symbol bit  $y_4$ ,

the code bit  $b_3$  to the symbol bit  $y_2$ ,

the code bit  $b_4$  to the symbol bit  $y_5$ ,

the code bit  $b_5$  to the symbol bit  $y_3$ ,

the code bit  $b_6$  to the symbol bit  $y_6$ , and  
the code bit  $b_7$  to the symbol bit  $y_0$ .

[0369]

In particular, FIG. 60B illustrates an example of the replacement method of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $3/5$  and besides the modulation method is 64QAM and the multiple  $b$  is 2.

[0370]

Where the modulation method is 64QAM, 6 (=  $m$ ) bits from among the code bits are mapped as one symbol to some of 64 signal points prescribed by 64QAM.

[0371]

Further, where the code length  $N$  is 64,800 bits and the multiple  $b$  is 2, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has 12 columns for storing  $6 \times 2$  (=  $mb$ ) bits in the row direction and stores  $64,800/(6 \times 2)$  bits in the column direction.

[0372]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 64,800 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $6 \times 2$  (=  $mb$ ) bits in the row

direction and supplied to the replacement section 32 (FIGS. 16 and 17).

[0373]

The replacement section 32 replaces, for example, the  $6 \times 2$  (= mb) code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8, b_9, b_{10}$  and  $b_{11}$  read out from the memory 31 such that, as seen in FIG. 60B, the  $6 \times 2$  (= mb) code bits  $b_0$  to  $b_{11}$  are allocated to  $6 \times 2$  (= mb) symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9, y_{10}$  and  $y_{11}$  of successive two (= b) symbols.

[0374]

In particular, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_{11}$ ,  
the code bit  $b_1$  to the symbol bit  $y_7$ ,  
the code bit  $b_2$  to the symbol bit  $y_3$ ,  
the code bit  $b_3$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_4$  to the symbol bit  $y_6$ ,  
the code bit  $b_5$  to the symbol bit  $y_2$ ,  
the code bit  $b_6$  to the symbol bit  $y_9$ ,  
the code bit  $b_7$  to the symbol bit  $y_5$ ,  
the code bit  $b_8$  to the symbol bit  $y_1$ ,  
the code bit  $b_9$  to the symbol bit  $y_8$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_4$ , and

the code bit  $b_{11}$  to the symbol bit  $y_0$ .

[0375]

In particular, FIG. 60C illustrates an example of the replacement method of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $3/5$  and besides the modulation method is 256QAM and the multiple  $b$  is 2.

[0376]

Where the modulation method is 256QAM, 8 (=  $m$ ) bits from among the code bits are mapped as one symbol to some of 256 signal points prescribed by 256QAM.

[0377]

Further, where the code length  $N$  is 64,800 bits and the multiple  $b$  is 2, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has 16 columns for storing  $8 \times 2$  (=  $mb$ ) bits in the row direction and stores  $64,800/(8 \times 2)$  bits in the column direction.

[0378]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 64,800 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $8 \times 2$  (=  $mb$ ) bits in the row direction and supplied to the replacement section 32

(FIGS. 16 and 17).

[0379]

The replacement section 32 replaces, for example, the  $8 \times 2$  (= mb) code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8, b_9, b_{10}, b_{11}, b_{12}, b_{13}, b_{14}$  and  $b_{15}$  read out from the memory 31 such that, as seen in FIG. 60C, the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  are allocated to  $8 \times 2$  (= mb) symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9, y_{10}, y_{11}, y_{12}, y_{13}, y_{14}$  and  $y_{15}$  of successive two (= b) symbols.

[0380]

In particular, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_{15}$ ,  
the code bit  $b_1$  to the symbol bit  $y_1$ ,  
the code bit  $b_2$  to the symbol bit  $y_{13}$ ,  
the code bit  $b_3$  to the symbol bit  $y_3$ ,  
the code bit  $b_4$  to the symbol bit  $y_8$ ,  
the code bit  $b_5$  to the symbol bit  $y_{11}$ ,  
the code bit  $b_6$  to the symbol bit  $y_9$ ,  
the code bit  $b_7$  to the symbol bit  $y_5$ ,  
the code bit  $b_8$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_9$  to the symbol bit  $y_6$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_4$ ,  
the code bit  $b_{11}$  to the symbol bit  $y_7$ ,

the code bit  $b_{12}$  to the symbol bit  $y_{12}$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_2$ ,  
 the code bit  $b_{14}$  to the symbol bit  $y_{14}$ , and  
 the code bit  $b_{15}$  to the symbol bit  $y_0$ .

[0381]

FIG. 61 shows an example of the replacement process of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 16,200 bits and an encoding rate of  $3/5$ .

[0382]

In particular, FIG. 61A illustrates an example of the replacement method of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 16,200 bits and an encoding rate of  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2.

[0383]

Where the modulation method is 16QAM, 4 ( $= m$ ) bits from among the code bits are mapped as one symbol to some of 16 signal points prescribed by 16QAM.

[0384]

Further, where the code length  $N$  is 16,200 bits and the multiple  $b$  is 2, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has 8 columns for storing  $4 \times 2 (= mb)$  bits in the row direction and stores  $16,200/(4 \times 2)$

bits in the column direction.

[0385]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 16,200 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $4 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32 (FIGS. 16 and 17).

[0386]

The replacement section 32 replaces, for example, the  $4 \times 2$  (= mb) code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6$  and  $b_7$  read out from the memory 31 such that, as seen in FIG. 61A, the  $4 \times 2$  (= mb) code bits  $b_0$  to  $b_7$  are allocated to  $4 \times 2$  (= mb) symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6$  and  $y_7$  of successive two (= b) symbols.

[0387]

In particular, the replacement section 32 carries out replacement for allocating the code bits  $b_0$  to  $b_7$  to the symbol bits  $y_0$  to  $y_7$  as in the case of FIG. 60A described above.

[0388]

In particular, FIG. 61B illustrates an example of the replacement method of an existing method where the

LDPC code is an LDPC code having a code length  $N$  of 16,200 bits and an encoding rate of  $3/5$  and besides the modulation method is 64QAM and the multiple  $b$  is 2.

[0389]

Where the modulation method is 64QAM, 6 (=  $m$ ) bits from among the code bits are mapped as one symbol to some of 64 signal points prescribed by 64QAM.

[0390]

Further, where the code length  $N$  is 16,200 bits and the multiple  $b$  is 2, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has 12 columns for storing  $6 \times 2$  (=  $mb$ ) bits in the row direction and stores  $16,200/(6 \times 2)$  bits in the column direction.

[0391]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 16,200 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $6 \times 2$  (=  $mb$ ) bits in the row direction and supplied to the replacement section 32 (FIGS. 16 and 17).

[0392]

The replacement section 32 replaces, for example, the  $6 \times 2$  (=  $mb$ ) code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6, b_7$ ,

$b_8, b_9, b_{10}$  and  $b_{11}$  read out from the memory 31 such that, as seen in FIG. 61B the  $6 \times 2$  ( $= mb$ ) code bits  $b_0$  to  $b_{11}$  are allocated to  $6 \times 2$  ( $= mb$ ) symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6, y_7, y_8, y_9, y_{10}$  and  $y_{11}$  of successive two ( $= b$ ) symbols.

[0393]

In particular, the replacement section 32 carries out replacement for allocating the code bits  $b_0$  to  $b_{11}$  to the symbol bits  $y_0$  to  $y_{11}$  as in the case of FIG. 60B described above.

[0394]

In particular, FIG. 61C illustrates an example of the replacement method of an existing method where the LDPC code is an LDPC code having a code length  $N$  of 16,200 bits and an encoding rate of  $3/5$  and besides the modulation method is 256QAM and the multiple  $b$  is 1.

[0395]

Where the modulation method is 256QAM, 8 ( $= m$ ) bits from among the code bits are mapped as one symbol to some of 256 signal points prescribed by 256QAM.

[0396]

Further, where the code length  $N$  is 16,200 bits and the multiple  $b$  is 1, the memory 31 (FIGS. 16 and 17) of the demultiplexer 25 has 8 columns for storing  $8 \times 1$  ( $=$

mb) bits in the row direction and stores  $16,200/(8 \times 1)$  bits in the column direction.

[0397]

In the demultiplexer 25, when the code bits of the LDPC code are written in the column direction of the memory 31 and writing of the 16,200 code bits (one codeword) ends, the code bits written in the memory 31 are read out in a unit of  $8 \times 1 (= mb)$  bits in the row direction and supplied to the replacement section 32 (FIGS. 16 and 17).

[0398]

The replacement section 32 replaces, for example, the  $8 \times 1 (= mb)$  code bits  $b_0, b_1, b_2, b_3, b_4, b_5, b_6,$  and  $b_7$  read out from the memory 31 such that, as seen in FIG. 61C, the  $8 \times 1 (= mb)$  code bits  $b_0$  to  $b_7$  are allocated to  $8 \times 1 (= mb)$  symbol bits  $y_0, y_1, y_2, y_3, y_4, y_5, y_6$  and  $y_7$  of successive one ( $= b$ ) symbols.

[0399]

In particular, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_7,$

the code bit  $b_1$  to the symbol bit  $y_3,$

the code bit  $b_2$  to the symbol bit  $y_1,$

the code bit  $b_3$  to the symbol bit  $y_5,$

the code bit  $b_4$  to the symbol bit  $y_2$ ,  
the code bit  $b_5$  to the symbol bit  $y_6$ ,  
the code bit  $b_6$  to the symbol bit  $y_4$ , and  
the code bit  $b_7$  to the symbol bit  $y_0$ .

[0400]

Now, a replacement process in accordance with an allocation rule (hereinafter referred to also as replacement process in accordance with the new replacement method) is described.

[0401]

FIGS. 62 to 64 are views illustrating the new replacement method.

[0402]

In the new replacement method, the replacement section 32 of the demultiplexer 25 carries out replacement of mb code bits in accordance with an allocation rule determined in advance.

[0403]

The allocation rule is a rule for allocating code bits of an LDPC code to symbol bits. In the allocation rule, a group set which is a combination of a code bit group of code bits and a symbol bit group of symbol bits to which the code bits of the code bit group are allocated and a bit number (hereinafter referred to also

as group bit number) of code bits and symbol bits of the code bit group and the symbol bit group of the group set are prescribed.

[0404]

Here, the code bits are different in error probability thereamong and also the symbol bits are different in error probability thereamong as described above. The code bit group is a group into which the code bits are grouped in accordance with the error probability and the symbol bit group is a group into which the symbol bits are grouped in accordance with the error probability.

[0405]

FIG. 62 illustrates code bit groups and symbol bit groups where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $2/3$  and besides the modulation method is 256QAM and the multiple  $b$  is 2.

[0406]

In this instance,  $8 \times 2$  (=  $mb$ ) code bits  $b_0$  to  $b_{15}$  read out from the memory 31 can be grouped into five code bit groups  $Gb_1$ ,  $Gb_2$ ,  $Gb_3$ ,  $Gb_4$  and  $Gb_5$  as seen in FIG. 62A in accordance with the difference in error probability.

[0407]

Here, the code bit group  $Gb_1$  is a group in which

code bits belonging to the code bit group  $Gb_i$  have a better (lower) error probability as the suffix  $i$  thereof has a lower value.

[0408]

In FIG. 62A, to the code bit group  $Gb_1$ , the code bit  $b_0$  belongs; to the code bit group  $Gb_2$ , the code bit  $b_1$  belongs; to the code bit group  $Gb_3$ , the code bits  $b_2$  to  $b_9$  belong; to the code bit group  $Gb_4$ , the code bit  $b_{10}$  belongs; and to the code bit group  $Gb_5$ , the code bits  $b_{11}$  to  $b_{15}$  belong.

[0409]

Where the modulation method is 256QAM and the multiple  $b$  is 2, the  $8 \times 2 (= mb)$  symbol bits  $y_0$  to  $y_{15}$  can be grouped into four symbol bit groups  $Gy_1$ ,  $Gy_2$ ,  $Gy_3$  and  $Gy_4$  as seen in FIG. 62B in accordance with the difference in error probability.

[0410]

Here, the symbol bit group  $Gy_i$  is a group in which symbol bits belonging to the symbol bit group  $Gy_i$  have a better error probability as the suffix  $i$  thereof has a lower value similarly to the code bit group.

[0411]

In FIG. 62B, to the symbol bit group  $Gy_1$ , the symbol bits  $y_0$ ,  $y_1$ ,  $y_8$  and  $y_9$  belong; to the symbol bit

group  $Gy_2$ , the symbol bits  $y_2, y_3, y_{10}$  and  $y_{11}$  belong; to the symbol bit group  $Gy_3$ , the symbol bits  $y_4, y_5, y_{12}$  and  $y_{13}$  belong; and to the symbol bit group  $Gy_4$ , the symbol bits  $y_6, y_7, y_{14}$  and  $y_{15}$  belong.

[0412]

FIG. 63 illustrates an allocation rule where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $2/3$  and besides the modulation method is 256QAM and the multiple  $b$  is 2.

[0413]

In the allocation rule of FIG. 63, the combination of the code bit group  $Gb_1$  and the symbol bit group  $Gy_4$  is defined in the first from the left of FIG. 63 as one group set. Further, the group bit number of the group set is prescribed to 1 bit.

[0414]

In the following description, a group set and a group bit number of the group set are collectively referred to as group set information. For example, the group set of the code bit group  $Gb_1$  and the symbol bit group  $Gy_4$  and 1 bit which is the group bit number of the group set are described as group set information ( $Gb_1, Gy_4, 1$ ).

[0415]

In the allocation rule of FIG. 63, group set information  $(Gb_2, Gy_4, 1)$ ,  $(Gb_3, Gy_1, 3)$ ,  $(Gb_3, Gy_2, 1)$ ,  $(Gb_3, Gy_3, 2)$ ,  $(Gb_3, Gy_4, 2)$ ,  $(Gb_4, Gy_3, 1)$ ,  $(Gb_5, Gy_1, 1)$ ,  $(Gb_5, Gy_2, 3)$  and  $(Gb_5, Gy_3, 1)$  is prescribed in addition to the group set information  $(Gb_1, Gy_4, 1)$ .

[0416]

For example, the group set information  $(Gb_1, Gy_4, 1)$  signifies that one code bit belonging to the code bit group  $Gb_1$  is allocated to one symbol bit belonging to the symbol bit group  $Gy_4$ .

[0417]

Accordingly, according to the allocation rule of FIG. 63, it is prescribed that,

depending upon the group set information  $(Gb_1, Gy_4, 1)$ , one code bit of the code bit group  $Gb_1$  which is best in error probability is allocated to one symbol bit of the symbol bit group  $Gy_4$  which is fourth best in error probability, that

depending upon the group set information  $(Gb_2, Gy_4, 1)$ , one code bit of the code bit group  $Gb_2$  which is second best in error probability is allocated to one symbol bit of the symbol bit group  $Gy_4$  which is fourth best in error probability, that

depending upon the group set information  $(Gb_3, Gy_1, 3)$ ,

3), three code bits of the code bit group  $G_{b_3}$  which is third best in error probability are allocated to three symbol bits of the symbol bit group  $G_{y_1}$  which is best in error probability, that

depending upon the group set information ( $G_{b_3}, G_{y_2}, 1$ ), one code bit of the code bit group  $G_{b_3}$  which is third best in error probability is allocated to one symbol bit of the symbol bit group  $G_{y_2}$  which is second best in error probability, that

depending upon the group set information ( $G_{b_3}, G_{y_3}, 2$ ), two code bits of the code bit group  $G_{b_3}$  which is third best in error probability is allocated to two symbol bits of the symbol bit group  $G_{y_3}$  which is third best in error probability, that

depending upon the group set information ( $G_{b_3}, G_{y_4}, 2$ ), two code bits of the code bit group  $G_{b_3}$  which is third best in error probability is allocated to two symbol bits of the symbol bit group  $G_{y_4}$  which is fourth best in error probability, that

depending upon the group set information ( $G_{b_4}, G_{y_3}, 1$ ), one code bit of the code bit group  $G_{b_4}$  which is fourth best in error probability is allocated to one symbol bit of the symbol bit group  $G_{y_3}$  which is third best in error probability, that

depending upon the group set information ( $G_{b_5}$ ,  $G_{y_1}$ , 1), one code bit of the code bit group  $G_{b_5}$  which is fifth best in error probability is allocated to one symbol bit of the symbol bit group  $G_{y_1}$  which is best in error probability, that

depending upon the group set information ( $G_{b_5}$ ,  $G_{y_2}$ , 3), three code bits of the code bit group  $G_{b_5}$  which is fifth best in error probability is allocated to three symbol bits of the symbol bit group  $G_{y_2}$  which is second best in error probability, and that

depending upon the group set information ( $G_{b_5}$ ,  $G_{y_3}$ , 1), one code bit of the code bit group  $G_{b_5}$  which is fifth best in error probability is allocated to one symbol bit of the symbol bit group  $G_{y_3}$  which is third best in error probability.

[0418]

As described above, the code bit group is a group into which code bits are grouped in accordance with the error probability, and the symbol bit group is a group into which symbol bits are grouped in accordance with the error probability. Accordingly, also it can be considered that the allocation rule prescribes a combination of the error probability of code bits and the error probability of symbol bits to which the code bits are allocated.

[0419]

In this manner, the allocation rule which prescribes a combination of the error probability of code bits and the error probability of symbol bits to which the code bits are allocated is determined such that the tolerance to errors (tolerance to noise) is made better, for example, through a simulation wherein the BER is measured or the like.

[0420]

It is to be noted that, even if the allocation destination of a code bit of a certain code bit group is changed among bits of the same symbol bit group, the tolerance to errors is not (little) influenced thereby.

[0421]

Accordingly, in order to improve the tolerance to errors, group set information which makes the BER (Bit Error Rate) including the error floor lower, in particular, combinations (group sets) of code bit groups of code bits and symbol bit groups of symbol bits to which the code bits of the code bit groups are to be allocated and the bit numbers (group bit numbers) of the code bits of the code bit groups and the symbol bit groups of the group sets and of the symbol bits, should be defined as an allocation rule, and replacement of the

code bits should be carried out such that the code bits are allocated to the symbol bits in accordance with the allocation rule.

[0422]

However, a particular allocation method in regard to to which symbol each code bit should be allocated in accordance with the allocation rule need be determined in advance between the transmission apparatus 11 and the reception apparatus 12 (FIG. 7).

[0423]

FIG. 64 illustrates an example of replacement of code bits in accordance with the allocation rule of FIG. 63.

[0424]

In particular, FIG. 64A illustrates a first example of replacement of code bits in accordance with the allocation rule of FIG. 63 where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $2/3$  and besides the modulation method is 256QAM and the multiple  $b$  is 2.

[0425]

Where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $2/3$  and besides the modulation method is 256QAM and the multiple

b is 2, in the demultiplexer 25, code bits written in the memory 31 for  $(64,800/(8 \times 2)) \times (8 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $8 \times 2$  (= mb) bits in the row direction and are supplied to the replacement section 32 (FIGS. 16 and 17).

[0426]

The replacement section 32 replaces the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  read out from the memory 31 in accordance with the allocation rule of FIG. 63 such that the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  are allocated, for example, to the  $8 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{15}$  of two (= b) successive symbols as seen in FIG. 64A.

[0427]

In particular, the replacement section 32 carries out replacement for allocating

- the code bit  $b_0$  to the symbol bit  $y_{15}$ ,
- the code bit  $b_1$  to the symbol bit  $y_7$ ,
- the code bit  $b_2$  to the symbol bit  $y_1$ ,
- the code bit  $b_3$  to the symbol bit  $y_5$ ,
- the code bit  $b_4$  to the symbol bit  $y_6$ ,
- the code bit  $b_5$  to the symbol bit  $y_{13}$ ,
- the code bit  $b_6$  to the symbol bit  $y_{11}$ ,
- the code bit  $b_7$  to the symbol bit  $y_9$ ,
- the code bit  $b_8$  to the symbol bit  $y_8$ ,

the code bit  $b_9$  to the symbol bit  $y_{14}$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_{12}$ ,  
the code bit  $b_{11}$  to the symbol bit  $y_3$ ,  
the code bit  $b_{12}$  to the symbol bit  $y_0$ ,  
the code bit  $b_{13}$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_{14}$  to the symbol bit  $y_4$ , and  
the code bit  $b_{15}$  to the symbol bit  $y_2$ .

[0428]

FIG. 64B illustrates a second example of replacement of code bits in accordance with the allocation rule of FIG. 63 where the LDPC code is an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate of  $2/3$  and besides the modulation method is 256QAM and the multiple  $b$  is 2.

[0429]

According to FIG. 64B, the replacement section 32 carries out replacement for allocating the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  read out from the memory 31 in accordance with the allocation rule of FIG. 63 in such a manner as to allocate

the code bit  $b_0$  to the symbol bit  $y_{15}$ ,  
the code bit  $b_1$  to the symbol bit  $y_{14}$ ,  
the code bit  $b_2$  to the symbol bit  $y_8$ ,  
the code bit  $b_3$  to the symbol bit  $y_5$ ,

the code bit  $b_4$  to the symbol bit  $y_6$ ,  
 the code bit  $b_5$  to the symbol bit  $y_4$ ,  
 the code bit  $b_6$  to the symbol bit  $y_2$ ,  
 the code bit  $b_7$  to the symbol bit  $y_1$ ,  
 the code bit  $b_8$  to the symbol bit  $y_9$ ,  
 the code bit  $b_9$  to the symbol bit  $y_7$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_{12}$ ,  
 the code bit  $b_{11}$  to the symbol bit  $y_3$ ,  
 the code bit  $b_{12}$  to the symbol bit  $y_{13}$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_{10}$ ,  
 the code bit  $b_{14}$  to the symbol bit  $y_0$ , and  
 the code bit  $b_{15}$  to the symbol bit  $y_{11}$ .

[0430]

Here, the allocation methods of the code bits  $b_i$  to the symbol bits  $y_i$  illustrated in FIG. 64A and FIG. 64B observe the allocation rule of FIG. 63 (follow the allocation rule).

[0431]

FIG. 65 illustrates a result of a simulation of the BER (Bit Error Rate) in a case wherein a replacement process of the new replacement system described hereinabove with reference to FIGS. 62 to 64 is carried out and in another case wherein a replacement process described hereinabove with reference to FIG. 60C from

among the existing methods is carried out.

[0432]

In particular, FIG. 65 illustrates the BER where an LDPC code which is prescribed in the DVB-S.2 and has a code length  $N$  of 64,800 and an encoding rate of  $2/3$  is determined as an object and besides 256QAM is adopted as the modulation method and 2 is adopted as the multiple  $b$ .

[0433]

It is to be noted that, in FIG. 65, the axis of abscissa indicates the  $E_s/N_0$  and the axis of ordinate indicates the BER. Further, a round mark represents the BER where a replacement process of the new replacement method is carried out, and an asterisk (star mark) represents the BER where a replacement process of the existing method is carried out.

[0434]

From FIG. 65, it can be recognized that, according to the replacement process of the new replacement method, the error floor drops significantly in comparison with that of the replacement process of the existing method and the tolerance to errors is improved.

[0435]

It is to be noted that, while, in the present embodiment, the replacement section 32 in the

demultiplexer 25 carries out the replacement process for code bits read out from the memory 31 for the convenience of description, the replacement process can be carried out by controlling writing or reading out of code bits into or from the memory 31.

[0436]

In particular, the replacement process can be carried out, for example, by controlling the address (read address) for reading out a code bit such that reading out of the code bits from the memory 31 is carried out in order of the code bits after the replacement.

[0437]

Now, as a countermeasure for improving the tolerance to errors, a method of adopting an LDPC code which lowers the error floor is available in addition to the method which adopts a replacement process of the replacement method which lowers the error floor.

[0438]

Thus, the LDPC encoding section 21 (FIG. 8) can carry out encoding of an LDPC code having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $2/3$  into an LDPC code of a high performance by adopting a parity check matrix initial value table which is different from the

parity check matrix initial value tables prescribed in the DVB-S.2 standard and from which an appropriate parity check matrix  $H$  is determined and using a parity check matrix determined from the parity check matrix initial value table.

[0439]

Here, the appropriate parity check matrix  $H$  is a parity check matrix which satisfies a predetermined condition for making the BER (Bit Error Rate) lower when a modulation signal of an LDPC code obtained from a parity check matrix is transmitted at a low  $E_s/N_0$  (signal power to noise power ratio per one symbol) or  $E_b/N_0$  (signal power to noise power ratio per one bit). Further, the LDPC code of a high performance is an LDPC code obtained from an appropriate parity check matrix.

[0440]

The appropriate parity check matrix  $H$  can be determined, for example, by carrying out a simulation of the BER when a modulation signal of an LDPC code obtained from various parity check matrices which satisfy a predetermined condition is transmitted at a low  $E_s/N_0$ .

[0441]

The predetermined condition which the appropriate parity check matrix  $H$  should satisfy is, for example,

that the result of an analysis obtained by an analysis method of a performance of a code called density evolution is good, that the parity check matrix  $H$  does not include a loop of elements of the value 1 called cycle 4, that the parity check matrix  $H$  does not include the cycle 6, and so forth.

[0442]

Here, the density evolution and incorporation of the same are disclosed, for example, in S. Y. Chung, G. D. Forney, T. J. Richardson and R. Urbanke, "On the Design of Low-Density Parity-Check Codes within 0.0045 dB of the Shannon Limit," IEEE Communications Letters, VOL. 5, NO. 2, Feb. 2001.

[0443]

For example, if the variance value of noise is gradually increased from zero on an AWGN channel, then although the expected value of the error probability of an LDPC code is zero first, it becomes different from zero if the variance value of noise becomes higher than a certain threshold value (threshold).

[0444]

According to the density evolution, the expected value of the error probability of the same becomes different from zero. By comparing the threshold value of

the variance value (hereinafter referred to as performance threshold value) of noise, it can be determined whether or not the performance of the LDPC code (appropriateness of the parity check matrix) is good. Here, as the performance threshold value, the  $E_b/N_0$  when the BER begins to drop (decrease).

[0445]

If a performance threshold value, obtained by analysis by density evolution, regarding an LDPC code which is defined in the DVB-S.2 standard and has a code length  $N$  of 64,800 and an encoding rate  $r$  of  $2/3$  (such LDPC code is hereinafter referred to also as standard code) is represented by  $V$ , then in the simulation, an LDPC code (parity check matrix) which has a code length  $N$  of 64,800 and an encoding rate  $r$  of  $2/3$  and exhibits a performance threshold value lower than  $V + \Delta$  obtained by adding a predetermined margin  $\Delta$  to  $V$  was selected as the LDPC code having a good performance.

[0446]

FIGS. 66 to 68 illustrate a parity check matrix initial value table for one of LDPC codes whose  $E_b/N_0$  as the performance threshold value is lower than  $V + \Delta$  (LDPC code having a code length  $N$  of 64,800 and an encoding rate  $r$  of  $2/3$ ).

[0447]

It is to be noted that FIG. 67 is a view continuing to FIG. 66, and FIG. 68 is a view continuing to FIG. 67.

[0448]

In a parity check matrix  $H$  determined from the parity check matrix initial value table of FIGS. 66 to 68, neither the cycle 4 nor the cycle 6 exist.

[0449]

FIG. 69 illustrates a result of the simulation of the BER regarding an LDPC code of a parity check matrix  $H$  determined from the parity check matrix initial value table of FIGS. 66 to 68 (such LDPC code is hereinafter referred to also as proposed code).

[0450]

In particular, FIG. 69 illustrates, where the modulation method is 256QAM, the BER with respect to the  $E_s/N_0$  of the standard code (in the figure, the BER is indicated by a round mark) and the BER for the  $E_s/N_0$  of the proposed code (in the figure, the BER is indicated by a square mark).

[0451]

From FIG. 69, it can be recognized that the proposed code is better in performance than the standard code and that particularly the error floor is improved

significantly.

[0452]

It is to be noted that the predetermined condition which the appropriate parity check matrix  $H$  should satisfy can be determined suitably from such a point of view as enhancement of the decoding performance of an LDPC code, facilitation (simplification) of a decoding process of an LDPC code, and so forth.

[0453]

FIG. 70 is a block diagram showing an example of a configuration of the reception apparatus 12 of FIG. 7.

[0454]

Referring to FIG. 70, the reception apparatus 12 is a data processing apparatus for receiving a modulation signal from the transmission apparatus 11 (FIG. 7) and includes an orthogonal demodulation section 51, a demapping section 52, a deinterleaver 53 and an LDPC decoding section 56.

[0455]

The orthogonal demodulation section 51 receives a modulation signal from the transmission apparatus 11 and carries out orthogonal demodulation, and then supplies symbols obtained as a result of the orthogonal demodulation (values on the I and Q axes) to the

demapping section 52.

[0456]

The demapping section 52 carries out demapping of converting the signal points from the orthogonal demodulation section 51 to code bits of an LDPC code to be symbolized symbols and supplies the code bits to the deinterleaver 53.

[0457]

The deinterleaver 53 includes a multiplexer (MUX) 54 and a column twist deinterleaver 55 and carries out deinterleave of the symbols of the symbol bits from the demapping section 52.

[0458]

In particular, the multiplexer 54 carries out a reverse replacement process (reverse process to the replacement process) corresponding to the replacement process carried out by the demultiplexer 25 of FIG. 8 for the symbols of the symbol bits from the demapping section 52, that is, a reverse replacement process of returning the positions of the code bits (symbol bits) of the LDPC codes replaced by the replacement process to the original positions. Then, the multiplexer 54 supplies an LDPC code obtained as a result of the reverse replacement process to the column twist deinterleaver 55.

[0459]

The column twist deinterleaver 55 carries out column twist deinterleave (reverse process to the column twist interleave) corresponding to the column twist interleave as the re-arrangement process carried out by the column twist interleaver 24 of FIG. 8, that is, for example, column twist deinterleave as a reverse re-arrangement process of returning the arrangement of the code bits of the LDPC code having an arrangement changed by the column twist interleave as the re-arrangement process to the original arrangement, for the LDPC code from the multiplexer 54.

[0460]

In particular, the column twist deinterleaver 55 carries out column twist deinterleave by writing the code bits of the LDPC code into and reading out the written code bits from the memory for deinterleave, the memory being configured similarly to the memory 31 shown in FIG. 22 and so forth.

[0461]

It is to be noted that, in the column twist deinterleaver 55, writing of the code bits is carried out in the row direction of the memory for deinterleave using read addresses upon reading out the codes from the memory

31 as write addresses. Meanwhile, readout of the code bits is carried out in the column direction of the memory for deinterleave using the write addresses upon writing of the code bits into the memory 31 as read addresses.

[0462]

The LDPC codes obtained as a result of the column twist interleave are supplied from the column twist deinterleaver 55 to the LDPC decoding section 56.

[0463]

Here, while the LDPC code supplied from the demapping section 52 to the deinterleaver 53 has been obtained by the parity interleave, column twist interleave and replacement process carried out in this order therefor, the deinterleaver 53 carries out only a reverse replacement process corresponding to the replacement process and column twist deinterleave corresponding to the column twist interleave. Accordingly, parity deinterleave corresponding to the parity interleave (process reverse to the parity interleave), that is, the parity deinterleave returning the arrangement of the code bits of the LDPC codes, whose arrangement has been varied by the parity interleave, to the original arrangement, is not carried out.

[0464]

Accordingly, the LDPC code for which the reverse replacement process and the column twist deinterleave have been carried out but the parity deinterleave has not been carried out is supplied from the (column twist deinterleaver 55 of the) deinterleaver 53 to the LDPC decoding section 56.

[0465]

The LDPC decoding section 56 carries out LDPC decoding of the LDPC code from the deinterleaver 53 using a conversion parity check matrix, obtained by carrying out at least column replacement corresponding to the parity interleave for the parity check matrix  $H$  used for the LDPC encoding by the LDPC encoding section 21 of FIG. 8, and outputs data obtained as a result of the LDPC decoding as a decoding result of the object data.

[0466]

FIG. 71 is a flow chart illustrating a reception process carried out by the reception apparatus 12 of FIG. 70.

[0467]

The orthogonal demodulation section 51 receives a modulation signal from the transmission apparatus 11 at step S111. Then, the processing advances to step S112, at which the orthogonal demodulation section 51 carries out

orthogonal demodulation of the modulation signal. The orthogonal demodulation section 51 supplies signal points obtained as a result of the orthogonal demodulation to the demapping section 52, whereafter the processing advances from step S112 to step S113.

[0468]

At step S113, the demapping section 52 carries out demapping of converting the signal points from the orthogonal demodulation section 51 into symbols and supplies the code bits to the deinterleaver 53, whereafter the processing advances to step S114.

[0469]

At step S114, the deinterleaver 53 carries out deinterleave of the symbols of the symbol bits from the demapping section 52, whereafter the processing advances to step S115.

[0470]

In particular, at step S114, the multiplexer 54 in the deinterleaver 53 carries out a reverse replacement process for the symbols of the symbol bits from the demapping section 52 and supplies LDPC code obtained as a result of the reverse replacement process to the column twist deinterleaver 55.

[0471]

The column twist deinterleaver 55 carries out column twist deinterleave for the LDPC code from the multiplexer 54 and supplies an LDPC code obtained as a result of the column twist deinterleave to the LDPC decoding section 56.

[0472]

At step S115, the LDPC decoding section 56 carries out LDPC decoding of the LDPC code from the column twist deinterleaver 55 using a conversion parity check matrix obtained by carrying out at least column replacement corresponding to the parity interleave for the parity check matrix H used for the LDPC encoding by the LDPC encoding section 21 of FIG. 8, and outputs data obtained by the LDPC decoding as a decoding result of the object data. Thereafter, the processing is ended.

[0473]

It is to be noted that the reception process of FIG. 71 is carried out repetitively.

[0474]

Also in FIG. 70, the multiplexer 54 for carrying out the reverse replacement process and the column twist deinterleaver 55 for carrying out the column twist deinterleave are configured separately from each other for the convenience of description similarly as in the

case of FIG. 8. However, the multiplexer 54 and the column twist deinterleaver 55 can be configured integrally with each other.

[0475]

Further, where the transmission apparatus 11 of FIG. 8 does not carry out the column twist interleave, there is no necessity to provide the column twist deinterleaver 55 in the reception apparatus 12 of FIG. 70.

[0476]

Now, the LDPC decoding carried out by the LDPC decoding section 56 of FIG. 70 is further described.

[0477]

The LDPC decoding section 56 of FIG. 70 carries out LDPC decoding of an LDPC code, for which the reverse replacement process and the column twist deinterleave have been carried out but the parity deinterleave has not been carried out, from the column twist deinterleaver 55 as described above using a conversion parity check matrix obtained by carrying out at least column replacement corresponding to the parity interleave for the parity check matrix  $H$  used for the LDPC encoding by the LDPC encoding section 21 of FIG. 8.

[0478]

Here, LDPC decoding which can suppress the

operation frequency within a sufficiently implementable range while suppressing the circuit scale by carrying out the LDPC decoding using the conversion parity check matrix has been proposed formerly (refer to, for example, Japanese Patent Laid-Open No. 2004-343170).

[0479]

Thus, the formerly proposed LDPC decoding which uses a conversion parity check matrix is described first with reference to FIGS. 72 to 75.

[0480]

FIG. 72 shows an example of the parity check matrix  $H$  of an LDPC code whose code length  $N$  is 90 and encoding rate is  $2/3$ .

[0481]

It is to be noted that, in FIG. 72, 0 is represented by a period (.) (this similarly applies also to FIGS. 73 and 74 hereinafter described).

[0482]

In the parity check matrix  $H$  of FIG. 72, the parity matrix has a staircase structure.

[0483]

FIG. 73 illustrates a parity check matrix  $H'$  obtained by applying row replacement of an expression (11) and column replacement of an expression (12) to the

parity check matrix H of FIG. 72.

[0484]

Row replacement:  $6s+t+1\text{th row} \rightarrow 5t+s+1\text{th row}$

... (11)

[0485]

Column replacement:  $6x+y+61\text{th column} \rightarrow 5y+x+61\text{th}$

column

... (12)

[0486]

However, in the expressions (11) and (12),  $s$ ,  $t$ ,  $x$  and  $y$  are integers within the ranges of  $0 \leq s < 5$ ,  $0 \leq t < 6$ ,  $0 \leq x < 5$  and  $0 \leq t < 6$ , respectively.

[0487]

According to the row replacement of the expression (11), the replacement is carried out in such a manner that the 1st, 7th, 13th, 19th and 25th rows each of whose numbers indicates a remainder of 1 where it is divided by 6 are replaced to the 1st, 2nd, 3rd, 4th and 5th rows, and the 2nd, 8th, 14th, 20th and 26th rows each of whose numbers indicates a remainder of 2 where it is divided by 6 are replaced to 6th, 7th, 8th, 9th and 10th rows.

[0488]

On the other hand, according to the column replacement of the expression (12), the replacement is

carried out for the 61st and succeeding columns (parity matrix) such that the 61st, 67th, 73rd, 79th and 85th columns each of whose numbers indicates a remainder of 1 where it is divided by 6 are replaced to 61st, 62nd, 63rd, 64th and 65th columns, and the 62nd, 68th, 74th, 80th and 86th columns each of whose numbers indicates a remainder of 2 where it is divided by 6 are replaced to 66th, 67th, 68th, 69th and 70th columns.

[0489]

A matrix obtained by carrying out replacement of the rows and the columns for the parity check matrix H of FIG. 72 is a parity check matrix H' of FIG. 73.

[0490]

Here, even if the row replacement of the parity check matrix H is carried out, this does not have an influence on the arrangement of the code bits of the LDPC code.

[0491]

Meanwhile, the column replacement of the expression (12) corresponds to parity interleave when the information length K, the unit column number P of the cyclic structure and the divisor q ( $= M/P$ ) of the parity length M (here, 30) in the parity interleave of interleaving the  $K+qx+y+1$ th code bit to the position of

the  $K+P_y+x+1$ th code bit are set to 60, 5 and 6, respectively.

[0492]

If the parity check matrix  $H'$  (hereinafter referred to suitably as replacement parity check matrix) of FIG. 73 is multiplied by a result of replacement same as that of the expression (12) for the LDPC code of the parity check matrix  $H$  (hereinafter referred to suitably as original parity check matrix) of FIG. 72, then the 0 vector is outputted. In particular, where a row vector obtained by applying the column replacement of the expression (12) for the row vector  $c$  as the LDPC code (one codeword) of the original parity check matrix  $H$  is represented by  $c'$ , since  $Hc^T$  becomes the 0 vector on the basis of the characteristic of the parity check matrix, also  $H'c'^T$  naturally becomes the 0 vector.

[0493]

From the foregoing, the conversion parity check matrix  $H'$  of FIG. 73 becomes the parity check matrix of an LDPC code  $c'$  obtained by carrying out the column replacement of the expression (12) for the LDPC code  $c$  of the original parity check matrix  $H$ .

[0494]

Accordingly, by carrying out the column replacement

of the expression (12) for the LDPC code  $c$  of the original parity check matrix  $H$ , decoding (LDPC decoding) the LDPC code  $c'$  after the column replacement using the parity check matrix  $H'$  of FIG. 73 and then carrying out reverse replacement to the column replacement of the expression (12) for result of decoding, a decoding result similar to that obtained where the LDPC code of the original parity check matrix  $H$  is decoded using the parity check matrix  $H$  can be obtained.

[0495]

FIG. 74 shows the conversion parity check matrix  $H'$  of FIG. 73 wherein a space is provided between units of  $5 \times 5$  matrices.

[0496]

In FIG. 74, the conversion parity check matrix  $H'$  is represented by a combination of a unit matrix of  $5 \times 5$  elements, another matrix (hereinafter referred to suitably as quasi unit matrix) which corresponds to the unit matrix whose element or elements of 1 are changed into an element or elements of 0, a further matrix (hereinafter referred to suitably as shift matrix) which corresponds to the unit matrix or quasi unit matrix after it is cyclically shifted (cyclic shift), a still further matrix (hereinafter referred to suitably as sum matrix)

of two or more of the unit matrix, quasi unit matrix and shift matrix, and a 0 matrix of  $5 \times 5$  elements.

[0497]

It can be regarded that the conversion parity check matrix  $H'$  of FIG. 74 is composed of a unit matrix, a quasi unit matrix, a shift matrix, a sum matrix and a 0 matrix of  $5 \times 5$  elements. Therefore, the matrices of  $5 \times 5$  elements which compose the conversion parity check matrix  $H'$  are hereinafter referred to as component matrices.

[0498]

For decoding of an LDPC code represented by a parity check matrix represented by a matrix of  $P \times P$  components, an architecture which carries out check node mathematical operation and variable node mathematical operation simultaneously for  $P$  check nodes and  $P$  variable nodes can be used.

[0499]

FIG. 75 is a block diagram showing an example of a configuration of a decoding apparatus which carries out such decoding as just described.

[0500]

In particular, FIG. 75 shows an example of a configuration of a decoding apparatus which carries out decoding of LDPC codes of the original parity check

matrix  $H$  of FIG. 72 using the conversion parity check matrix  $H'$  of FIG. 74 obtained by carrying out at least the column replacement of the expression (12).

[0501]

The decoding apparatus of FIG. 75 includes an edge data storage memory 300 including six FIFOs  $300_1$  to  $300_6$ , a selector 301 for selecting the FIFOs  $300_1$  to  $300_6$ , a check node calculation section 302, two cyclic shift circuits 303 and 308, an edge data storage memory 304 including 18 FIFOs  $304_1$  to  $304_{18}$ , a selector 305 for selecting the FIFOs  $304_1$  to  $304_{18}$ , a reception data memory 306 for storing reception information, a variable node calculation section 307, a decoded word calculation section 309, a reception data re-arrangement section 310, and a decoded data re-arrangement section 311.

[0502]

First, a storage method of data into the edge data storage memories 300 and 304 is described.

[0503]

The edge data storage memory 300 includes the six FIFOs  $300_1$  to  $300_6$  the number of which is equal to a quotient when the row number 30 of the conversion parity check matrix  $H'$  of FIG. 74 is divided by the row number 5 of the component matrices. Each of the FIFOs  $300_y$  ( $y = 1,$

2, ..., 6) has a plurality of stages of storage regions such that messages corresponding to five edges whose number is equal to the number of rows and the number of columns of the component matrices can be read out from or written into the storage regions of each stage at the same time. Further, the number of stages of the storage regions of each FIFO 300<sub>y</sub> is nine which is the maximum number of 1s (Hamming weight) in the row direction of the conversion parity check matrix of FIG. 74.

[0504]

In the FIFO 300<sub>1</sub>, data (messages  $v_i$  from variable nodes) corresponding to the positions of the value 1 in the first to fifth rows of the conversion parity check matrix  $H'$  of FIG. 74 are stored in a closed form in the horizontal direction in the individual rows (in the form wherein 0 is ignored). In particular, if an element in the  $j$  row of the  $i$ th column is represented as  $(j, i)$ , then in the storage regions at the first stage of the FIFO 300<sub>1</sub>, data corresponding to the positions of the value 1 of the unit matrix of  $5 \times 5$  elements from  $(1, 1)$  to  $(5, 5)$  of the conversion parity check matrix  $H'$  are stored. In the storage regions at the second stage, data corresponding to the positions of the value 1 of a shift matrix from  $(1, 21)$  to  $(5, 25)$  of the conversion parity

check matrix  $H'$  (a shift matrix obtained by cyclically shifting the unit matrix of  $5 \times 5$  elements by three in the rightward direction). Also in the storage regions at the third to eighth stages, data are stored in an associated relationship with the conversion parity check matrix  $H'$ . Then, in the storage regions at the ninth stage, data corresponding to the positions of the value of a shift matrix of (1, 86) to (5, 90) of the conversion parity check matrix  $H'$  (a shift matrix obtained by replacing the value 1 in the first row of the unit matrix of  $5 \times 5$  elements with the value 0 and then cyclically shifting the unit matrix after the replacement by one in the leftward direction) are stored.

[0505]

In the FIFO 300<sub>2</sub>, data corresponding to the positions of the value 1 from the sixth to tenth rows of the conversion parity check matrix  $H'$  of FIG. 74 are stored. In particular, in the storage region at the first stage of the FIFO 300<sub>2</sub>, data corresponding to the positions of the value 1 of a first shift matrix which forms a sum matrix from (6, 1) to (10, 5) of the conversion parity check matrix  $H'$  (a sum matrix which is the sum of a first shift matrix obtained by cyclically shifting the unit matrix of  $5 \times 5$  elements by one in the

rightward direction and a second shift matrix obtained by cyclically shifting the unit matrix of  $5 \times 5$  elements by two in the rightward direction) are stored. Further, in the storage region at the second stage, data corresponding to the positions of the value 1 of the second shift matrix which forms the sum matrix from (6, 1) to (10, 5) of the conversion parity check matrix  $H'$  are stored.

[0506]

In particular, with regard to a component matrix whose weight is 2 or more, where the component matrix is represented in the form of the sum of plural ones from among a unit matrix of  $P \times P$  elements having the weight 1, a quasi unit matrix which corresponds to the unit matrix whose one or more elements having the value 1 are replaced with 0 and a shift matrix obtained by cyclically shifting the unit matrix or the quasi unit matrix, data corresponding to the positions of the value 1 of the unit matrix, quasi unit matrix or shift matrix whose weight is 1 (messages corresponding to edges belonging to the unit matrix, quasi unit matrix or shift matrix) are stored into the same address (same FIFO from among the FIFOs 300<sub>1</sub> to 300<sub>6</sub>).

[0507]

Also in the storage regions at the third to ninth stages, data are stored in an associated relationship with the conversion parity check matrix  $H'$ .

[0508]

Also the FIFOs  $300_3$  to  $300_6$  store data in an associated relationship with the conversion parity check matrix  $H'$ .

[0509]

The edge data storage memory 304 includes 18 FIFOs  $304_1$  to  $304_{18}$  the number of which is equal to the quotient when the column number 90 of the conversion parity check matrix  $H'$  is divided by the column number 5 of the component matrix. Each edge data storage memory  $304_x$  ( $x = 1, 2, \dots, 18$ ) includes a plurality of stages of storage regions, and messages corresponding to five edges the number of which is equal to the number of rows and the number of columns of the conversion parity check matrix  $H'$  can be read out from or written into the storage regions of each stage at the same time.

[0510]

In the FIFO  $304_1$ , data corresponding to the positions of the value 1 from the first to fifth columns of the conversion parity check matrix  $H'$  of FIG. 74 (messages  $u_j$  from the check nodes) are stored in a closed

form in the vertical direction in the individual columns (in the form wherein 0 is ignored). In particular, in the storage regions at the first stage of the FIFO 304<sub>1</sub>, data corresponding to the positions of the value 1 of the unit matrix of  $5 \times 5$  elements from (1, 1) to (5, 5) of the conversion parity check matrix  $H'$  are stored. In the storage regions at the second stage, data corresponding to the positions of the value of a first shift matrix which forms a sum matrix from (6, 1) to (10, 5) of the vertical parity check matrix  $H'$  (a sum matrix which is the sum of a first shift matrix obtained by cyclically shifting the unit matrix of  $5 \times 5$  elements by one to the right and a second shift matrix obtained by cyclically shifting the unit matrix of  $5 \times 5$  elements by two to the right) are stored. Further, in the storage regions at the third stage, data corresponding to the positions of the value 1 of the second shift matrix which forms the sum matrix from (6, 1) to (10, 5) of the vertical parity check matrix  $H'$ .

[0511]

In particular, with regard to a component matrix whose weight is 2 or more, where the component matrix is represented in the form of the sum of plural ones from among a unit matrix of  $P \times P$  elements having the weight 1,

a quasi unit matrix which corresponds to the unit matrix whose one or more elements having the value 1 are replaced with 0 and a shift matrix obtained by cyclically shifting the unit matrix or the quasi unit matrix, data corresponding to the positions of the value 1 of the unit matrix, quasi unit matrix or shift matrix whose weight is 1 (messages corresponding to edges belonging to the unit matrix, quasi unit matrix or shift matrix) are stored into the same address (same FIFO from among the FIFOs 304<sub>1</sub> to 304<sub>18</sub>).

[0512]

Also with regard to the storage regions at the fourth and fifth stages, data are stored in an associated relationship with the conversion parity check matrix  $H'$ . The number of stages of the storage regions of the FIFO 304<sub>1</sub> is 5 which is a maximum number of the number of 1s (Hamming weight) in the row direction in the first to fifth columns of the conversion parity check matrix  $H'$ .

[0513]

Also the FIFOs 304<sub>2</sub> and 304<sub>3</sub> store data in an associated relationship with the conversion parity check matrix  $H'$  similarly, and each length (stage number) of the FIFOs 304<sub>2</sub> and 304<sub>3</sub> is 5. Also the FIFOs 304<sub>4</sub> to 304<sub>12</sub> store data in an associated relationship with the

conversion parity check matrix  $H'$  similarly, and each length of the FIFOs  $304_4$  to  $304_{12}$  is 3. Also the FIFOs  $304_{13}$  to  $304_{18}$  store data in an associated relationship with the conversion parity check matrix  $H'$  similarly, and each length of the FIFOs  $304_{13}$  to  $304_{18}$  is 2.

[0514]

Now, operation of the decoding apparatus of FIG. 75 is described.

[0515]

The edge data storage memory 300 includes the six FIFOs  $300_1$  to  $300_6$ , and FIFOs into which data are to be stored are selected from among the FIFOs  $300_1$  to  $300_6$  in accordance with information (Matrix data)  $D312$  representing to which row of the conversion parity check matrix  $H'$  five messages  $D311$  supplied from the cyclic shift circuit 308 at the preceding stage belong. Then, the five messages  $D311$  are stored collectively and in order into the selected FIFOs. Further, when data are to be read out, the edge data storage memory 300 reads out five messages  $D300_1$  in order from the FIFO  $300_1$  and supplies the five messages  $D300_1$  to the selector 301 at the succeeding stage. After the reading out of the messages from the FIFO  $300_1$  ends, the edge data storage memory 300 reads out the messages in order also from the

FIFOs 330<sub>2</sub> to 300<sub>6</sub> and supplies the read out messages to the selector 301.

[0516]

The selector 301 selects the five messages from that FIFO from which data are currently read out from among the FIFOs 300<sub>1</sub> to 300<sub>6</sub> in accordance with a select signal D301 and supplies the five messages as messages D302 to the check node calculation section 302.

[0517]

The check node calculation section 302 includes five check node calculators 302<sub>1</sub> to 302<sub>5</sub> and carries out the check node mathematical operation in accordance with the expression (7) using the messages D302 (D302<sub>1</sub> to D302<sub>5</sub>) (messages  $v_i$  of the expression (7)) supplied thereto through the selector 301. Then, the check node calculation section 302 supplies five messages D303 (D303<sub>1</sub> to D303<sub>5</sub>) (messages  $u_j$  of the expression (7)) obtained as a result of the check node mathematical operation to the cyclic shift circuit 303.

[0518]

The cyclic shift circuit 303 cyclically shifts the five messages D303<sub>1</sub> to 303<sub>5</sub> determined by the check node calculation section 302 based on information (Matrix data) D305 regarding by what number of original unit

matrices the corresponding edges are cyclically shifted in the conversion parity check matrix  $H'$ , and supplies a result of the cyclic shift as a message D304 to the edge data storage memory 304.

[0519]

The edge data storage memory 304 includes 18 FIFOs 304<sub>1</sub> to 304<sub>18</sub>. The edge data storage memory 304 selects a FIFO into which data are to be stored from among the FIFOs 304<sub>1</sub> to 304<sub>18</sub> in accordance with the information D305 regarding to which row of the conversion parity check matrix  $H'$  the five messages D304 supplied from the cyclic shift circuit 303 at the preceding stage belong and collectively stores the five messages D304 in order into the selected FIFO. On the other hand, when data are to be read out, the edge data storage memory 304 reads out five messages D306<sub>1</sub> in order from the FIFO 304<sub>1</sub> and supplies the messages D306<sub>1</sub> to the selector 305 at the succeeding stage. After the reading out of data from the FIFO 304<sub>1</sub> ends, the edge data storage memory 304 reads out messages in order also from the FIFOs 304<sub>2</sub> to 304<sub>18</sub> and supplies the messages to the selector 305.

[0520]

The selector 305 selects the five messages from the FIFO from which data are currently read out from among

the FIFOs 304<sub>1</sub> to 304<sub>18</sub> in accordance with a select signal D307 and supplies the selected messages as messages D308 to the variable node calculation section 307 and the decoded word calculation section 309.

[0521]

On the other hand, the reception data re-arrangement section 310 carries out the column replacement of the expression (12) to re-arrange an LDPC code D313 received through a communication path and supplies the re-arranged LDPC code D313 as reception data D314 to the reception data memory 306. The reception data memory 306 calculates and stores a reception LLR (logarithmic likelihood ratio) from the reception data D314 supplied thereto from the reception data re-arrangement section 310 and collects and supplies every five ones of the reception LLRs as reception values D309 to the variable node calculation section 307 and the decoded word calculation section 309.

[0522]

The variable node calculation section 307 includes five variable node calculators 307<sub>1</sub> to 307<sub>5</sub> and carries out variable node mathematical operation in accordance with the expression (1) using the messages D308 (308<sub>1</sub> to 308<sub>5</sub>) (messages  $u_j$  of the expression (1)) supplied thereto

through the selector 305 and the five reception values D309 (reception values  $u_{oi}$  of the expression (1)) supplied thereto from the reception data memory 306. Then, the variable node calculation section 307 supplies messages D310 ( $D301_1$  to  $D310_5$ ) (messages  $v_i$  of the expression (1)) obtained as a result of the mathematical operation to the cyclic shift circuit 308.

[0523]

The cyclic shift circuit 308 cyclically shifts messages  $D310_1$  to  $D310_5$  calculated by the variable node calculation section 307 based on information regarding by what number of original unit matrices the corresponding edge is cyclically shifted in the conversion parity check matrix  $H'$ , and supplies a result of the cyclic shifting as a message D311 to the edge data storage memory 300.

[0524]

By carrying out the sequence of operations described above, decoding in one cycle of an LDPC code can be carried out. In the decoding apparatus of FIG. 75, after an LDPC code is decoded by a predetermined number of times, a final decoding result is determined by the decoded word calculation section 309 and the decoded data re-arrangement section 311 and then outputted.

[0525]

In particular, the decoded word calculation section 309 includes five decoded word calculators  $309_1$  to  $309_5$  and acts as a final stage in a plurality of cycles of decoding to calculate a decoding result (decoded word) in accordance with the expression (5) using the five messages D308 ( $D308_1$  to  $D308_5$ ) (messages  $u_j$  of the expression (5)) outputted from the selector 305 and the five reception values D309 (reception values  $u_{0i}$  of the expression (5)) outputted from the reception data memory 306. Then, the decoded word calculation section 309 supplies decoded data D315 obtained as a result of the calculation to the decoded data re-arrangement section 311.

[0526]

The decoded data re-arrangement section 311 carries out reverse replacement to the column replacement of the expression (12) for the decoded data D315 supplied thereto from the decoded word calculation section 309 to re-arrange the order of the decoded data D315 and outputs the re-arranged decoded data D315 as a decoding result D316.

[0527]

As described above, by applying one or both of row replacement and column replacement to a parity check

matrix (original parity check matrix) to convert the parity check matrix into a parity check matrix (conversion parity check matrix) which can be represented by a combination of a unit matrix of  $P \times P$  elements, a quasi unit matrix which corresponds to the unit matrix whose element or elements of 1 are changed into an element or elements of 0, a shift matrix which corresponds to the unit matrix or quasi unit matrix after it is cyclically shifted, a sum matrix of two or more of the unit matrix, quasi unit matrix and shift matrix, and a 0 matrix of  $P \times P$  elements as described above, it becomes possible to adopt for LDPC code decoding an architecture which carries out check node mathematical operation and variable node mathematical operation simultaneously for  $P$  check nodes and  $P$  variable nodes. Consequently, by carrying out the node mathematical operation simultaneously for  $P$  nodes, it is possible to suppress the operation frequency within an implementable range to carry out LDPC decoding.

[0528]

The LDPC decoding section 56 which composes the reception apparatus 12 of FIG. 70 carries out check node mathematical operation and variable node mathematical operation simultaneously for  $P$  check nodes and  $P$  variable

nodes to carry out LDPC decoding similarly to the decoding apparatus of FIG. 75.

[0529]

In particular, it is assumed now to simplify description that the parity check matrix of an LDPC code outputted from the LDPC encoding section 21 which composes the transmission apparatus 11 of FIG. 8 is, for example, the parity check matrix  $H$  wherein the parity matrix has a staircase structure shown in FIG. 72. In this instance, the parity interleaver 23 of the transmission apparatus 11 carries out parity interleave for interleaving the  $K+qx+y+1$ th code bit to the position of the  $K+Py+x+1$ th code bit with the information length  $K$  set to 60, with the unit column number  $P$  of the cyclic structure set to 5 and with the divisor  $q$  ( $= M/P$ ) of the parity length  $M$  to 6.

[0530]

Since this parity interleave corresponds to the column replacement of the expression (12), the LDPC decoding section 56 need not carry out the column replacement of the expression (12).

[0531]

Therefore, in the reception apparatus 12 of FIG. 70, an LDPC code for which parity deinterleave has not been

carried out, that is, an LDPC code in a state wherein the column replacement of the expression (12) is carried out, is supplied from the column twist deinterleaver 55 to the LDPC decoding section 56 as described above. The LDPC decoding section 56 carries out processing similar to that of the decoding apparatus of FIG. 75 except that the column replacement of the expression (12) is not carried out.

[0532]

In particular, FIG. 76 shows an example of a configuration of the LDPC decoding section 56 of FIG. 70.

[0533]

Referring to FIG. 76, the LDPC decoding section 56 is configured similarly to that of the decoding apparatus of FIG. 75 except that the reception data re-arrangement section 310 of FIG. 75 is not provided and carries out processing similar to that of the decoding apparatus of FIG. 75 except that the column replacement of the expression (12) is not carried out. Therefore, description of the LDPC decoding section 56 is omitted herein.

[0534]

Since the LDPC decoding section 56 can be configured without including the reception data re-

arrangement section 310 as described above, it can be reduced in scale in comparison with the decoding apparatus of FIG. 75.

[0535]

It is to be noted that, while, in FIGS. 72 to 76, it is assumed that the code length  $N$  of the LDPC code is 90; the information length  $K$  is 60; the unit column number  $P$  (row number and column number of a component matrix) of the cyclic structure is 5; and the divisor  $q$  ( $= M/P$ ) of the parity length  $M$  is 6, for simplified description, the code length  $N$ , information length  $K$ , unit column number  $P$  of the cyclic structure and the divisor  $q$  ( $= M/P$ ) are not individually limited to the specific values given above.

[0536]

In particular, while the LDPC encoding section 21 in the transmission apparatus 11 of FIG. 8 outputs an LDPC code wherein, for example, the code length  $N$  is 64,800 or 16,200, the information length  $K$  is  $N - Pq$  ( $= N - M$ ), the unit column number  $P$  of the cyclic structure is 360 and the divisor  $q$  is  $M/P$ , the LDPC decoding section 56 of FIG. 76 can be applied also where LDPC decoding is carried out by carrying out the check node mathematical operation and the variable node mathematical operation

simultaneously for P check nodes and P variable nodes in regard to such an LDPC code as just described.

[0537]

While the series of processes described above can be executed by hardware, it may otherwise be executed by software. Where the series of processes is executed by software, a program which constructs the software is installed into a computer for universal use or the like.

[0538]

FIG. 77 shows an example of a configuration of an embodiment of a computer into which a program for executing the series of processes described hereinabove is installed.

[0539]

The program can be recorded in advance on a hard disk 705 or in a ROM 703 as a recording medium built in the computer.

[0540]

Or, the program can be stored (recorded) temporarily or permanently on or in a removable recording medium 711 such as a flexible disk, a CD-ROM (Compact Disc Read Only Memory), an MO (Magneto Optical) disc, a DVD (Digital Versatile Disc), a magnetic disc or a semiconductor memory. Such a removable recording medium

711 as just described can be provided as so-called package software.

[0541]

It is to be noted that the program not only can be installed from such a removable recording medium 711 as described above into the computer but also can be installed into the hard disk 705 built in the computer where it is transferred thereto and received by a communication section 708. In this instance, the program may be transferred to the computer by wireless communication from a download site through an artificial satellite for digital satellite broadcasting or transferred to the computer by wire communication through a network such as a LAN (Local Area Network) or the Internet.

[0542]

The computer has a CPU (Central Processing Unit) 702 built therein. An input/output interface 710 is connected to the CPU 702 by a bus 701, and if an instruction is inputted to the CPU 702 through the input/output interface 710 when an inputting section 707 configured from a keyboard, a mouse, a microphone and so forth is operated by a user or in a like case, the CPU 702 executes the program stored in the ROM (Read Only

Memory) 703. Or, the CPU 702 loads a program stored on the hard disk 705, a program transferred from a satellite or a network, received by the communication section 708 and installed in the hard disk 705 or a program read out from the removable recording medium 711 loaded in a drive 709 and installed in the hard disk 705 into a RAM (Random Access Memory) 704 and executes the program. Consequently, the CPU 702 carries out processing in accordance with the flow chart described hereinabove or processing carried out by the configuration of the block diagram described hereinabove. Then, the CPU 702 outputs a result of the processing from an outputting section 706 configured from an LCD (Liquid Crystal Display), a speaker and so forth and transmits the processing result from the communication section 708 through the input/output interface 710 or records the processing result on the hard disk 705 as occasion demands.

[0543]

Here, in the present specification, processing steps which describe the program for causing the computer to carry out various processes need not necessarily be processed in a time series in accordance with the order described as a flow chart but include those processes to be executed in parallel or individually (for example,

parallel processes or processes by an object).

[0544]

Further, the program may be processed by a single computer or may be processed by distributed processing by a plurality of computers. Further, the program may be transferred to and executed by a computer at a remote place.

[0545]

Now, a process for LDPC encoding by the LDPC encoding section 21 of the transmission apparatus 11 is described further.

[0546]

For example, in the DVB-S.2 standard, LDPC encoding of the two different code lengths  $N$  of 64,800 bits and 16,200 bits are prescribed.

[0547]

And, for the LDPC code whose code length  $N$  is 64,800 bits, the 11 encoding rates  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$ ,  $8/9$  and  $9/10$  are prescribed, and for the LDPC code whose code length  $N$  is 16,200 bits, the 10 encoding rates  $1/4$ ,  $1/3$ ,  $2/5$ ,  $1/2$ ,  $3/5$ ,  $2/3$ ,  $3/4$ ,  $4/5$ ,  $5/6$  and  $8/9$  are prescribed.

[0548]

The LDPC encoding section 21 carries out encoding

(error correction encoding) into LDPC codes of the different encoding rates whose code length  $N$  is 64,800 bits or 16,200 bits in accordance with a parity check matrix  $H$  prepared for each code length  $N$  and for each encoding rate.

[0549]

In particular, the LDPC encoding section 21 stores a parity check matrix initial value table hereinafter described for producing a parity check matrix  $H$  for each code length  $N$  and for each encoding rate.

[0550]

Here, in the DVB-S.2 standard, LDPC codes of the two different code lengths  $N$  of 64,800 bits and 16,200 bits are prescribed as described hereinabove, and the 11 different encoding rates are prescribed for the LDPC code whose code length  $N$  is 64,800 bits and the 10 different encoding rates are prescribed for the LDPC code whose code length  $N$  is 16,200 bits.

[0551]

Accordingly, where the transmission apparatus 11 is an apparatus which carries out processing in compliance with the DVB-S.2 standard, parity check matrix initial value tables individually corresponding to the 11 different encoding rates for the LDPC code whose code

length  $N$  is 64,800 bits and parity check matrix initial value tables individually corresponding to the 10 different encoding rates for the LDPC code whose code length  $N$  is 16,200 bits are stored in the LDPC encoding section 21.

[0552]

The LDPC encoding section 21 sets a code length  $N$  and an encoding rate  $r$  for LDPC codes, for example, in response to an operation of an operator. The code length  $N$  and the encoding rate  $r$  set by the LDPC encoding section 21 are hereinafter referred to suitably as set code length  $N$  and set encoding rate  $r$ , respectively.

[0553]

The LDPC encoding section 21 places, based on the parity check matrix initial value tables corresponding to the set code length  $N$  and the set encoding rate  $r$ , elements of the value 1 of an information matrix  $H_A$  corresponding to an information length  $K$  ( $= Nr = \text{code length } N - \text{parity length } M$ ) corresponding to the set code length  $N$  and the set encoding rate  $r$  in a period of 360 columns (unit column number  $P$  of the cyclic structure) in the column direction to produce a parity check matrix  $H$ .

[0554]

Then, the LDPC encoding section 21 extracts

information bits for the information length  $K$  from object data which are an object of transmission such as image data or sound data supplied from the transmission apparatus 11. Further, the LDPC encoding section 21 calculates parity bits corresponding to the information bits based on the parity check matrix  $H$  to produce a codeword (LDPC code) for one code length.

[0555]

In other words, the LDPC encoding section 21 successively carries out mathematical operation of a parity bit of the codeword  $c$  which satisfies the following expression.

[0556]

$$Hc^T = 0$$

[0557]

Here, in the expression above,  $c$  indicates a row vector as the codeword (LDPC code), and  $c^T$  indicates inversion of the row vector  $c$ .

[0558]

Where, from within the row vector  $c$  as an LDPC code (one codeword), a portion corresponding to the information bits is represented by a row vector  $A$  and a portion corresponding to the parity bits is represented by a row vector  $T$ , the row vector  $c$  can be represented by

an expression  $c = [A|T]$  from the row vector  $A$  as the information bits and the row vector  $T$  as the parity bits.

[0559]

Meanwhile, the parity check matrix  $H$  can be represented, from the information matrix  $H_A$  of those of the code bits of the LDPC code which correspond to the information bits and the parity matrix  $H_T$  of those of the code bits of the LDPC code which correspond to the parity bits by an expression  $H = [H_A|H_T]$  (matrix wherein the elements of the information matrix  $H_A$  are elements on the left side and the elements of the parity matrix  $H_T$  are elements on the right side).

[0560]

Further, for example, in the DVB-S.2 standard, the parity check matrix  $H_T$  of the parity check matrix  $H = [H_A|H_T]$  has a staircase structure.

[0561]

It is necessary for the parity check matrix  $H$  and the row vector  $c = [A|T]$  as an LDPC code to satisfy the expression  $Hc^T = 0$ , and where the parity matrix  $H_T$  of the parity check matrix  $H = [H_A|H_T]$  has a staircase structure, the row vector  $T$  as parity bits which configures the row vector  $c = [A|T]$  which satisfies the expression  $Hc^T = 0$  can be determined sequentially by setting the elements of

each row to zero in order beginning with the elements in the first row of the column vector  $Hc^T$  in the expression  $Hc^T = 0$ .

[0562]

If the LDPC encoding section 21 determines a parity bit  $T$  for an information bit  $A$ , then it outputs a codeword  $c = [A|T]$  represented by the information bit  $A$  and the parity bit  $T$  as an LDPC encoding result of the information bit  $A$ .

[0563]

As described above, the LDPC encoding section 21 stores the parity check matrix initial value tables corresponding to the code lengths  $N$  and the encoding rates  $r$  in advance therein and carries out LDPC encoding of the set code length  $N$  and the set encoding rate  $r$  using a parity check matrix  $H$  produced from the parity check matrix initial value tables corresponding to the set code length  $N$  and the set encoding rate  $r$ .

[0564]

Each parity check matrix initial value table is a table which represents the position of elements of the value 1 of the information matrix  $H_A$  corresponding to the information length  $K$  corresponding to the code length  $N$  and the encoding rate  $r$  of the LDPC code of the parity

check matrix  $H$  (LDPC code defined by the parity check matrix  $H$ ) for every 360 rows (unit column number  $P$  of the periodic structure), and is produced in advance for a parity check matrix  $H$  for each code length  $N$  and each encoding rate  $r$ .

[0565]

FIGS. 78 to 123 illustrate the parity check matrix initial value tables for producing various parity check matrices  $H$  including parity check matrix initial value tables prescribed in the DVB-S.2 standard.

[0566]

In particular, FIG. 78 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $2/3$ .

[0567]

FIGS. 79 to 81 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $2/3$ .

[0568]

It is to be noted that FIG. 80 is a view continuing from FIG. 79 and FIG. 81 is a view continuing from FIG. 80.

[0569]

FIG. 82 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $3/4$ .

[0570]

FIGS. 83 to 86 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $3/4$ .

[0571]

It is to be noted that FIG. 84 is a view continuing from FIG. 83 and FIG. 85 is a view continuing from FIG. 84. Further, FIG. 86 is a view continuing from FIG. 85.

[0572]

FIG. 87 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $4/5$ .

[0573]

FIGS. 88 to 91 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $4/5$ .

[0574]

It is to be noted that FIG. 89 is a view continuing from FIG. 88 and FIG. 90 is a view continuing from FIG. 89. Further, FIG. 91 is a view continuing from FIG. 90.

[0575]

FIG. 92 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $5/6$ .

[0576]

FIGS. 93 to 96 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $5/6$ .

[0577]

It is to be noted that FIG. 94 is a view continuing from FIG. 93 and FIG. 95 is a view continuing from FIG. 94. Further, FIG. 96 is a view continuing from FIG. 95.

[0578]

FIG. 97 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $8/9$ .

[0579]

FIGS. 98 to 101 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $8/9$ .

[0580]

It is to be noted that FIG. 99 is a view continuing from FIG. 98 and FIG. 100 is a view continuing from FIG. 99. Further, FIG. 101 is a view continuing from FIG. 100.

[0581]

FIGS. 102 to 105 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $9/10$ .

[0582]

It is to be noted that FIG. 103 is a view continuing from FIG. 102 and FIG. 104 is a view continuing from FIG. 103. Further, FIG. 105 is a view continuing from FIG. 104.

[0583]

FIGS. 106 and 107 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $1/4$ .

[0584]

It is to be noted that FIG. 107 is a view continuing from FIG. 106.

[0585]

FIGS. 108 and 109 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $1/3$ .

[0586]

It is to be noted that FIG. 109 is a view continuing from FIG. 108.

[0587]

FIGS. 110 and 111 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $2/5$ .

[0588]

It is to be noted that FIG. 111 is a view continuing from FIG. 110.

[0589]

FIGS. 112 to 114 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $1/2$ .

[0590]

It is to be noted that FIG. 113 is a view continuing from FIG. 112 and FIG. 114 is a view continuing from FIG. 113.

[0591]

FIGS. 115 to 117 show the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 64,800 bits and an encoding rate  $r$  of  $3/5$ .

[0592]

It is to be noted that FIG. 116 is a view continuing from FIG. 115 and FIG. 117 is a view continuing from FIG. 116.

[0593]

FIG. 118 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $1/4$ .

[0594]

FIG. 119 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $1/3$ .

[0595]

FIG. 120 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $2/5$ .

[0596]

FIG. 121 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $1/2$ .

[0597]

FIG. 122 shows the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $3/5$ .

[0598]

FIG. 123 shows the parity check matrix initial value table for a parity check matrix  $H$  having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $3/5$ , which can be used in place of the parity check matrix initial value table of FIG. 122.

[0599]

The LDPC encoding section 21 of the transmission apparatus 11 determines a parity check matrix  $H$  in the following manner using the parity check matrix initial

value tables.

[0600]

In particular, FIG. 124 illustrates a method for determining a parity check matrix  $H$  from a parity check matrix initial value table.

[0601]

It is to be noted that the parity check matrix initial value table of FIG. 124 indicates the parity check matrix initial value table for a parity check matrix  $H$  prescribed in the DVB-S.2 standard and having a code length  $N$  of 16,200 bits and an encoding rate  $r$  of  $2/3$  shown in FIG. 178.

[0602]

As described above, the parity check matrix initial value table is a table which represents the position of elements of the value 1 of a information matrix  $H_A$  corresponding to the information length  $K$  corresponding to the code length  $N$  and the encoding rate  $r$  of the LDPC code for every 360 columns (for every unit column number  $P$  of the cyclic structure), and in the first row of the parity check matrix initial value table, a number of row numbers of elements of the value 1 in the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  (row numbers where the row number of the first row of the parity check

matrix H is 0) equal to the number of column weights which the  $1+360 \times (i-1)$ th column has.

[0603]

Here, it is assumed that the parity matrix  $H_T$  of the parity check matrix H corresponding to the parity length M has a staircase structure and is determined in advance. According to the parity check matrix initial value table, the information matrix  $H_A$  corresponding to the information length K from within the parity check matrix H is determined.

[0604]

The row number  $k+1$  of the parity check matrix initial value table differs depending upon the information length K.

[0605]

The information length K and the row number  $k+1$  of the parity check matrix initial value table satisfy a relationship given by the following expression.

[0606]

$$K = (k + 1) \times 360$$

[0607]

Here, 360 in the expression above is the unit column number P of the cyclic structure.

[0608]

In the parity check matrix initial value table of FIG. 124, 13 numerical values are listed in the first to third rows, and three numerical values are listed in the fourth to  $k+1$ th (in FIG. 124, 30th) rows.

[0609]

Accordingly, the number of column weights in the parity check matrix  $H$  determined from the parity check matrix initial value table of FIG. 124 is 13 in the first to  $1+360 \times (3-1)-1$ th rows but is 3 in the  $1+360 \times (3-1)$ th to  $K$ th rows.

[0610]

The first row of the parity check matrix initial value table of FIG. 124 includes 0, 2084, 1613, 1548, 1286, 1460, 3196, 4297, 2481, 3369, 3451, 4620 and 2622, and this indicates that, in the first column of the parity check matrix  $H$ , the elements in rows of the row numbers of 0, 2084, 1613, 1548, 1286, 1460, 3196, 4297, 2481, 3369, 3451, 4620 and 2622 have the value 1 (and besides the other elements have the value 0).

[0611]

Meanwhile, the second row of the parity check matrix initial value table of FIG. 124 includes 1, 122, 1516, 3448, 2880, 1407, 1847, 3799, 3529, 373, 971, 4358 and 3108, and this indicates that, in the 361st (=

$1+360 \times (2-1)$ th) column of the parity check matrix  $H$ , the elements in rows of the row numbers of 1, 122, 1546, 3448, 2880, 1407, 1847, 3799, 3529, 373, 971, 4358 and 3108 have the value 1.

[0612]

As given above, the parity check matrix initial value table represents the position of elements of the value 1 of the information matrix  $H_A$  of the parity check matrix  $H$  for every 360 columns.

[0613]

Each of the columns of the parity check matrix  $H$  other than the  $1+360 \times (i-1)$ th column, that is, each of the columns from  $2+360 \times (i-1)$ th to  $360 \times i$ th columns, includes elements of the value of 1 obtained by cyclically shifting the elements of the value of 1 of the  $1+360 \times (i-1)$ th column which depend upon the parity check matrix initial value table periodically in the downward direction (in the downward direction of the column) in accordance with the parity length  $M$ .

[0614]

In particular, for example, the  $2+360 \times (i-1)$ th column is a column obtained by cyclically shifting the  $1+360 \times (i-1)$ th column in the downward direction by  $M/360$  ( $= q$ ), and the next  $3+360 \times (i-1)$ th is a column obtained by

cyclically shifting the  $1+360 \times (i-1)$ th column in the downward direction by  $2 \times M/360$  ( $= 2 \times q$ ) and then cyclically shifting the cyclically shifted column ( $2+360 \times (i-1)$ th column) in the downward direction by  $M/360$  ( $= q$ ).

[0615]

Now, if it is assumed that the numeral value in the  $j$ th column ( $j$ th from the left) in the  $i$ th row ( $i$ th row from above) of the parity check matrix initial value table is represented by  $b_{i,j}$  and the row number of the  $j$ th element of the value 1 in the  $w$ th column of the parity check matrix  $H$  is represented by  $H_{w-j}$ , then the row number  $H_{w-j}$  of the element of the value 1 in the  $w$ th column which is a column other than the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  can be determined in accordance with the following expression.

[0616]

$$H_{w-j} = \text{mod}\{h_{i,j} + \text{mod}((w-1), P) \times q, M\}$$

[0617]

Here,  $\text{mod}(x, y)$  signifies a remainder when  $x$  is divided by  $y$ .

[0618]

Meanwhile,  $P$  is a unit number of columns of the cyclic structure described hereinabove and is, for

example, in the DVB-S.2 standard, 360. Further,  $q$  is a value  $M/360$  obtained by dividing the parity length  $M$  by the unit column number  $P$  ( $= 360$ ) of the cyclic structure.

[0619]

The LDPC encoding section 21 specifies the row number of the elements of the value 1 in the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  from the parity check matrix initial value table.

[0620]

Further, the LDPC encoding section 21 determines the row number  $H_{w-j}$  of the element of the value 1 in the  $w$ th column which is a column other than the  $1+360 \times (i-1)$ th column of the parity check matrix  $H$  and produces a parity check matrix  $H$  in which the elements of the row numbers obtained by the foregoing have the value 1.

[0621]

Now, variations of the method of replacement of code bits of an LDPC code in the replacement process by the replacement section 32 of the demultiplexer 25 in the transmission apparatus 11, that is, of the allocation pattern (hereinafter referred to as bit allocation pattern) of code bits of an LDPC code and symbol bits representative of a symbol, are described.

[0622]

In the demultiplexer 25, the code bits of the LDPC code are written in the column direction of the memory 31, which stores  $(N/(mb)) \times (mb)$  bits in the column direction  $\times$  row direction. Thereafter, the code bits are read out in a unit of  $mb$  bits in the row direction. Further, in the demultiplexer 25, the replacement section 32 replaces the  $mb$  code bits read out in the row direction of the memory 31 and determines the code bits after the replacement as  $mb$  symbol bits of (successive)  $b$  symbols.

[0623]

In particular, the replacement section 32 determines the  $i+1$ th bit from the most significant bit of the  $mb$  code bits read out in the row direction of the memory 31 as the code bit  $b_i$  and determines the  $i+1$ th bit from the most significant bit of the  $mb$  symbol bits of the  $b$  (successive) symbols as the symbol bit  $y_i$ , and then replaces the  $mb$  code bits  $b_0$  to  $b_{mb-1}$  in accordance with a predetermined bit allocation pattern.

[0624]

FIG. 125 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $5/6$  or  $9/10$  and besides the modulation method is 4096QAM and the multiple  $b$  is 1.

[0625]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $5/6$  or  $9/10$  and besides the modulation method is 4096QAM and the multiple  $b$  is 1, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(12 \times 1)) \times (12 \times 1)$  bits in the column direction  $\times$  row direction are read out in a unit of  $12 \times 1$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0626]

The replacement section 32 replaces  $12 \times 1$  (= mb) code bits  $b_0$  to  $b_{11}$  such that the  $12 \times 1$  (= mb) code bits  $b_0$  to  $b_{11}$  to be read out from the memory 31 may be allocated to the  $12 \times 1$  (= mb) symbol bits  $y_0$  to  $y_{11}$  of one (=  $b$ ) symbol as seen in FIG. 125.

[0627]

In particular, according to FIG. 125, the replacement section 32 carries out, with regard to both of an LDPC code having the encoding rate of  $5/6$  and an LDPC code having the encoding rate of  $9/10$  from among LDPC codes having the code length  $N$  of 64,800 bits, replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_8$ ,

the code bit  $b_1$  to the symbol bit  $y_0$ ,

the code bit  $b_2$  to the symbol bit  $y_6$ ,  
 the code bit  $b_3$  to the symbol bit  $y_1$ ,  
 the code bit  $b_4$  to the symbol bit  $y_4$ ,  
 the code bit  $b_5$  to the symbol bit  $y_5$ ,  
 the code bit  $b_6$  to the symbol bit  $y_2$ ,  
 the code bit  $b_7$  to the symbol bit  $y_3$ ,  
 the code bit  $b_8$  to the symbol bit  $y_7$ ,  
 the code bit  $b_9$  to the symbol bit  $y_{10}$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_{11}$ , and  
 the code bit  $b_{11}$  to the symbol bit  $y_9$ .

[0628]

FIG. 226 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $5/6$  or  $9/10$  and besides the modulation method is 4096QAM and the multiple  $b$  is 2.

[0629]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $5/6$  or  $9/10$  and besides the modulation method is 4096QAM and the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(12 \times 2)) \times (12 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $12 \times 2$  (= mb) bits in the row

direction and supplied to the replacement section 32.

[0630]

The replacement section 32 replaces  $12 \times 2$  (= mb) code bits  $b_0$  to  $b_{23}$  such that the  $12 \times 2$  (= mb) code bits  $b_0$  to  $b_{23}$  to be read out from the memory 31 may be allocated to the  $12 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{23}$  of two (= b) successive symbols as seen in FIG. 126.

[0631]

In particular, according to FIG. 126, the replacement section 32 carries out, with regard to both of an LDPC code having the encoding rate of  $5/6$  and an LDPC code having the encoding rate of  $9/10$  from among LDPC codes having the code length  $N$  of 64,800 bits, replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_8$ ,  
the code bit  $b_2$  to the symbol bit  $y_0$ ,  
the code bit  $b_4$  to the symbol bit  $y_6$ ,  
the code bit  $b_6$  to the symbol bit  $y_1$ ,  
the code bit  $b_8$  to the symbol bit  $y_4$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_5$ ,  
the code bit  $b_{12}$  to the symbol bit  $y_2$ ,  
the code bit  $b_{14}$  to the symbol bit  $y_3$ ,  
the code bit  $b_{16}$  to the symbol bit  $y_7$ ,  
the code bit  $b_{18}$  to the symbol bit  $y_{10}$ ,

the code bit  $b_{20}$  to the symbol bit  $y_{11}$ ,  
 the code bit  $b_{22}$  to the symbol bit  $y_9$ ,  
 the code bit  $b_1$  to the symbol bit  $y_{20}$ ,  
 the code bit  $b_3$  to the symbol bit  $y_{12}$ ,  
 the code bit  $b_5$  to the symbol bit  $y_{18}$ ,  
 the code bit  $b_7$  to the symbol bit  $y_{13}$ ,  
 the code bit  $b_9$  to the symbol bit  $y_{16}$ ,  
 the code bit  $b_{11}$  to the symbol bit  $y_{17}$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_{14}$ ,  
 the code bit  $b_{15}$  to the symbol bit  $y_{15}$ ,  
 the code bit  $b_{17}$  to the symbol bit  $y_{19}$ ,  
 the code bit  $b_{19}$  to the symbol bit  $y_{22}$ ,  
 the code bit  $b_{21}$  to the symbol bit  $y_{23}$ , and  
 the code bit  $b_{23}$  to the symbol bit  $y_{21}$ .

[0632]

Here, the bit allocation pattern of FIG. 126  
 utilizes the bit allocation pattern of FIG. 125 wherein  
 the multiple  $b$  is 1 without any modification. In  
 particular, in FIG. 126, the allocation of the code bits  
 $b_0, b_2, \dots, b_{22}$  to the symbol bits  $y_i$  and the allocation of  
 the  $b_1, b_3, \dots, b_{23}$  to the symbol bits  $y_i$  are similar to the  
 allocation of the code bits  $b_0$  to  $b_{11}$  to the symbol bits  $y_i$   
 of FIG. 125.

[0633]

FIG. 127 shows an example of a bit allocation pattern which can be adopted where the modulation method is 1024QAM and the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/4$ ,  $5/6$  or  $8/9$  and besides the multiple  $b$  is 2 and also where the modulation method is 1024QAM and the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding length is  $3/4$ ,  $5/6$  or  $9/10$  and besides the multiple  $b$  is 2.

[0634]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/4$ ,  $5/6$  or  $8/9$  and the modulation method is 1024QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(10 \times 2)) \times (10 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $10 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0635]

On the other hand, where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/4$ ,  $5/6$  or  $9/10$  and the modulation method is 1024QAM and besides the multiple  $b$  is 2, in the

demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(10 \times 2)) \times (10 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $10 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0636]

The replacement section 32 replaces  $10 \times 2$  (= mb) code bits  $b_0$  to  $b_{19}$  such that the  $10 \times 2$  (= mb) code bits  $b_0$  to  $b_{19}$  to be read out from the memory 31 may be allocated to the  $10 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{19}$  of two (= b) successive symbols as seen in FIG. 127.

[0637]

In particular, according to FIG. 127, the replacement section 32 carries out, with regard to all of the LDPC codes having the encoding rate of  $3/4$ , LDPC codes having the encoding rate of  $5/6$  and LDPC codes having a further encoding rate of  $8/9$  from among LDPC codes having the code length of 16,200 bits as well as LDPC code having the encoding rate of  $3/4$ , LDPC codes having the encoding rate of  $5/6$  and LDPC codes having a further encoding rate of  $9/10$  from among LDPC codes having another code length  $N$  of 64,800, replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_8$ ,

the code bit  $b_1$  to the symbol bit  $y_3$ ,  
 the code bit  $b_2$  to the symbol bit  $y_7$ ,  
 the code bit  $b_3$  to the symbol bit  $y_{10}$ ,  
 the code bit  $b_4$  to the symbol bit  $y_{19}$ ,  
 the code bit  $b_5$  to the symbol bit  $y_4$ ,  
 the code bit  $b_6$  to the symbol bit  $y_9$ ,  
 the code bit  $b_7$  to the symbol bit  $y_5$ ,  
 the code bit  $b_8$  to the symbol bit  $y_{17}$ ,  
 the code bit  $b_9$  to the symbol bit  $y_6$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_{14}$ ,  
 the code bit  $b_{11}$  to the symbol bit  $y_{11}$ ,  
 the code bit  $b_{12}$  to the symbol bit  $y_2$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_{18}$ ,  
 the code bit  $b_{14}$  to the symbol bit  $y_{16}$ ,  
 the code bit  $b_{15}$  to the symbol bit  $y_{15}$ ,  
 the code bit  $b_{16}$  to the symbol bit  $y_0$ ,  
 the code bit  $b_{17}$  to the symbol bit  $y_1$ ,  
 the code bit  $b_{18}$  to the symbol bit  $y_{13}$ , and  
 the code bit  $b_{19}$  to the symbol bit  $y_{12}$ .

[0638]

FIG. 128 shows an example of a bit allocation  
 pattern which can be adopted where the modulation method  
 is 4096QAM and the LDPC code is an LDPC code whose code  
 length  $N$  is 16,200 bits and whose encoding rate is  $5/6$  or

8/9 and besides the multiple  $b$  is 2 and also where the modulation method is 4096QAM and the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is 5/6 or 9/10 and besides the multiple  $b$  is 2.

[0639]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is 5/6 or 8/9 and the modulation method is 4096QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(12 \times 2)) \times (12 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $12 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0640]

On the other hand, where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is 5/6 or 9/10 and the modulation method is 4096QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(12 \times 2)) \times (12 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $12 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0641]

The replacement section 32 replaces  $12 \times 2$  (= mb) code bits  $b_0$  to  $b_{23}$  such that the  $12 \times 2$  (= mb) bits to be read out from the memory 31 may be allocated to the  $12 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{23}$  of two (= b) successive symbols as seen in FIG. 128.

[0642]

In particular, according to FIG. 128, the replacement section 32 carries out, with regard to all of the LDPC codes having the encoding rate of  $5/6$  and LDPC codes having the encoding rate of  $8/9$  from among LDPC codes having the code length of 16,200 bits as well as LDPC codes having the encoding rate of  $5/6$  and LDPC codes having the encoding rate of  $9/10$  from among LDPC codes having another code length  $N$  of 64,800, replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_1$  to the symbol bit  $y_{15}$ ,  
the code bit  $b_2$  to the symbol bit  $y_4$ ,  
the code bit  $b_3$  to the symbol bit  $y_{19}$ ,  
the code bit  $b_4$  to the symbol bit  $y_{21}$ ,  
the code bit  $b_5$  to the symbol bit  $y_{16}$ ,  
the code bit  $b_6$  to the symbol bit  $y_{23}$ ,  
the code bit  $b_7$  to the symbol bit  $y_{18}$ ,

the code bit  $b_8$  to the symbol bit  $y_{11}$ ,  
 the code bit  $b_9$  to the symbol bit  $y_{14}$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_{22}$ ,  
 the code bit  $b_{11}$  to the symbol bit  $y_5$ ,  
 the code bit  $b_{12}$  to the symbol bit  $y_6$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_{17}$ ,  
 the code bit  $b_{14}$  to the symbol bit  $y_{13}$ ,  
 the code bit  $b_{15}$  to the symbol bit  $y_{20}$ ,  
 the code bit  $b_{16}$  to the symbol bit  $y_1$ ,  
 the code bit  $b_{17}$  to the symbol bit  $y_3$ ,  
 the code bit  $b_{18}$  to the symbol bit  $y_9$ ,  
 the code bit  $b_{19}$  to the symbol bit  $y_2$ ,  
 the code bit  $b_{20}$  to the symbol bit  $y_7$ ,  
 the code bit  $b_{21}$  to the symbol bit  $y_8$ ,  
 the code bit  $b_{22}$  to the symbol bit  $y_{12}$ , and  
 the code bit  $y_{23}$  to the symbol bit  $y_0$ .

[0643]

According to the bit allocation patterns shown in  
 FIGS. 125 to 128, the same bit allocation pattern can be  
 adopted for a plurality of kinds of LDPC codes, and  
 besides, the tolerance to errors can be set to a desired  
 performance with regard to all of the plural kinds of  
 LDPC codes.

[0644]

In particular, FIGS. 129 to 132 illustrates results of simulations of the BER (Bit Error Rate) where a replacement process is carried out in accordance with the bit allocation patterns of FIGS. 125 to 128.

[0645]

It is to be noted that, in FIGS. 129 to 132, the axis of abscissa represents  $E_s/N_0$  (signal power to noise power ratio per one symbol) and the axis of ordinate represents the BER.

[0646]

Further, a solid line curve represents the BER where a replacement process is carried out and an alternate long and short dash line represents the BER where a replacement process is not carried out.

[0647]

FIG. 129 illustrates the BER where a replacement process in accordance with the bit allocation pattern of FIG. 125 is carried out for LDPC codes whose code length  $N$  is 64,800 and whose encoding rate is  $5/6$  and  $9/10$  adopting 4096QAM as the modulation method and setting the multiple  $b$  to 1.

[0648]

FIG. 130 illustrates the BER where a replacement process in accordance with the bit allocation pattern of

FIG. 126 is carried out for LDPC codes whose code length  $N$  is 64,800 and whose encoding rate is  $5/6$  and  $9/10$  adopting 4096QAM as the modulation method and setting the multiple  $b$  to 2.

[0649]

It is to be noted that, in FIGS. 129 and 130, a graph having a triangular mark applied thereto represents the BER regarding the LDPC code having the encoding rate of  $5/6$ , and a graph having an asterisk applied thereto represents the BER regarding the LDPC code having the encoding rate of  $9/10$ .

[0650]

FIG. 131 illustrates the BER where a replacement process in accordance with the bit allocation pattern of FIG. 127 is carried out for LDPC codes whose code length  $N$  is 16,200 and whose encoding rate is  $3/4$ ,  $5/6$  and  $8/9$  and for LDPC codes whose code length  $N$  is 64,800 and whose encoding rate is  $3/4$ ,  $5/6$  and  $9/10$  adopting 1024QAM as the modulation method and setting the multiple  $b$  to 2.

[0651]

It is to be noted that, in FIG. 131, a graph having an asterisk applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 64,800 and the encoding rate of  $9/10$ , and a graph having an upwardly

directed triangular mark applied thereto represents the BER regarding the LDPC codes having the code length  $N$  of 64,800 and the encoding rate of  $5/6$ . Further, a graph having a square mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 64,800 and the encoding rate of  $3/4$ .

[0652]

Further, in FIG. 131, a graph having a round mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 16,200 and the encoding rate of  $8/9$ , and a graph having a downwardly directed triangular mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 16,200 and the encoding rate of  $5/6$ . Further, a graph having a plus mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 16,200 and the encoding rate of  $3/4$ .

[0653]

FIG. 132 illustrates the BER where a replacement process in accordance with the bit allocation pattern of FIG. 128 is carried out for LDPC codes whose code length  $N$  is 16,200 and whose encoding rate is  $5/6$  and  $8/9$  and for LDPC codes whose code length  $N$  is 64,800 and whose encoding rate is  $5/6$  and  $9/10$  adopting 4096QAM as the

modulation method and setting the multiple  $b$  to 2.

[0654]

It is to be noted that, in FIG. 132, a graph having an asterisk applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 64,800 and the encoding rate of  $9/10$ , and a graph having an upwardly directed triangular mark applied thereto represents the BER regarding the LDPC codes having the code length  $N$  of 64,800 and the encoding rate of  $5/6$ .

[0655]

Further, in FIG. 132, a graph having a round mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 16,200 and the encoding rate of  $8/9$ , and a graph having a downwardly directed triangular mark applied thereto represents the BER regarding the LDPC code having the code length  $N$  of 16,200 and the encoding rate of  $5/6$ .

[0656]

According to FIGS. 129 to 132, the same bit allocation pattern can be adopted with regard to a plurality of kinds of LDPC codes. Besides, the tolerance to errors can be set to a desired performance with regard to all of the plural kinds of LDPC codes.

[0657]

In particular, where a bit allocation pattern for exclusive use is adopted for each of a plurality of kinds of LDPC codes which have different code lengths and different encoding rates, the tolerance to an error can be raised to a very high performance. However, it is necessary to change the bit allocation pattern for each of a plurality of kinds of LDPC codes.

[0658]

On the other hand, according to the bit allocation patterns of FIGS. 125 to 128, the same bit allocation pattern can be adopted for a plurality of kinds of LDPC codes which have different code lengths and different encoding rates, and the necessity to change the bit allocation pattern for each of a plurality of kinds of LDPC codes as in a case wherein a bit allocation pattern for exclusive use is adopted for each of a plurality of kinds of LDPC codes is eliminated.

[0659]

Further, according to the bit allocation patterns of FIGS. 125 to 128, the tolerance to errors can be raised to a high performance although it is a little lower than that where a bit allocation pattern for exclusive use is adopted for each of a plurality of kinds of LDPC codes.

[0660]

In particular, for example, where the modulation method is 4096QAM, the same bit allocation pattern in FIG. 125 or 126 can be used for all of the LDPC codes which have the code length  $N$  of 64,800 and the encoding rate of  $5/6$  and  $9/10$ . Even where the same bit allocation pattern is adopted in this manner, the tolerance to errors can be raised to a high performance.

[0661]

Further, for example, where the modulation method is 1024QAM, the same bit allocation pattern of FIG. 127 can be adopted for all of the LDPC codes which have the code length  $N$  of 16,200 and the encoding rate of  $3/4$ ,  $5/6$  and  $8/9$  and the LDPC codes which have the code length  $N$  of 64,800 and the encoding rate of  $3/4$ ,  $5/6$  and  $9/10$ . Then, even if the same bit allocation pattern is adopted in this manner, the tolerance to errors can be raised to a high performance.

[0662]

Meanwhile, for example, where the modulation method is 4096QAM, the same bit allocation pattern of FIG. 128 can be adopted for all of the LDPC codes which have the code length  $N$  of 16,200 and the encoding rate of  $5/6$  and  $8/9$  and the LDPC codes which have the code length  $N$  of

64,800 and the encoding rate of 5/6 and 9/10. Then, even if the same bit allocation pattern is adopted in this manner, the tolerance to errors can be raised to a high performance.

[0663]

Variations of the bit allocation pattern are further described.

[0664]

FIG. 133 illustrates an example of a bit allocation pattern which can be adopted where the LDPC code is any LDPC code which has the code length  $N$  of 16,200 or 64,800 bits and one of the encoding rates for the LDPC code defined by a parity check matrix  $H$  produced, for example, from any of the parity check matrix initial value tables shown in FIGS. 78 to 123 other than the encoding rate of 3/5 and besides the modulation method is QPSK and the multiple  $b$  is 1.

[0665]

Where the LDPC code is an LDPC code which has the code length  $N$  of 16,200 or 64,800 bits and has the encoding rate other than 3/5 and besides the modulation method is QPSK and the multiple  $b$  is 1, the demultiplexer 25 reads out code bits written in the memory 31 for storing  $(N/(2 \times 1)) \times (2 \times 1)$  bits in the column

direction  $\times$  row direction in a unit of  $2 \times 1$  (= mb) bits in the row direction and supplies the read out code bits to the replacement section 32.

[0666]

The replacement section 32 replaces the  $2 \times 1$  (= mb) code bits  $b_0$  and  $b_1$  read out from the memory 31 in such a manner that the  $2 \times 1$  (= mb) code bits  $b_0$  and  $b_1$  are allocated to the  $2 \times 1$  (= mb) symbol bits  $y_0$  and  $y_1$  of one (= b) symbol as seen in FIG. 133.

[0667]

In particular, according to FIG. 133, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_0$  and

the code bit  $b_1$  to the symbol bit  $y_1$ .

[0668]

It is to be noted that, in this instance, also it is possible to consider that replacement is not carried out and the code bits  $b_0$  and  $b_1$  are determined as they are as the symbol bits  $y_0$  and  $y_1$ , respectively.

[0669]

FIG. 134 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code which has the code length  $N$  of 16,200 or 64,800

bits and has the encoding rate other than  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2.

[0670]

Where the LDPC code is an LDPC code which has the code length  $N$  of 16,200 or 64,800 bits and has the encoding rate other than  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2, the demultiplexer 25 reads out the code bits written in the memory 31 for storing  $(N/(4 \times 2)) \times (4 \times 2)$  bits in the column direction  $\times$  row direction in a unit of  $4 \times 2$  (=  $mb$ ) bits in the row direction and supplies the read out code bits to the replacement section 32.

[0671]

The replacement section 32 replaces the  $4 \times 2$  (=  $mb$ ) code bits  $b_0$  to  $b_7$  read out from the memory 31 in such a manner that the  $4 \times 2$  (=  $mb$ ) code bits are allocated to the  $4 \times 2$  (=  $mb$ ) symbol bits  $y_0$  to  $y_7$  of two (=  $b$ ) successive symbols as seen in FIG. 134.

[0672]

In particular, according to FIG. 134, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_7$ ,

the code bit  $b_1$  to the symbol bit  $y_1$ ,

the code bit  $b_2$  to the symbol bit  $y_4$ ,  
 the code bit  $b_3$  to the symbol bit  $y_2$ ,  
 the code bit  $b_4$  to the symbol bit  $y_5$ ,  
 the code bit  $b_5$  to the symbol bit  $y_3$ ,  
 the code bit  $b_6$  to the symbol bit  $y_6$ , and  
 the code bit  $b_7$  to the symbol bit  $y_0$ .

[0673]

FIG. 135 shows an example of a bit allocation pattern which can be adopted where the modulation method is 64QAM and the LDPC code is an LDPC code whose code length  $N$  is 16,200 or 64,800 bits and whose encoding rate is any other than  $3/5$  and besides the multiple  $b$  is 2.

[0674]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 or 64,800 bits and whose encoding rate is any other than  $3/5$  and the modulation method is 64QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(N/(6 \times 2)) \times (6 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $6 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0675]

The replacement section 32 replaces the  $6 \times 2$  (=

mb) code bits  $b_0$  to  $b_{11}$  read out from the memory 31 such that the  $6 \times 2$  (= mb) code bits  $b_0$  to  $b_{11}$  may be allocated to the  $6 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{11}$  of two (= b) successive symbols as seen in FIG. 135.

[0676]

In particular, according to FIG. 135, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_{11}$ ,  
the code bit  $b_1$  to the symbol bit  $y_7$ ,  
the code bit  $b_2$  to the symbol bit  $y_3$ ,  
the code bit  $b_3$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_4$  to the symbol bit  $y_6$ ,  
the code bit  $b_5$  to the symbol bit  $y_2$ ,  
the code bit  $b_6$  to the symbol bit  $y_9$ ,  
the code bit  $b_7$  to the symbol bit  $y_5$ ,  
the code bit  $b_8$  to the symbol bit  $y_1$ ,  
the code bit  $b_9$  to the symbol bit  $y_8$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_4$ , and  
the code bit  $b_{11}$  to the symbol bit  $y_0$ .

[0677]

FIG. 136 shows an example of a bit allocation pattern which can be adopted where the modulation method is 256QAM and the LDPC code is an LDPC code whose code

length  $N$  is 64,800 bits and whose encoding rate is any other than  $3/5$  and besides the multiple  $b$  is 2.

[0678]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is any other than  $3/5$  and the modulation method is 256QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(8 \times 2)) \times (8 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $8 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0679]

The replacement section 32 replaces the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  read out from the memory 31 such that the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  may be allocated to the  $8 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{15}$  of two (=  $b$ ) successive symbols as seen in FIG. 136.

[0680]

In particular, according to FIG. 136, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_{15}$ ,

the code bit  $b_1$  to the symbol bit  $y_1$ ,

the code bit  $b_2$  to the symbol bit  $y_{13}$ ,  
 the code bit  $b_3$  to the symbol bit  $y_3$ ,  
 the code bit  $b_4$  to the symbol bit  $y_8$ ,  
 the code bit  $b_5$  to the symbol bit  $y_{11}$ ,  
 the code bit  $b_6$  to the symbol bit  $y_9$ ,  
 the code bit  $b_7$  to the symbol bit  $y_5$ ,  
 the code bit  $b_8$  to the symbol bit  $y_{10}$ ,  
 the code bit  $b_9$  to the symbol bit  $y_6$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_4$ ,  
 the code bit  $b_{11}$  to the symbol bit  $y_7$ ,  
 the code bit  $b_{12}$  to the symbol bit  $y_{12}$ ,  
 the code bit  $b_{13}$  to the symbol bit  $y_2$ ,  
 the code bit  $b_{14}$  to the symbol bit  $y_{14}$ , and  
 the code bit  $b_{15}$  to the symbol bit  $y_0$ .

[0681]

FIG. 137 shows an example of a bit allocation pattern which can be adopted where the modulation method is 256QAM and the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is any other than  $3/5$  and besides the multiple  $b$  is 1.

[0682]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is any other than  $3/5$  and the modulation method is 256QAM and

besides the multiple  $b$  is 1, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(8 \times 1)) \times (8 \times 1)$  bits in the column direction  $\times$  row direction are read out in a unit of  $8 \times 1 (= mb)$  bits in the row direction and supplied to the replacement section 32.

[0683]

The replacement section 32 replaces the  $8 \times 1 (= mb)$  code bits  $b_0$  to  $b_7$  read out from the memory 31 such that the  $8 \times 1 (= mb)$  code bits  $b_0$  to  $b_7$  may be allocated to the  $8 \times 1 (= mb)$  symbol bits  $y_0$  to  $y_7$  of one  $(= b)$  symbol as seen in FIG. 137.

[0684]

In particular, according to FIG. 137, the replacement section 32 carries out replacement for allocating

- the code bit  $b_0$  to the symbol bit  $y_7$ ,
- the code bit  $b_1$  to the symbol bit  $y_3$ ,
- the code bit  $b_2$  to the symbol bit  $y_1$ ,
- the code bit  $b_3$  to the symbol bit  $y_5$ ,
- the code bit  $b_4$  to the symbol bit  $y_2$ ,
- the code bit  $b_5$  to the symbol bit  $y_6$ ,
- the code bit  $b_6$  to the symbol bit  $y_4$ , and
- the code bit  $b_7$  to the symbol bit  $y_0$ .

[0685]

FIG. 138 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code whose code length  $N$  is 16,200 or 64,800 bits and whose encoding rate is any other than  $3/5$  and besides the modulation method is QPSK and the multiple  $b$  is 1.

[0686]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 or 64,800 bits and whose encoding rate is any other than  $3/5$  and besides the modulation method is QPSK and the multiple  $b$  is 1, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(N/(2 \times 1)) \times (2 \times 1)$  bits in the column direction  $\times$  row direction are read out in a unit of  $2 \times 1 (= mb)$  bits in the row direction and supplied to the replacement section 32.

[0687]

The replacement section 32 replaces the  $2 \times 1 (= mb)$  code bits  $b_0$  and  $b_1$  read out from the memory 31 such that the  $2 \times 1 (= mb)$  code bits  $b_0$  and  $b_1$  may be allocated to the  $2 \times 1 (= mb)$  symbol bits  $y_0$  and  $y_1$  of one  $(= b)$  symbol as seen in FIG. 138.

[0688]

In particular, according to FIG. 138, the

replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_0$ , and

the code bit  $b_1$  to the symbol bit  $y_2$ .

[0689]

It is to be noted that, in this instance, also it is possible to consider that replacement is not carried out and the code bits  $b_0$  and  $b_1$  are determined as they are as the symbol bits  $y_0$  and  $y_1$ , respectively.

[0690]

FIG. 139 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2.

[0691]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(4 \times 2)) \times (4 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $4 \times 2 (= mb)$  bits in the row direction and supplied to the replacement section 32.

[0692]

The replacement section 32 replaces the  $4 \times 2$  (= mb) code bits  $b_0$  to  $b_7$  read out from the memory 31 such that the  $4 \times 2$  (= mb) code bits  $b_0$  to  $b_7$  may be allocated to the  $4 \times 2$  (= mb) symbol bits  $y_0$  to  $y_7$  of two (= b) successive symbols as seen in FIG. 139.

[0693]

In particular, according to FIG. 139, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_0$ ,  
 the code bit  $b_1$  to the symbol bit  $y_5$ ,  
 the code bit  $b_2$  to the symbol bit  $y_1$ ,  
 the code bit  $b_3$  to the symbol bit  $y_2$ ,  
 the code bit  $b_4$  to the symbol bit  $y_4$ ,  
 the code bit  $b_5$  to the symbol bit  $y_7$ ,  
 the code bit  $b_6$  to the symbol bit  $y_3$ , and  
 the code bit  $b_7$  to the symbol bit  $y_6$ .

[0694]

FIG. 140 shows an example of a bit allocation pattern which can be adopted where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2.

[0695]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and besides the modulation method is 16QAM and the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(4 \times 2)) \times (4 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $4 \times 2 (= mb)$  bits in the row direction and supplied to the replacement section 32.

[0696]

The replacement section 32 replaces the  $4 \times 2 (= mb)$  code bits  $b_0$  to  $b_7$  read out from the memory 31 such that the  $4 \times 2 (= mb)$  code bits  $b_0$  to  $b_7$  may be allocated to the  $4 \times 2 (= mb)$  symbol bits  $y_0$  to  $y_7$  of two  $(= b)$  successive symbols as seen in FIG. 240.

[0697]

In particular, according to FIG. 140, the replacement section 32 carries out replacement for allocating

- the code bit  $b_0$  to the symbol bit  $y_7$ ,
- the code bit  $b_1$  to the symbol bit  $y_1$ ,
- the code bit  $b_2$  to the symbol bit  $y_4$ ,
- the code bit  $b_3$  to the symbol bit  $y_2$ ,
- the code bit  $b_4$  to the symbol bit  $y_5$ ,

the code bit  $b_5$  to the symbol bit  $y_3$ ,  
 the code bit  $b_6$  to the symbol bit  $y_6$ , and  
 the code bit  $b_7$  to the symbol bit  $y_0$ .

[0698]

FIG. 141 shows an example of a bit allocation pattern which can be adopted where the modulation method is 64QAM and the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and besides the multiple  $b$  is 2.

[0699]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and the modulation method is 64QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(6 \times 2)) \times (6 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $6 \times 2 (= mb)$  bits in the row direction and supplied to the replacement section 32.

[0700]

The replacement section 32 replaces the  $6 \times 2 (= mb)$  code bits  $b_0$  to  $b_{11}$  read out from the memory 31 such that the  $6 \times 2 (= mb)$  code bits  $b_0$  to  $b_{11}$  may be allocated to the  $6 \times 2 (= mb)$  symbol bits  $y_0$  to  $y_{11}$  of two  $(= b)$  successive symbols as seen in FIG. 141.

[0701]

In particular, according to FIG. 141, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_2$ ,  
 the code bit  $b_1$  to the symbol bit  $y_7$ ,  
 the code bit  $b_2$  to the symbol bit  $y_6$ ,  
 the code bit  $b_3$  to the symbol bit  $y_9$ ,  
 the code bit  $b_4$  to the symbol bit  $y_0$ ,  
 the code bit  $b_5$  to the symbol bit  $y_3$ ,  
 the code bit  $b_6$  to the symbol bit  $y_1$ ,  
 the code bit  $b_7$  to the symbol bit  $y_8$ ,  
 the code bit  $b_8$  to the symbol bit  $y_4$ ,  
 the code bit  $b_9$  to the symbol bit  $y_{11}$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_5$ , and  
 the code bit  $b_{11}$  to the symbol bit  $y_{10}$ .

[0702]

FIG. 142 shows an example of a bit allocation pattern which can be adopted where the modulation method is 64QAM and the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and besides the multiple  $b$  is 2.

[0703]

Where the LDPC code is an LDPC code whose code

length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and the modulation method is 64QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(6 \times 2)) \times (6 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $6 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0704]

The replacement section 32 replaces the  $6 \times 2$  (= mb) code bits  $b_0$  to  $b_{11}$  read out from the memory 31 such that the  $6 \times 2$  (= mb) code bits  $b_0$  to  $b_{11}$  may be allocated to the  $6 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{11}$  of two (= b) successive symbols as seen in FIG. 142.

[0705]

In particular, according to FIG. 142, the replacement section 32 carries out replacement for allocating

- the code bit  $b_0$  to the symbol bit  $y_{11}$ ,
- the code bit  $b_1$  to the symbol bit  $y_7$ ,
- the code bit  $b_2$  to the symbol bit  $y_3$ ,
- the code bit  $b_3$  to the symbol bit  $y_{10}$ ,
- the code bit  $b_4$  to the symbol bit  $y_6$ ,
- the code bit  $b_5$  to the symbol bit  $y_2$ ,
- the code bit  $b_6$  to the symbol bit  $y_9$ ,

the code bit  $b_7$  to the symbol bit  $y_5$ ,  
 the code bit  $b_8$  to the symbol bit  $y_1$ ,  
 the code bit  $b_9$  to the symbol bit  $y_8$ ,  
 the code bit  $b_{10}$  to the symbol bit  $y_4$ , and  
 the code bit  $b_{11}$  to the symbol bit  $y_0$ .

[0706]

FIG. 143 shows an example of a bit allocation pattern which can be adopted where the modulation method is 256QAM and the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and besides the multiple  $b$  is 2.

[0707]

Where the LDPC code is an LDPC code whose code length  $N$  is 64,800 bits and whose encoding rate is  $3/5$  and the modulation method is 256QAM and besides the multiple  $b$  is 2, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(64,800/(8 \times 2)) \times (8 \times 2)$  bits in the column direction  $\times$  row direction are read out in a unit of  $8 \times 2$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0708]

The replacement section 32 replaces the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  read out from the memory 31 such that the  $8 \times 2$  (= mb) code bits  $b_0$  to  $b_{15}$  may be allocated

to the  $8 \times 2$  (= mb) symbol bits  $y_0$  to  $y_{15}$  of two (= b) successive symbols as seen in FIG. 143.

[0709]

In particular, according to FIG. 143, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_2$ ,  
the code bit  $b_1$  to the symbol bit  $y_{11}$ ,  
the code bit  $b_2$  to the symbol bit  $y_3$ ,  
the code bit  $b_3$  to the symbol bit  $y_4$ ,  
the code bit  $b_4$  to the symbol bit  $y_0$ ,  
the code bit  $b_5$  to the symbol bit  $y_9$ ,  
the code bit  $b_6$  to the symbol bit  $y_1$ ,  
the code bit  $b_7$  to the symbol bit  $y_8$ ,  
the code bit  $b_8$  to the symbol bit  $y_{10}$ ,  
the code bit  $b_9$  to the symbol bit  $y_{13}$ ,  
the code bit  $b_{10}$  to the symbol bit  $y_7$ ,  
the code bit  $b_{11}$  to the symbol bit  $y_{14}$ ,  
the code bit  $b_{12}$  to the symbol bit  $y_6$ ,  
the code bit  $b_{13}$  to the symbol bit  $y_{15}$ ,  
the code bit  $b_{14}$  to the symbol bit  $y_5$ , and  
the code bit  $b_{15}$  to the symbol bit  $y_{12}$ .

[0710]

FIG. 144 shows an example of a bit allocation

pattern which can be adopted where the modulation method is 256QAM and the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and besides the multiple  $b$  is 1.

[0711]

Where the LDPC code is an LDPC code whose code length  $N$  is 16,200 bits and whose encoding rate is  $3/5$  and the modulation method is 256QAM and besides the multiple  $b$  is 1, in the demultiplexer 25, the code bits written in the memory 31 for storing  $(16,200/(8 \times 1)) \times (8 \times 1)$  bits in the column direction  $\times$  row direction are read out in a unit of  $8 \times 1$  (= mb) bits in the row direction and supplied to the replacement section 32.

[0712]

The replacement section 32 replaces the  $8 \times 1$  (= mb) code bits  $b_0$  to  $b_7$  read out from the memory 31 such that the  $8 \times 1$  (= mb) code bits  $b_0$  to  $b_7$  may be allocated to the  $8 \times 1$  (= mb) symbol bits  $y_0$  to  $y_7$  of one (= b) symbol as seen in FIG. 144.

[0713]

In particular, according to FIG. 144, the replacement section 32 carries out replacement for allocating

the code bit  $b_0$  to the symbol bit  $y_7$ ,

the code bit  $b_1$  to the symbol bit  $y_3$ ,  
the code bit  $b_2$  to the symbol bit  $y_1$ ,  
the code bit  $b_3$  to the symbol bit  $y_5$ ,  
the code bit  $b_4$  to the symbol bit  $y_2$ ,  
the code bit  $b_5$  to the symbol bit  $y_6$ ,  
the code bit  $b_6$  to the symbol bit  $y_4$ , and  
the code bit  $b_7$  to the symbol bit  $y_0$ .

[0714]

Now, the deinterleaver 53 which composes the reception apparatus 12 is described.

[0715]

FIG. 145 is a view illustrating processing of the multiplexer 54 which composes the deinterleaver 53.

[0716]

In particular, FIG. 145A shows an example of a functional configuration of the multiplexer 54.

[0717]

The multiplexer 54 is composed of a reverse replacement section 1001 and a memory 1002.

[0718]

The multiplexer 54 determines symbol bits of symbols supplied from the demapping section 52 at the preceding stage as an object of processing thereof and carries out a reverse replacement process corresponding

to the replacement process carried out by the demultiplexer 25 of the transmission apparatus 11 (process reverse to the replacement process), that is, a reverse replacement process of returning the positions of the code bits (symbol bits) of the LDPC code replaced by the replacement process. Then, the multiplexer 54 supplies an LDPC code obtained as a result of the reverse replacement process to the column twist deinterleaver 55 at the succeeding stage.

[0719]

In particular, in the multiplexer 54,  $m_b$  symbol bits  $y_0, y_1, \dots, y_{m_b-1}$  of  $b$  symbols are supplied in a unit of  $b$  (successive) symbols to the reverse replacement section 1001.

[0720]

The reverse replacement section 1001 carries out reverse replacement of returning the arrangement of the  $m_b$  symbol bits  $y_0$  to  $y_{m_b-1}$  to the original arrangement of the  $m_b$  code bits  $b_0, b_1, \dots, b_{m_b-1}$  (arrangement of the code bits  $b_0$  to  $b_{m_b-1}$  before the replacement by the replacement section 32 which composes the demultiplexer 25 on the transmission apparatus 11 side is carried out). The reverse replacement section 1001 outputs code bits  $b_0$  to  $b_{m_b-1}$  obtained as a result of the reverse replacement.

[0721]

The memory 1002 has a storage capacity of storing  $mb$  bits in the row (horizontal) direction and storing  $N/(mb)$  bits in the column (vertical) direction similarly to the memory 31 which composes the demultiplexer 25 of the transmission apparatus 11 side. In other words, the reverse replacement section 1001 is configured from  $mb$  columns each of which stores  $N/(mb)$  bits.

[0722]

However, in the memory 1002, writing of the code bits of LDPC codes outputted from the reverse replacement section 1001 is carried out in a direction in which reading out of code bits from the memory 31 of the demultiplexer 25 of the transmission apparatus 11 is carried out, and reading out of code bits written in the memory 1002 is carried out in a direction in which writing of code bits into the memory 31 is carried out.

[0723]

In particular, the multiplexer 54 of the reception apparatus 12 successively carries out writing of code bits of an LDPC code outputted from the reverse replacement section 1001 in a unit of  $mb$  bits in the row direction beginning with the first row of the memory 1002 toward a lower row as seen in FIG. 145A.

[0724]

Then, when the writing of code bits for one code length ends, the multiplexer 54 reads out the code bits in the column direction from the memory 1002 and supplies the code bits to the column twist deinterleaver 55 at the succeeding stage.

[0725]

Here, FIG. 145B is a view illustrating reading out of the code bits from the memory 1002.

[0726]

The multiplexer 54 carries out reading out of code bits of an LDPC code in a downward direction (column direction) from above of a column which composes the memory 1002 beginning with a leftmost column toward a right side column.

[0727]

Now, processing of the column twist deinterleaver 55 which composes the deinterleaver 53 of the reception apparatus 12 is described with reference to FIG. 146.

[0728]

FIG. 146 shows an example of a configuration of the memory 1002 of the multiplexer 54.

[0729]

The memory 1002 has a storage capacity for storing

mb bits in the column (vertical) direction and stores  $N/(mb)$  bits in the row (horizontal) direction and is composed of mb columns.

[0730]

The column twist deinterleaver 55 writes code bits of an LDPC code in the row direction into the memory 1002 and controls the position at which reading out is started when the code bits are read out in the column direction to carry out column twist deinterleave.

[0731]

In particular, the column twist deinterleaver 55 carries out a reverse re-arrangement process of suitably changing the reading out starting position at which reading out of code bits with regard to each of a plurality of columns is to be started to return the arrangement of code bits re-arranged by the column twist interleave to the original arrangement.

[0732]

Here, FIG. 146 shows an example of a configuration of the memory 1002 where the modulation method is 16QAM and the multiple b is 1. Accordingly, the bit number m of one symbol is 4 bits, and the memory 1002 includes four (= mb) columns.

[0733]

The column twist deinterleaver 55 carries out (in place of the multiplexer 54), writing of code bits of an LDPC code outputted from the replacement section 1001 in the row direction successively into the memory 1002 beginning with the first row toward a lowermost row.

[0734]

Then, if writing of code bits for one code length ends, then the column twist deinterleaver 55 carries out reading out of code bits in the downward direction (column direction) from a top of the memory 1002 beginning with a leftmost column toward a right side column.

[0735]

However, the column twist deinterleaver 55 carries out reading out of the code bits from the memory 1002 determining the writing starting position upon writing of the code bits by the column twist interleaver 24 on the transmission apparatus 11 side to a reading out starting position of the code bits.

[0736]

In particular, if the address of the position of the top of each column is determined as 0 and the address of each position in the column direction is represented by an integer given in an ascending order, then where the

modulation method is 16QAM and the multiple  $b$  is 1, the column twist deinterleaver 55 sets the reading out starting position for the leftmost column to the position whose address is 0, sets the reading out starting position for the second column (from the left) to the position whose address is 2, sets the reading out starting position for the third column to the position whose address is 4, and sets the reading out starting position for the fourth column to the position whose address is 7.

[0737]

It is to be noted that, with regard to each of those columns whose reading out starting position has an address other than 0, reading out of code bits is carried out such that, after such reading out is carried out down to the lowermost position, the reading out position is returned to the top (position whose address is 0) of the column and the reading out is carried out downwardly to the position immediately preceding to the reading out starting position. Then, after that, reading out is carried out from the next (right) column.

[0738]

By carrying out such column twist interleave as described above, the arrangement of the code bits re-

arranged by the column twist interleave is returned to the original arrangement.

[0739]

FIG. 147 is a block diagram showing another example of the configuration of the reception apparatus 12.

[0740]

Referring to FIG. 147, the reception apparatus 12 is a data processing apparatus which receives a modulation signal from the transmission apparatus 11 and includes an orthogonal demodulation section 51, a demapping section 52, a deinterleaver 53 and an LDPC decoding section 1021.

[0741]

The orthogonal demodulation section 51 receives a modulation signal from the transmission apparatus 11, carries out orthogonal demodulation and supplies symbols (values in the I and Q axis directions) obtained as a result of the orthogonal demodulation to the demapping section 52.

[0742]

The demapping section 52 carries out demapping of converting the symbols from the orthogonal demodulation section 51 into code bits of an LDPC code and supplies the code bits to the deinterleaver 53.

[0743]

The deinterleaver 53 includes a multiplexer (MUX) 54, a column twist deinterleaver 55 and a parity deinterleaver 1011 and carries out deinterleave of the code bits of the LDPC code from the demapping section 52.

[0744]

In particular, the multiplexer 54 determines an LDPC code from the demapping section 52 as an object of processing thereof and carries out a reverse replacement process corresponding to the replacement process carried out by the demultiplexer 25 of the transmission apparatus 11 (reverse process to the replacement process), that is, a reverse replacement process of returning the positions of the code bits replaced by the replacement process to the original positions. Then, the multiplexer 54 supplies an LDPC code obtained as a result of the reverse replacement process to the column twist deinterleaver 55.

[0745]

The column twist deinterleaver 55 determines the LDPC code from the multiplexer 54 as an object of processing and carries out column twist deinterleave corresponding to the column twist interleave as a rearrangement process carried out by the column twist interleaver 24 of the transmission apparatus 11.

[0746]

The LDPC code obtained as a result of the column twist deinterleave is supplied from the column twist deinterleaver 55 to the parity deinterleaver 1011.

[0747]

The parity deinterleaver 1011 determines the code bits after the column twist deinterleave by the column twist deinterleaver 55 as an object of processing thereof and carries out parity deinterleave corresponding to the parity interleave carried out by the parity interleaver 23 of the transmission apparatus 11 (reverse process to the parity interleave), that is, parity deinterleave of returning the arrangement of the code bits of the LDPC code whose arrangement was changed by the parity interleave to the original arrangement.

[0748]

The LDPC code obtained as a result of the parity deinterleave is supplied from the parity deinterleaver 1011 to the LDPC decoding section 1021.

[0749]

Accordingly, in the reception apparatus 12 of FIG. 147, the LDPC code for which the reverse replacement process, column twist deinterleave and parity deinterleave have been carried out, that is, an LDPC code

obtained by LDPC coding in accordance with the parity check matrix H, is supplied to the LDPC decoding section 1021.

[0750]

The LDPC decoding section 1021 carries out LDPC decoding of the LDPC code from the deinterleaver 53 using the parity check matrix H itself used for LDPC encoding by the LDPC encoding section 21 of the transmission apparatus 11 or a conversion parity check matrix obtained by carrying out at least column conversion corresponding to the parity interleave for the parity check matrix H. Then, the LDPC decoding section 1021 outputs data obtained by the LDPC decoding as a decoding result of the object data.

[0751]

Here, in the reception apparatus 12 of FIG. 147, since an LDPC code obtained by LDPC encoding in accordance with the parity check matrix H is supplied from the (parity deinterleaver 1011 of) the deinterleaver 53 to the LDPC decoding section 1021, where the LDPC decoding of the LDPC code is carried out using the parity check matrix H itself used for the LDPC encoding by the LDPC encoding section 21 of the transmission apparatus 11, the LDPC decoding section 1021 can be configured, for

example, from a decoding apparatus which carries out LDPC decoding in accordance with a full serial decoding method wherein mathematical operation of messages (check node messages and variable node messages) is carried out for one by one node or another decoding apparatus wherein LDPC decoding is carried out in accordance with a full parallel decoding method wherein mathematical operation of messages are carried out simultaneously (in parallel) for all nodes.

[0752]

Further, where LDPC decoding of an LDPC code is carried out using a conversion parity check matrix obtained by carrying out at least column replacement corresponding to the parity interleave for the parity check matrix  $H$  used in the LDPC encoding by the LDPC encoding section 21 of the transmission apparatus 11, the LDPC decoding section 1021 can be confirmed from a decoding apparatus of an architecture which carries out the check node mathematical operation and the variable node mathematical operation simultaneously for  $P$  (or a divisor of  $P$  other than 1) check nodes and  $P$  variable nodes and which has a reception data re-arrangement section 310 for carrying out column replacement similar to the column replacement for obtaining a conversion

parity check matrix for the LDPC code to re-arrange the code bits of the LDPC codes.

[0753]

It is to be noted that, while, in FIG. 147, the multiplexer 54 for carrying out the reverse replacement process, column twist deinterleaver 55 for carrying out the column twist deinterleave and parity deinterleaver 1011 for carrying out the parity deinterleave are configured separately from each other for the convenience of description, two or more of the multiplexer 54, column twist deinterleaver 55 and parity deinterleaver 1011 can be configured integrally similarly to the parity interleaver 23, column twist interleaver 24 and demultiplexer 25 of the transmission apparatus 11.

[0754]

FIG. 148 is a block diagram showing a first example of a configuration of a reception system which can be applied to the reception apparatus 12.

[0755]

Referring to FIG. 148, the reception system includes an acquisition section 1101, a transmission line decoding processing section 1102 and an information source decoding processing section 1103.

[0756]

The acquisition section 1101 acquires a signal including an LDPC code obtained at least by LDPC encoding object data such as image data and music data of a program through a transmission line such as, for example, terrestrial digital broadcasting, satellite digital broadcasting, a CATV network, the Internet or some other network. Then, the acquisition section 1101 supplies the acquired signal to the transmission line decoding processing section 1102.

[0757]

Here, where the signal acquired by the acquisition section 1101 is broadcast, for example, from a broadcasting station through ground waves, satellite waves, a CATV (Cable Television) or the like, the acquisition section 1101 is configured from a tuner, an STB (Set Top Box) or the like. On the other hand, where the signal acquired by the acquisition section 1101 is transmitted in a multicast state as in the IPTV (Internet Protocol Television), for example, from a web server, the acquisition section 11 is configured from a network I/F (Inter face) such as, for example, an NIC (Network Interface Card).

[0758]

The transmission line decoding processing section

1102 carries out a transmission line decoding process including at least a process for correcting errors produced in the transmission line for the signal acquired through the transmission line by the acquisition section 1101, and supplies a signal obtained as a result of the transmission line decoding process to the information source decoding processing section 1103.

[0759]

In particular, the signal acquired through the transmission line by the acquisition section 1101 is a signal obtained by carrying out at least error correction encoding for correcting errors produced in the transmission line, and for such a signal as just described, the transmission line decoding processing section 1102 carries out a transmission line decoding process such as, for example, an error correction process.

[0760]

Here, as the error correction encoding, for example, LDPC encoding, Reed-Solomon encoding and so forth are available. Here, as the error correction encoding, at least LDPC encoding is carried out.

[0761]

Further, the transmission line decoding process sometimes includes demodulation of a modulation signal

and so forth.

[0762]

The information source decoding processing section 1103 carries out an information source decoding process including at least a process for decompressing compressed information into original information for the signal for which the transmission line decoding process has been carried out.

[0763]

In particular, the signal acquired through the transmission line by the acquisition section 1101 has sometimes been processed by compression encoding for compressing information in order to reduce the data amount such as images, sound and so forth as information. In this instance, the information source decoding processing section 1103 carries out an information source decoding process such as a process (decompression process) for decompressing the compressed information into original information for a signal for which the transmission line decoding process has been carried out.

[0764]

It is to be noted that, where the signal acquired through the transmission line by the acquisition section 1101 has not been carried out compression encoding, the

information source decoding processing section 1103 does not carry out the process of decompressing the compressed information into the original information.

[0765]

Here, as the decompression process, for example, MPEG decoding and so forth are available. Further, the transmission line decoding process sometimes includes descrambling in addition to the decompression process.

[0766]

In the reception system configured in such a manner as described above, the acquisition section 1101 receives a signal obtained by carrying out compression encoding such as MPEG encoding for data of, for example, images, sound and so forth and further carrying out error correction encoding such as LDPC encoding for the compression encoded data through a transmission line. The signal is supplied to the transmission line decoding processing section 1102.

[0767]

In the transmission line decoding processing section 1102, processes similar to those carried out, for example, by the orthogonal demodulation section 51, demapping section 52, deinterleaver 53 and LDPC decoding section 56 (or LDPC decoding section 1021) are carried

out as the transmission line decoding process for the signal from the acquisition section 1101. Then, a signal obtained as a result of the transmission line decoding process is supplied to the information source decoding processing section 1103.

[0768]

In the information source decoding processing section 1103, an information source decoding process such as MPEG decoding is carried out for the signal from the transmission line decoding processing section 1102, and an image or sound obtained as a result of the information decoding process is outputted.

[0769]

Such a reception system of FIG. 148 as described above can be applied, for example, to a television tuner for receiving television broadcasting as digital broadcasting and so forth.

[0770]

It is to be noted that it is possible to configure the acquisition section 1101, transmission line decoding processing section 1102 and information source decoding processing section 1103 each as an independent apparatus (hardware (IC (Integrated Circuit) or the like) or a software module).

[0771]

Further, as regards the acquisition section 1101, transmission line decoding processing section 1102 and information source decoding processing section 1103, a set of the acquisition section 1101 and transmission line decoding processing section 1102, another set of the transmission line decoding processing section 1102 and information source decoding processing section 1103 or a further set of the acquisition section 1101, transmission line decoding processing section 1102 and information source decoding processing section 1103 can be configured as a single independent apparatus.

[0772]

FIG. 149 is a block diagram showing a second example of the configuration of the reception system which can be applied to the reception apparatus 12.

[0773]

It is to be noted that, in FIG. 149, elements corresponding those in FIG. 148 are denoted by like reference numerals, and description of them is suitably omitted in the following description.

[0774]

The reception system of FIG. 149 is common to that of FIG. 148 in that it includes an acquisition section

1101, a transmission line decoding processing section 1102 and an information source decoding processing section 1103 but is different from that of FIG. 148 in that it newly includes an outputting section 1111.

[0775]

The outputting section 1111 is, for example, a display apparatus for displaying an image or a speaker for outputting sound and outputs an image, a sound of the like as a signal outputted from the information source decoding processing section 1103. In other words, the outputting section 1111 displays an image or outputs sound.

[0776]

Such a reception system of FIG. 149 as described above can be applied, for example, to a TV (television receiver) for receiving a television broadcast as a digital broadcast, a radio receiver for receiving a radio broadcast and so forth.

[0777]

It is to be noted that, where the signal acquired by the acquisition section 1101 is not in a form wherein compression encoding is not applied, a signal outputted from the transmission line decoding processing section 1102 is supplied to the outputting section 1111.

[0778]

FIG. 150 is a block diagram showing a third example of the configuration of the reception system which can be applied to the reception apparatus 12.

[0779]

It is to be noted that, in FIG. 150, corresponding elements to those of FIG. 148 are denoted by like reference numerals, and in the following description, description of them is suitably omitted.

[0780]

The reception system of FIG. 150 is common to that of FIG. 148 in that it includes an acquisition section 1101 and a transmission line decoding processing section 1102.

[0781]

However, the reception system of FIG. 150 is different from that of FIG. 148 in that it does not include the information source decoding processing section 1103 but newly includes a recording section 1121.

[0782]

The recording section 1121 records (stores) a signal (for example, a TS packet of a TS of MPEG) outputted from the transmission line decoding processing section 1102 on or into a recording (storage) medium such

as an optical disk, a hard disk (magnetic disk) or a flash memory.

[0783]

Such a reception system of FIG. 150 as described above can be applied to a recorder for recording a television broadcast or the like.

[0784]

It is to be noted that, in FIG. 150, the reception system may include the information source decoding processing section 1103 such that a signal after an information source decoding process has been carried out by the information source decoding processing section 1103, that is, an image or sound obtained by decoding, is recorded by the recording section 1121.

[0785]

It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

## Claims

1. An encoding apparatus for carrying out encoding by an LDPC (Low Density Parity Check) code, comprising:

encoding means for carrying out encoding by an LDPC code which has a code length of 64,800 bits and an encoding rate of  $2/3$ ;

a parity check matrix of the LDPC code being configured such that elements of the value 1 of an information matrix, which corresponds to the code length of the parity check matrix and an information length corresponding to the encoding rate, decided by a parity check matrix initial value table representative of the

positions of the elements of the value 1 of the information matrix are arranged in a period of every 360 columns in the column direction;

the parity check matrix initial value table being formed from

317 2255 2324 2723 3538 3576 6194 6700 9101 10057 12739

17407 21039

1958 2007 3294 4394 12762 14505 14593 14692 16522 17737

19245 21272 21379

127 860 5001 5633 8644 9282 12690 14644 17553 19511 19681

20954 21002

2514 2822 5781 6297 8063 9469 9551 11407 11837 12985

15710 20236 20393

1565 3106 4659 4926 6495 6872 7343 8720 15785 16434 16727

19884 21325

706 3220 8568 10896 12486 13663 16398 16599 19475 19781

20625 20961 21335

4257 10449 12406 14561 16049 16522 17214 18029 18033

18802 19062 19526 20748

412 433 558 2614 2978 4157 6584 9320 11683 11819 13024

14486 16860

777 5906 7403 8550 8717 8770 11436 12846 13629 14755

15688 16392 16419

4093 5045 6037 7248 8633 9771 10260 10809 11326 12072

17516 19344 19938

2120 2648 3155 3852 6888 12258 14821 15359 16378 16437

17791 20614 21025

1085 2434 5816 7151 8050 9422 10884 12728 15353 17733

18140 18729 20920

856 1690 12787

6532 7357 9151

4210 16615 18152

11494 14036 17470

2474 10291 10323

1778 6973 10739

4347 9570 18748

2189 11942 20666

3868 7526 17706

8780 14796 18268

160 16232 17399

1285 2003 18922

4658 17331 20361

2765 4862 5875

4565 5521 8759

3484 7305 15829

5024 17730 17879

7031 12346 15024

179 6365 11352

2490 3143 5098

2643 3101 21259

4315 4724 13130

594 17365 18322

5983 8597 9627

10837 15102 20876

10448 20418 21478

3848 12029 15228

708 5652 13146

5998 7534 16117

2098 13201 18317

9186 14548 17776

5246 10398 18597

3083 4944 21021

13726 18495 19921

6736 10811 17545

10084 12411 14432

1064 13555 17033

679 9878 13547

3422 9910 20194

3640 3701 10046

5862 10134 11498

5923 9580 15060

1073 3012 16427

5527 20113 20883  
7058 12924 15151  
9764 12230 17375  
772 7711 12723  
555 13816 15376  
10574 11268 17932  
15442 17266 20482  
390 3371 8781  
10512 12216 17180  
4309 14068 15783  
3971 11673 20009  
9259 14270 17199  
2947 5852 20101  
3965 9722 15363  
1429 5689 16771  
6101 6849 12781  
3676 9347 18761  
350 11659 18342  
5961 14803 16123  
2113 9163 13443  
2155 9808 12885  
2861 7988 11031  
7309 9220 20745  
6834 8742 11977

2133 12908 14704

10170 13809 18153

13464 14787 14975

799 1107 3789

3571 8176 10165

5433 13446 15481

3351 6767 12840

8950 8974 11650

1430 4250 21332

6283 10628 15050

8632 14404 16916

6509 10702 16278

15900 16395 17995

8031 18420 19733

3747 4634 17087

4453 6297 16262

2792 3513 17031

14846 20893 21563

17220 20436 21337

275 4107 10497

3536 7520 10027

14089 14943 19455

1965 3931 21104

2439 11565 17932

154 15279 21414  
10017 11269 16546  
7169 10161 16928  
10284 16791 20655  
36 3175 8475  
2605 16269 19290  
8947 9178 15420  
5687 9156 12408  
8096 9738 14711  
4935 8093 19266  
2667 10062 15972  
6389 11318 14417  
8800 18137 18434  
5824 5927 15314  
6056 13168 15179  
3284 13138 18919  
13115 17259 17332.

2. An encoding method for an encoding apparatus which carries out encoding by an LDPC (Low Density Parity Check) code, comprising:

a step carried out by said encoding apparatus of carrying out encoding by an LDPC code which has a code length of 64,800 bits and an encoding rate of  $2/3$ ;

a parity check matrix of the LDPC code being

configured such that elements of the value 1 of an information matrix, which corresponds to the code length of the parity check matrix and an information length corresponding to the encoding rate, decided by a parity check matrix initial value table representative of the positions of the elements of the value 1 of the information matrix are arranged in a period of every 360 columns in the column direction;

the parity check matrix initial value table being formed from

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317 2255 2324 2723 3538 3576 6194 6700 9101 10057 12739
17407 21039
1958 2007 3294 4394 12762 14505 14593 14692 16522 17737
19245 21272 21379
127 860 5001 5633 8644 9282 12690 14644 17553 19511 19681
20954 21002
2514 2822 5781 6297 8063 9469 9551 11407 11837 12985
15710 20236 20393
1565 3106 4659 4926 6495 6872 7343 8720 15785 16434 16727
19884 21325
706 3220 8568 10896 12486 13663 16398 16599 19475 19781
20625 20961 21335
4257 10449 12406 14561 16049 16522 17214 18029 18033
18802 19062 19526 20748

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412 433 558 2614 2978 4157 6584 9320 11683 11819 13024

14486 16860

777 5906 7403 8550 8717 8770 11436 12846 13629 14755

15688 16392 16419

4093 5045 6037 7248 8633 9771 10260 10809 11326 12072

17516 19344 19938

2120 2648 3155 3852 6888 12258 14821 15359 16378 16437

17791 20614 21025

1085 2434 5816 7151 8050 9422 10884 12728 15353 17733

18140 18729 20920

856 1690 12787

6532 7357 9151

4210 16615 18152

11494 14036 17470

2474 10291 10323

1778 6973 10739

4347 9570 18748

2189 11942 20666

3868 7526 17706

8780 14796 18268

160 16232 17399

1285 2003 18922

4658 17331 20361

2765 4862 5875

4565 5521 8759

3484 7305 15829

5024 17730 17879

7031 12346 15024

179 6365 11352

2490 3143 5098

2643 3101 21259

4315 4724 13130

594 17365 18322

5983 8597 9627

10837 15102 20876

10448 20418 21478

3848 12029 15228

708 5652 13146

5998 7534 16117

2098 13201 18317

9186 14548 17776

5246 10398 18597

3083 4944 21021

13726 18495 19921

6736 10811 17545

10084 12411 14432

1064 13555 17033

679 9878 13547

3422 9910 20194  
3640 3701 10046  
5862 10134 11498  
5923 9580 15060  
1073 3012 16427  
5527 20113 20883  
7058 12924 15151  
9764 12230 17375  
772 7711 12723  
555 13816 15376  
10574 11268 17932  
15442 17266 20482  
390 3371 8781  
10512 12216 17180  
4309 14068 15783  
3971 11673 20009  
9259 14270 17199  
2947 5852 20101  
3965 9722 15363  
1429 5689 16771  
6101 6849 12781  
3676 9347 18761  
350 11659 18342  
5961 14803 16123

2113 9163 13443  
2155 9808 12885  
2861 7988 11031  
7309 9220 20745  
6834 8742 11977  
2133 12908 14704  
10170 13809 18153  
13464 14787 14975  
799 1107 3789  
3571 8176 10165  
5433 13446 15481  
3351 6767 12840  
8950 8974 11650  
1430 4250 21332  
6283 10628 15050  
8632 14404 16916  
6509 10702 16278  
15900 16395 17995  
8031 18420 19733  
3747 4634 17087  
4453 6297 16262  
2792 3513 17031  
14846 20893 21563  
17220 20436 21337

275 4107 10497

3536 7520 10027

14089 14943 19455

1965 3931 21104

2439 11565 17932

154 15279 21414

10017 11269 16546

7169 10161 16928

10284 16791 20655

36 3175 8475

2605 16269 19290

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4935 8093 19266

2667 10062 15972

6389 11318 14417

8800 18137 18434

5824 5927 15314

6056 13168 15179

3284 13138 18919

13115 17259 17332.

DATA PROCESSING APPARATUS AND DATA PROCESSING METHOD AS  
WELL AS ENCODING APPARATUS AND ENCODING METHOD

Abstract

The invention relates to a data processing apparatus and a data processing method as well as an encoding apparatus and an encoding method which can improve the tolerance to errors.

Of an LDPC code which is prescribed in the DVB-S.2 and has a code length of 64,800 and an encoding rate of  $2/3$ ,  $m$  code bits are replaced, and the code bits after the replacement become symbol bits of  $b$  symbols. When  $m$  is 8 and  $b$  is 2, where the  $i$ -th bit from the most significant bit of  $8 \times 2$  code bits and  $8 \times 2$  symbol bits of two successive symbols are represented by  $b_i$  and  $y_i$ , respectively, replacement of allocating  $b_0$  to  $y_{15}$ ,  $b_1$  to  $y_7$ ,  $b_2$  to  $y_1$ ,  $b_3$  to  $y_5$ ,  $b_4$  to  $y_6$ ,  $b_5$  to  $y_{13}$ ,  $b_6$  to  $y_{11}$ ,  $b_7$  to  $y_9$ ,  $b_8$  to  $y_8$ ,  $b_9$  to  $y_{14}$ ,  $b_{10}$  to  $y_{12}$ ,  $b_{11}$  to  $y_3$ ,  $b_{12}$  to  $y_0$ ,  $b_{13}$  to  $y_{10}$ ,  $b_{14}$  to  $y_4$  and  $b_{15}$  to  $y_2$ . The present invention can be applied, for example, to a transmission system for transmitting an LDPC code and so forth.

Fig. 64