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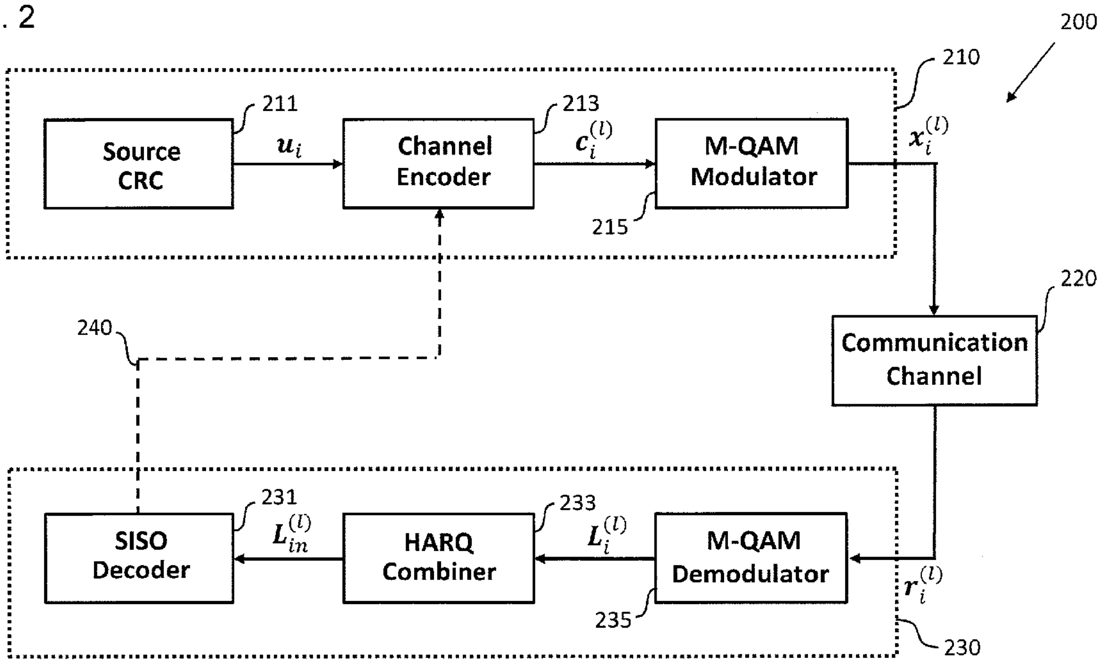
(54) **Title:** CONSTRUCTION OF QC-LDPC CODES FOR A HYBRID AUTOMATIC REPEAT REQUEST (HARQ) SCHEME

Fig. 2



(57) **Abstract:** The invention relates to a device and method for generating a QC- LDPC code for a HARQ communication apparatus using incremental redundancy. A first and a second protograph matrix P and P' of size m x n and (m + d) x (n + d), respectively, are generated, wherein the first protograph matrix P defines a first code H used for a first transmission and the second protograph matrix P' defines a second code H' used for a retransmission. The second protograph matrix P' is generated by: (i) setting the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1n) of the first protograph matrix P; (ii) setting the elements (1:m, n+1:n +d) of the second protograph matrix P' equal to -1 ("-1" representing a z x z zero matrix); (iii) pre-setting the elements (m+1:m+d, 1:n +d) of the second protograph matrix P' equal to -1; (iv) setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1 (representing a shifted z x z identity matrix); and (v) setting

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the diagonal elements of the submatrix defined by the elements (m+1 :m+d, n+1 :n+d) of the second protograph matrix P' equal to 0 ("0" representing a z x z identity matrix). Alternately, alternatively or in combination, row spitting can be used for constructing the second protograph matrix P'.

DEVICES AND METHODS FOR GENERATING A CODE FOR A HARQ COMMUNICATION APPARATUS

TECHNICAL FIELD

The present invention relates to the field of channel coding. More specifically, the invention relates to devices and methods for generating a code for a communication apparatus as well as a communication apparatus using such a code, in particular in the context of a hybrid automatic repeat request (HARQ) scheme.

BACKGROUND

Hybrid automatic repeat request (HARQ) schemes are used in communication systems to provide both efficient and reliable data transmissions. Incremental Redundancy (IR) is a HARQ method for combining the payloads from different retransmissions. A fixed retransmitted payload is currently used in the LTE system as a baseline.

Some known HARQ schemes are based on matrix-based low density parity check (LDPC).

US 20110239075 discloses a channel coding, modulating and mapping method for a HARQ scheme based on a LDPC. A uniform matrix H is considered for different code lengths. Modular or floor lifting is used to obtain a matrix with a new size of the circulant. Moreover, a constellation rearrangement strategy is disclosed, where high-order bits are mapped to reliable points in the constellation.

US 2011138260 discloses a row-splitting scheme to obtain the matrix for the second retransmission of the HARQ scheme. Some rows are split and some new columns are added. The splitting degree may be different for different rows.

Using low-rate codes and transmitting different sets of parity bits at different transmissions is disclosed, for instance, in US 2007113147, US 2010192037 and US 2007220399. US 2007113147 proposes arranging transmitted parity bits at regular intervals. In US 2010192037 the transmission order of parity bits is based on their column degree. In US 2007220399 the order of transmission is based on the notion of k-step recoverable nodes.

Although the conventional approaches described above already provide some improvements compared to other prior art approaches, there is still a need for improved devices and methods for generating a code for a HARQ communication apparatus.

SUMMARY

It is an object of the invention to provide improved devices and methods for generating a code for a HARQ communication apparatus.

The foregoing and other objects are achieved by the subject matter of the independent claims. Further implementation forms are apparent from the dependent claims, the description and the figures.

According to a first aspect the invention relates to a device for generating on the basis of a first protograph matrix P of size $(m \times n)$, wherein the first protograph matrix P defines a first code H, a second protograph matrix P' of size $(m + d \times n + d)$, wherein the second protograph matrix P' defines a second code H', wherein the device comprises a processor configured to generate the second protograph matrix P' by: (i) setting the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P; (ii) setting the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1; (iii) pre-setting the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1; (iv) setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1; and (v) setting the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0.

In a first possible implementation form of the device according to the first aspect, the processor is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to 0.

In a second possible implementation form of the device according to the first aspect, the processor is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to p.

In a third possible implementation form of the device according to the first aspect, the first protograph matrix has a circulant size z and the processor is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to (-1-zero block circulant).

In a fourth possible implementation form of the device according to the first aspect as such or any one of the first to third implementation form thereof, a parameter D is associated with the number of diagonals of the first protograph matrix P and the processor is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1 by (i) determining a $(1 \times n)$ vector $ColWeight$ such that $ColWeight(j)$ is equal to the number of elements of the j-th column of the first protograph matrix P, which are not equal to -1, (ii) determining a sequence $i_1, i_2, \dots, i_n$ such that $ColWeight(i_1) \leq ColWeight(i_2) \dots \leq ColWeight(i_n)$, and (iii) generating for each value of the index j from 1 to d a set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ including all indices with k > 0 and setting for the respective value of the index j for each k being element of the set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ the respective element of the second protograph matrix identified by j and k to a value different from -1.

In a fifth possible implementation form of the device according to the fourth implementation form of the first aspect, the following relation holds between the parameter D and the values d and n: $D \leq d \leq n$.

In a sixth possible implementation form of the device according to the first aspect as such or any one of the first to fifth implementation form thereof, the first protograph matrix P and the second protograph matrix P' have the same circulant size z.

In a seventh possible implementation form of the device according to the first aspect as such or any one of the first to sixth implementation form thereof, the first protograph matrix P and the second protograph matrix P' are repeat accumulate matrices.

According to a second aspect the invention relates to a communication apparatus comprising a channel encoder comprising a device for generating a protograph matrix according to the first aspect of the invention.

According to a third aspect the invention relates to a communication apparatus comprising a channel encoder comprising a first protograph matrix P or a corresponding first code H and a second protograph matrix P' or a corresponding second code H', wherein the channel encoder is configured to use the first code H for a first transmission of a HARQ scheme and the second code H' for a retransmission of the HARQ scheme and wherein the first protograph matrix P or the corresponding first code H and the second protograph matrix P' or the corresponding second code H' have been provided by a device for generating a protograph matrix according to the first aspect of the invention.

In a first possible implementation form of the communication apparatus according to the second aspect as such or the communication apparatus according to the third aspect as such, the channel encoder is configured to use the first code H for a first transmission of the HARQ scheme and the second code H' for a retransmission of the HARQ scheme for code rates smaller than a code rate threshold and to use a third code H* for a retransmission of the HARQ scheme for code rates larger than a code rate threshold, wherein the third code H* is based on a third protograph matrix, which has been derived from the first protograph matrix using a row splitting scheme. In an implementation form, the code rate threshold has a value of 0.6.

According to a fourth aspect the invention relates to a method for generating on the basis of a first protograph matrix P of size $(m \times n)$, wherein the first protograph matrix P defines a first code H, a second protograph matrix P' of size $(m + d \times n + d)$, wherein the second protograph matrix P' defines a second code H', wherein the method comprises: setting the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P; setting the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1; pre-setting the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1; setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1; and setting the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0.

In a first possible implementation form of the method according to the fourth aspect of the invention as such, a parameter D is associated with the number of diagonals of the first protograph matrix P and the step of setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1 comprises the following steps: (i) determining a $(1 \times n)$ vector $ColWeight$ such that $ColWeight(j)$ is equal to the number of elements of the j-th column of the first protograph matrix P, which are not equal to -1; (ii) determining a sequence $i_1, i_2, \ldots, i_n$ such that $ColWeight(i_1) \leq ColWeight(i_2) \ldots \leq ColWeight(i_n)$; and (iii) generating for each value of the index j from 1 to d a set of indices $\{i_{j-D+1}, i_{j-D+2}, \ldots, i_j\}$ including all indices with k > 0 and setting for the respective value of the index j for each k being element of the set of indices $\{i_{j-D+1}, i_{j-D+2}, \ldots, i_j\}$ the respective element of the second protograph matrix identified by j and k to a value different from -1.

The method according to the fourth aspect of the invention can be performed by the device according to the first aspect of the invention. Further features and implementation forms of the method according to the fourth aspect of the invention result directly from the functionality of the device according to the first aspect of the invention and its different implementation forms.

According to a fifth aspect the invention relates to a computer program comprising program code for performing the method according to the fourth aspect when executed on a computer.

The invention can be implemented in hardware and/or software.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments of the invention will be described with respect to the following figures, wherein:

Fig. 1 shows a schematic diagram illustrating an apparatus for generating a code for a HAQR communication apparatus according to an embodiment;

Fig. 2 shows a schematic diagram illustrating a communication system comprising a HARQ communication apparatus according to an embodiment;

Fig. 3 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment;

Fig. 4 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment;

Fig. 5 shows a schematic diagram illustrating a first matrix and a second matrix generated by an apparatus for generating a code according to an embodiment;

Fig. 6 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment;

Fig. 7 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment; and

Fig. 8 shows a schematic diagram illustrating a method for generating a code for a HARQ communication apparatus according to an embodiment.

In the various figures, identical reference signs will be used for identical or at least functionally equivalent features.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following description, reference is made to the accompanying drawings, which form part of the disclosure, and in which are shown, by way of illustration, specific aspects in which the present invention may be placed. It is understood that other aspects may be utilized and structural or logical changes may be made without departing from the scope of the invention. The following detailed description, therefore, is not to be taken in a limiting sense, as the scope of the invention is defined be the appended claims.

For instance, it is understood that a disclosure in connection with a described method may also hold true for a corresponding device or system configured to perform the method and vice versa. For example, if a specific method step is described, a corresponding device may include a unit to perform the described method step, even if such unit is not explicitly described or illustrated in the figures. Further, it is understood that the features of the various exemplary aspects described herein may be combined with each other, unless specifically noted otherwise.

Figure 1 shows a schematic diagram illustrating a device 100 for generating a code for a HARQ communication apparatus, for instance, the HARQ communication apparatus 210 of the communication system 200 shown in figure 2.

Before describing the device 100 shown in figure 1 and the HARQ communication apparatus 210 shown in figure 2 in more detail, the following definitions and notation will be introduced. Let P be a $(m \times n)$ protograph matrix and z is a circulant size, that is,

$$P = \begin{array}{|c|c|c|c|c|}\hline p_{1,1} & p_{1,2} & \cdots & p_{1,n-1} & p_{1,n} \\ \hline p_{2,1} & p_{2,2} & \cdots & p_{2,n-1} & p_{2,n} \\ \hline \cdots & \cdots & \cdots & \cdots & \cdots \\ \hline p_{m-1,1} & p_{m-1,2} & \cdots & p_{m-1,n-1} & p_{m-1,n} \\ \hline p_{m,1} & p_{m,2} & \cdots & p_{m,n-1} & p_{m,n} \\ \hline \end{array}$$

such that $-1 \leq p_{i,j} \leq z-1$.

The LDPC code, in particular QC-LDPC code, of length $n \cdot z$ corresponding to the protograph matrix P is defined by the $(m \cdot z \times n \cdot z)$ parity-check base matrix H

$$H = H(P) = \begin{array}{|c|c|c|c|c|}\hline A_{1,1} & A_{1,2} & \cdots & A_{1,n-1} & A_{1,n} \\ \hline A_{2,1} & A_{2,2} & \cdots & A_{2,n-1} & A_{2,n} \\ \hline \cdots & \cdots & \cdots & \cdots & \cdots \\ \hline A_{m-1,1} & A_{m-1,2} & \cdots & A_{m-1,n-1} & A_{m-1,n} \\ \hline A_{m,1} & A_{m,2} & \cdots & A_{m,n-1} & A_{m,n} \\ \hline \end{array}$$

where the circulant permutation matrix (CPM) $A_{i,j}$ represents either the $(z \times z)$ zero matrix Z if $p_{i,j} = -1$, or the $(z \times z)$ circulant permutation matrix $I(p_{i,j})$ obtained by cyclically right-shifting the $(z \times z)$ identity matrix $I(0)$ by $p_{i,j}$ positions.

In embodiments of the invention, H represents a first LDPC code, in particular a first QC-LDPC code, which is used for the first transmission of a HARQ scheme, in particular an incremental redundancy (IR) HARQ scheme. In embodiments of the invention, the protograph matrix P is a repeat accumulate (RA) protograph matrix, which can be beneficial in communication systems, because the corresponding parity-check matrix has easy-encoding properties:

P =

	i_1	i_2	$\cdots$	i_{n-m}	p_1	p_2	$\cdots$	p_{m-1}	p_m
r_1	$p_{1,1}$	$p_{1,2}$	$\cdots$	$p_{1,n-m}$	0	-1	$\cdots$	-1	-1
r_2	$p_{2,1}$	$p_{2,2}$	$\cdots$	$p_{2,n-m}$	0	0	$\cdots$	-1	-1
r_3	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
r_4	$p_{m-1,1}$	$p_{m-1,2}$	$\cdots$	$p_{m-1,n-m}$	-1	-1	$\cdots$	0	-1
r_5	$p_{m,1}$	$p_{m,2}$	$\cdots$	$p_{m,n-m}$	-1	-1	$\cdots$	0	0

the above exemplary representation of the protograph matrix P the first row has been included for clarity to indicate which bits are either information bits or parity bits. The first column has been included to identify the row. As already described above, each $(m \times 1)$ column of P corresponds to $(m \cdot z \times z)$ submatrix of H(P), that is, i_j corresponds to a group of z information bits as well as p_j.

The device 100 for generating a code for a HARQ communication apparatus comprises a processor 101. The processor 101 of the device 100 is configured to generate on the basis of a first protograph matrix P corresponding to first code H a second protograph matrix P' corresponding to a second code H'. In an embodiment, the first code is based on a first protograph matrix P having m rows and n columns, i.e. a $(m \times n)$ matrix. In an embodiment, the first protograph matrix P has a circulant size z. Herein the first protograph matrix will be denoted as P or P_1, whereas the second protograph matrix will be denoted as P' or P_2. Further protograph matrices will be denoted as P_i with $i > 2$.

In an embodiment, the second protograph matrix P' is a matrix of dimensions $(m + d \times n + d)$ and also has a circulant size z. Thus, the parameter d defines the number of additional rows and columns of the second protograph matrix P' in comparison to the first protograph matrix P.

The additional parameter D is related to the number of diagonals of the first protograph matrix P. In an embodiment, the following relation holds: $D \leq d \leq n$.

In a first stage, the processor 101 of the device 100 is configured to determine a $(1 \times n)$ vector $ColWeight$ such that $ColWeight(j)$ is equal to the number of $p_{i,j} \neq -1,\ 1 \leq\ i \leq n$.

In a second stage, the processor 101 of the device 100 is configured to find a sequence $i_1, i_2, \dots, i_n$ such that $ColWeight(i_1) \leq\ ColWeight(i_2) \dots \leq\ ColWeight(i_n)$.
In a third stage, the processor 101 of the device 100 is configured to predetermine the upper part of the second protograph matrix P' as a $(m\ \times\ n + d)$ matrix of -1's. Moreover, the processor 101 of the device 100 is configured to set the first n columns of the upper part of the second protograph matrix P' equal to the corresponding columns of the first protograph matrix, i.e. UpPart(1:m, 1:n) = P.

In a fourth stage, the processor 101 of the device 100 is configured to predetermine the lower part of the second protograph matrix P' as a $(d\ \times\ n + d)$ matrix of -1's. Moreover, the processor 101 of the device 100 is configured to set selected elements of the lower part of the second protograph matrix P' to values different from -1. In an embodiment, the processor 101 of the device 100 is configured to set the selected elements of the lower part of the second protograph matrix P' to one of the following values: 0, p or (-1 - zero block circulant).

In an embodiment, the processer 101 of the device 100 is configured to select the elements of the lower part of the second protograph matrix P' to be set to values different from -1 in the following manner. For each value of the index j from 1 to d the processor 101 is configured to generate the set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ including all indices with k > 0 and to set for the respective value of the index j for each k being element of the set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ LowPart(j, k) to a value different from -1. Put differently, the processor 101 of the device 100 is configured to perform the steps defined by the following pseudo code:

For j = 1:d

Indices = $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ (at most D indices, i.e. we include i_k if k > 0);

For $k \in$ Indices

LowPart(j, k) ≠ -1;

End For

End

In a fifth stage, the processor 101 of the device 100 is configured to insert in the portion (1:d, n+1:n+d) of the lower part of the second protograph matrix P', i.e. LowPart (1:d, n+1:n+d), a zero-diagonal matrix.

The above-described stages 1 to 5 for generating the second protograph matrix P' on the basis of the first protograph matrix P can be considered as a generalized repeat accumulate (GRA) approach or algorithm. As already described above, the GRA algorithm according to embodiments of the invention takes as input the first protograph matrix P as well as the parameters d and D and generates as output the second protograph matrix P', i.e. P' = GRA (P, d, D).

In the following, an example for the above embodiments will be provided for the following first protograph matrix P having a circulant size $z = 5$:

P =

2	4	1	0	-1	-1
1	-1	3	0	0	-1
3	1	2	-1	0	0

For this example, D is equal to 2 and d has been selected to be equal to 4. Thus, the vector $ColWeight$ has the following components: $ColWeight = (3, 2, 3,2,2,1)$. The corresponding sequence of indices is given by (6, 2, 4, 5, 1, 3). The additional steps can be taken from the resulting second protograph matrix P' given below:

P' =

2	4	1	0	-1	-1	-1	-1	-1	-1
1	-1	3	0	0	-1	-1	-1	-1	-1
3	1	2	-1	0	0	-1	-1	-1	-1
-1	-1	-1	-1	-1	0	0	-1	-1	-1
-1	0	-1	-1	-1	0	-1	0	-1	-1
-1	0	-1	0	-1	-1	-1	-1	0	-1
-1	-1	-1	0	0	-1	-1	-1	-1	0

As already mentioned above, in an embodiment the selected elements can be set to a value of p. This allows to avoid short cycles of length 4 made of already assigned entries. This is generally possible, if the circulant size is at least (D-1)*m, since the number of such cycles is at most (D-1)*m.

Because of the specific structure of the obtained second protograph matrix P', easy (linear time) encoding can be performed. Indeed, the upper submatrix P(1:m,1:n+d) has a RA part and the lower submatrix P(m+1:m+d, 1:n+d) has a diagonal part.

As already mentioned above, in an embodiment the processor 101 is configured to set the selected elements of the lower part of the protograph matrix P' to a value of (-1 - zero block circulant), which helps to avoid harmful cycles creating a trapping set. This is important to improve decoding. In an embodiment, lifting can be performed by using the whole protograph after masking GRA circulants, which add a harmful trapping set.

This is exemplified on the basis of the following first protograph matrix P:

0	-1	-1	-1	-1	-1	-1	281	-1	37
0	0	-1	-1	-1	49	-1	43	280	-1
-1	0	0	-1	-1	316	35	229	-1	4
-1	-1	0	0	-1	145	170	-1	154	-1
-1	-1	-1	0	0	-1	10	-1	201	299

In this example the following mask matrix M is used:

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	0	1	1	1	1	1	1	1
1	1	0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1

Then the resulting second protograph matrix P' is given by the Hadamard product of the matrix P and the mask matrix M, namely

0	-1	-1	-1	-1	-1	-1	281	-1	37
0	0	-1	-1	-1	49	-1	43	280	-1
-1	0	-1	-1	-1	316	35	229	-1	4
-1	-1	-1	0	-1	145	170	-1	154	-1
-1	-1	-1	0	0	-1	10	-1	201	299

A first protograph matrix P and/or a corresponding first code H and a second protograph matrix P' and/or a corresponding second code H' as described above can be beneficially used in a HARQ scheme. In an embodiment, the first protograph matrix P and/or the corresponding first code H and the second protograph matrix P' and/or the corresponding second code H' are implemented in the communication apparatus 210 of the communication system 200 shown in figure 2.

More specifically, in an embodiment the first protograph matrix P and/or the corresponding first code H and the second protograph matrix P' and/or the corresponding second code H' can be stored in a channel encoder 213 of the communication apparatus 210, for instance, in a memory of the channel encoder 213. In such a scenario, the first protograph matrix P and/or the corresponding first code H and the second protograph matrix P' and/or the corresponding second code H' could be generated offline by the device 100 shown in figure 1 and provided to the channel encoder 213 of the communication apparatus 201. In another embodiment, the channel encoder 213 itself could comprise the device 100 shown in figure 1 for generating the second protograph matrix P' and/or the corresponding second code H' online on the basis of the first protograph matrix P.

In an embodiment, the communication system 200 shown in figure 2 implements a RB-HARQ scheme. The communication system 200 comprises the transmitting communication apparatus 210 and the receiving communication apparatus 220. In an embodiment, the transmitting communication apparatus 210 and the receiving communication apparatus 220 could be a base station, a user equipment or the like.

A binary information sequence with attached Cyclic Redundancy Check code bits of overall length K denoted as $\boldsymbol{u} = \big(u(1), u(2), \dots, u(K)\big)$ is provided by a source 211 of the communication apparatus 210. After channel encoding by the channel encoder 213 for transmission l one obtains a binary code sequence $\boldsymbol{c}^{(l)} = \big(c^l(1), c^l(2), \dots, c^l(N_l)\big)$, wherein N_l denotes the number of code bits for the l-th transmission. The modulator 215 maps this sequence to a M-QAM modulated sequence $\boldsymbol{x}^{(l)}$. After passing through the communication channel 220, e.g. a fully interleaved Rayleigh channel, one obtains $\boldsymbol{r}^{(l)}$, i.e. the vector of received complex symbols:

$$r_i^{(l)} = \text{⍰}_i^{(l)} \cdot x_i^{(l)} + n_i^{(l)}$$

where $\text{⍰}_i^{(l)}$ denotes the Rayleigh fading channel coefficient with zero mean and unit variance and $n_i^{(l)}$ denotes the complex Gaussian noise with variance $2 \cdot \sigma_l^2$.

The M-QAM demodulator 235 of the communication apparatus 230 can calculate channel log-likelihood ratios (LLRs) and can be implemented in Max-Log MAP fashion, so

$$L_{i,k}^{(l)} = \max_{\boldsymbol{\theta}_j \in \boldsymbol{A}:\theta_{j,k}=1} \log F\big(r_i^{(l)}, \widehat{\text{⍰}}_i^{(l)}, \widehat{\sigma_l}, \boldsymbol{\theta}_j\big) - \max_{\boldsymbol{\theta}_j \in \boldsymbol{A}:\theta_{j,k}=0} \log F\big(r_i^{(l)}, \widehat{\text{⍰}}_i^{(l)}, \widehat{\sigma_l}, \boldsymbol{\theta}_j\big),$$

where

$$\log F\left(r_i^{(l)}, \widehat{\text{⍰}}_i^{(l)}, \widehat{\sigma_l}, \boldsymbol{\theta}_j\right) = -\frac{\left\| r_i^{(l)} - \widehat{\text{⍰}}_i^{(l)} \cdot \boldsymbol{\theta}_j \right\|^2}{2 \cdot \widehat{\sigma_l}^2},$$

where $\widehat{\text{⍰}}_i^{(l)}$ and $\widehat{\sigma_l}^2$ are estimations of fading coefficient and noise variance respectively, $\boldsymbol{A}$- constellation points of M-QAM, $k = 1 \dots, \log_2 M$.

Thereafter, the HARQ combiner 233 follows, where input LLRs are summed at code positions that were previously sent (Chase combining) and LLRs for new parity bits are just concatenated to form one codeword (Incremental Redundancy). This codeword is provided to the Soft Input Soft Output (SISO) channel decoder 231 of the communication apparatus 230. This channel decoder 231 can be implemented as a Turbo, LDPC or convolutional code decoders. So $\boldsymbol{L}_{in}^{(l)}$ corresponds to input LLRs of the SISO decoder 231 at the l-th transmission and $\boldsymbol{L}_{out}^{(l)}$ - soft output LLRs of the decoder 231. Generally, RB-HARQ algorithms take $\boldsymbol{L}_{out}^{(l)}$ and in case of decoding failure (CRC fails) try to determine which bits should be retransmitted and signal it in the feedback channel 240.

In an embodiment, the communication system 200 shown in figure 2 can be implemented to perform the following steps defining a first stage of a HARQ scheme with $K \geq 2$ possible steps. Denote by n_i number of columns of protograph matrix P_i, $n = n_1, n_{i+1} > n_i$ for case of incremental redundancy $n_i = i \cdot n$.

Take information bits with attached CRC denoted by $\boldsymbol{u}$. Encode $\boldsymbol{u}$ using LDPC code $H(P)$ and get codeword $\boldsymbol{c_1}$ of length $n_1 \cdot z$. After modulation of the codeword, passing through the communication 220 channel, demodulation of the received signal one obtains soft information $\boldsymbol{L_1}$ consisting of LLR's corresponding to bits of $\boldsymbol{c_1}$. Using parity-check matrix $H(P)$ one can decode $\boldsymbol{L_1}$. After decoding the CRC can be checked. If the information is confirmed, then the correct information bits have been received. Otherwise the next stage with $iter = 2$ can be performed.

As will be described in more detail further below, in an embodiment depending on the code rate one of the different approaches to construct the protograph P' can be used, including the GRA approach described above. On the basis thereof the following steps defining a second stage can be performed: Encode $\boldsymbol{u}$ using LDPC code $H(P')$ and get codeword $\boldsymbol{c_2}$ of length $n_{iter} \cdot z$. Since $\boldsymbol{c_2}$ contains $\boldsymbol{c_{iter-1}}$ as a subword, only the remaining part of $\boldsymbol{c_2}$ is transmitted, that is $\boldsymbol{c_{iter}} \backslash \boldsymbol{c_{iter-1}}$ is transmitted. After modulation of the codeword, passing through the channel 220, demodulation of the received signal one gets soft information $\boldsymbol{L'}_{iter}$ consisting of LLR's corresponding to bits of $\boldsymbol{c}_{iter}\backslash\boldsymbol{c}_{iter-1}$. Then the soft information $\boldsymbol{L}_{iter-1}$ and $\boldsymbol{L'}_{iter}$ can be combined into $\boldsymbol{L}_{iter}$ (in an embodiment, this is just a concatenation into vector of length $n_{iter} \cdot z$). Using parity-check matrix $H(P')$ $\boldsymbol{L}_{iter}$ can be decoded. After decoding the CRC can be checked. If the information is confirmed, then the correct information bits have been received. Otherwise, if $iter < K$ the above second stage with $iter = iter + 1$ can be repeated.

In an embodiment, the device 100 shown in figure 1 and/or the communication apparatus 210 shown in figure 2 are configured to generate or implement different second codes based on the code rate. In an embodiment, the processor 101 of the device 100 can be configured to generate a set of K protograph matrices $P_2, \dots, P_K$ on the basis of a first protograph matrix P_1 of size $m \times n$ and the number $K$of maximum HARQ iterations.

In an embodiment, the proposed rate-adaption algorithms could be used for the HARQ scheme. In an embodiment, the code rate R of the first code $H(P_1)$ can be determined as $R = 1 - \frac{m}{n}$. In an embodiment, for constructing P_{i+1} based on P_i with adding d_i new rows and columns, one can take $Q_1 = P_i$ as well as any set of numbers $0 \le a_j, b_j, j \in \{1, \dots, n_i\}, \sum_{j=1}^{n_i} a_j + b_j = d_i$, any set of $T_j \in \{A, B\}$, any set of numbers $D_j < n$ and repeat the following procedure n_i times:

$$Q_{2j} = RS(Q_{2j-1}, a_j, T_j)$$
$$Q_{2j+1} = GRA(Q_{2j}, b_j, D_j),$$

wherein $RS(\ )$ denotes a row-splitting algorithm for constructing a protograph matrix, which will be described in more detail further below.

The above algorithm leads to the result $P_{i+1} = Q_{2n_j+1}$ and can be repeated for each i up to $K - 1$. For incremental redundancy $d_i = n$ can be chosen, which gives rate $R_i = \frac{R}{i}$ for protograph matrix P_i.

In an embodiment, for $R > 0.6$, $n_i = 1, d_i = n, a_1 = n, b_1 = 0, T_1 = A$, a single time RS approach can be used to generate the second protograph matrix.
In an embodiment, for $R < 0.6$, $n_i = 1, d_i = n,\ a_1 = 0, b_1 = 0, D_1 = 2$, a single time GRA approach can be used to generate the second protograph matrix.

One can see that the rate of the code $H(P_2)$ corresponding to the second protograph matrix P_2 is $R/2$.

In other embodiments, combinations of the RS approach and the GRA approach can be used to generate the second protograph matrix P_2.

In an embodiment, the first protograph matrix is a repeat accumulate (RA) protograph matrix.

As already described above, in embodiments of the invention the RS approach or algorithm can be used by the device 100 to generate the second protograph matrix P'. In an embodiment, the processor 101 of the device 100 is configured to generate the second protograph matrix P' of size $(m + d \times n + d)$ with circulant size z on the basis of the first protograph matrix P of size $(m \times n)$ with circulant size z using the following RS algorithm. In an embodiment, the first protograph matrix P and/or the second protograph matrix P' are RA matrices. In an embodiment, further input parameters for the RS algorithm are d – integer, option $O \in \{A, B\}$.

In a first step of the RS algorithm a $(m \times 1)$ vector $RowWeight$ is defined, such that $RowWeight(i)$ is equal to the number of $p_{i,j} \neq -1,\ 1 \leq j \leq n - m$.

In a further step of the RS algorithm an integer $Weight = \sum_{i=1}^{m} RowWeight(\mathrm{i})$ is defined.

In a further step of the RS algorithm it is checked whether $Weight < m + d$, and, if this is the case, the RS algorithm will be terminated.

If $O = A$, then the $(m \times 1)$ vector splittingFactors is defined, such that $\text{splittingFactors(i)} \leq RowWeight(i)$, and all values of splittingFactors are close (may be equal) to each other, and $\sum \text{splittingFactors(i)} = \text{m} + \text{d}$.

If $O = B$, then the $(m \times 1)$ vector splittingFactors is defined, such that $\text{splittingFactors(i)} \leq RowWeight(i)$ and all values of $\frac{\text{splittingFactors(i)}}{RowWeight(i)}$ are close (may be equal) to each other, and $\sum \text{splittingFactors(i)} = \text{m} + \text{d}$.

The vector splittingFactors(i) determines how many rows will appear in the second protograph matrix P' instead of i-th row of P. Options A and B allow to control regularity or irregularity of obtained QC-LDPC code H(P').

The Matrix P' consists of m submatrices $P'(i)$

P' =

P'(1)
P'(2)
...
...
P'(m)

The submatrix P'(i) is obtained by splitting the i-th row of the first protograph matrix P and adding some new columns in the way, as expressed by the following pseudo code.

P'(i) is predetermined as a $(\text{splittingFactor(i)} \times n + d)$ matrix of -1's.

```
Residue = 0;
For any j ∈ [n − m]
        If P(i,j) = =  − 1
                Continue;
        End If
        Residue = Residue + 1;
                        Residue = mod(Residue, splittingFactor(i));
```

$$P'(i, \text{Residue}) = P(i,j);$$

End For

$$begPos(i) = n - m + \textstyle\sum_{k=1}^{i-1} \text{splittingFactor(k)} \quad ;$$

Insert in P'(i, $begPos(i) + 1{:}\, begPos(i) +$ splittingFactor(i)) a (splittingFactor(i)) × splittingFactor(i))) matrix representing a RA part of LDPC code;

End For

The second protograph matrix P' generated in the way described above has an RA part, so that easy (linear-time) encoding can be performed.

The general RS approach described above will be further illustrated on the basis of the following exemplary first protograph matrix P with circulant size 5:

P =

	i_1	i_2	i_3	p_1	p_2	p_3
r_1	2	4	1	0	-1	-1
r_2	1	-1	3	0	0	-1
r_3	3	1	2	-1	0	0

Input: P and d = 4;

1) $RowWeight = (3,2,3)^T$;
2) $Weight = 3 + 3 + 3 = 8$;
3) Check 8 > 7;
4) A) splittingFactor = $(2,2,3)^T$;
   B) splittingFactor = $(3,1,3)^T$;

For option A:

P' =

	i_1	i_2	i_3	p_1	p_2	p_3	p_4	p_5	p_6	p_7
r_{11}	2	-1	1	0	-1	-1	-1	-1	-1	-1
r_{12}	-1	4	-1	0	0	-1	-1	-1	-1	-1
r_{21}	1	-1	-1	-1	0	0	-1	-1	-1	-1

r_{22}	-1	-1	3	-1	-1	0	0	-1	-1	-1
r_{31}	3	-1	-1	-1	-1	-1	0	0	-1	-1
r_{32}	-1	1	-1	-1	-1	-1	-1	0	0	-1
r_{33}	-1	-1	2	-1	-1	-1	-1	-1	0	0

Rows r_{11} and r_{12} of the matrix P' are based on row r_1 of the matrix P. Rows r_{21} and r_{22} of the matrix P' are based on row r_2 of the matrix P. Rows r_{31}, r_{32} and r_{33} of the matrix P' are based on row r_3 of the matrix P.

For option B:

P' =

	i_1	i_2	i_3	p_1	p_2	p_3	p_4	p_5	p_6	p_7
r_{11}	2	-1	-1	0	-1	-1	-1	-1	-1	-1
r_{12}	-1	4	-1	0	0	-1	-1	-1	-1	-1
r_{13}	-1	-1	1	-1	0	0	-1	-1	-1	-1
r_{21}	1	-1	3	-1	-1	0	0	-1	-1	-1
r_{31}	3	-1	-1	-1	-1	-1	0	0	-1	-1
r_{32}	-1	1	-1	-1	-1	-1	-1	0	0	-1
r_{33}	-1	-1	2	-1	-1	-1	-1	-1	0	0

Rows r_{11}, r_{12} and r_{13} of the matrix P' are based on row r_1 of the matrix P. Row r_{21} of the matrix P' is based on row r_2 of the matrix P. Rows r_{31} and r_{32} of the matrix P' are based on row r_3 of the matrix P.

P'' =

	i_1	i_2	i_3	p_1	p_2	p_3	p_4	p_5	p_6	p_7
r_1	2	4	1	-1	-1	0	-1	-1	-1	-1
r_2	1	-1	3	-1	-1	0	0	-1	-1	-1
r_3	3	1	2	-1	-1	-1	0	-1	-1	0

The RS approach described above leads to coherent matrices P and P' as well as the corresponding LDPC codes. Indeed, $r_i = \sum_j r_{ij}$, thus rows in each layer of P' (using the rule (-1+k) = k and (k+k) = -1) can be summed and the matrix P", which could be the same as P, can be obtained, if columns with zero weight, i.e. columns consist of -1's only, are excluded. In other words, if information bits (i_1, i_2, i_3) are encoded with the LDPC code corresponding to the protograph matrix P' resulting in a codeword $(i_1, i_2, i_3, p_1, p_2, p_3, p_4, p_5, p_6, p_7)$, then a subword $(i_1, i_2, i_3, p_3, p_4, p_7)$ is a codeword of the LDPC code corresponding to the protograph matrix P with the same information bits (i_1, i_2, i_3).

Embodiments of the invention allow getting a better performance (BLER and throughput) than conventional LTE HARQ systems for moderate and high code rates. In the following the performance of embodiments of the invention are illustrated for different channel conditions.

In the following, an LTE turbo code with 8 iterations and scaled Max Log MAP decoding (scale factor = 0.75 for all iterations) will be used as a comparison. By way of example, a CRC of length 24 is chosen. For the following examples the maximal number of transmissions is restricted to 2 (in case of a wrong decoding after the first transmission, the second transmission is used). Moreover, a SC-LDPC code with 30 iterations and Layered Min Sum decoding is used. Also in this case a CRC of length 24 is chosen. Two algorithms are compared. As a baseline algorithm the currently used LTE system is used.

Figures 3 and 4 show the results of simulations for the specific standard case for the downlink channel. The modulation coding scheme (MCS) index is 8, modulation is 4-QAM, data size K is 1408, coding rate (CR_1) for the first transmission is 0.51, the number of resource blocks (RB) is 10, the total length of codeword is 2760.

In this case the rate of the first transmission is moderate. As consequence, according to an embodiment of the invention, the GRA approach described above will be chosen for constructing the LDPC matrix for the second transmission in such a way that at the second transmission only new parity-check bits are transmitted, i.e. the input parameter in this case is d = n. For this case, if for the first transmission a first $m \times n$ protograph matrix P is used, then for the second transmission a second protograph matrix P' of size

$(m + n \times 2n)$ is used. Figure 5 shows the first and second LDPC matrices for the first transmission and for the second transmission. In this example, the RA part of LDPC code is moved from the right side to the left side, as described above for the RS algorithm.

In Figure 3 the block error rate is shown for each transmission. In Figure 4 the throughput for IR-HARQ LTE protocol and IR-HARQ LDPC protocol is shown.

Figures 6 and 7 show the results for simulations for the specific standard case for the downlink channel: modulation coding scheme (MCS) index is 25, modulation is 64-QAM, data size K is 17016, coding rate (CR_1) for the first transmission is 0.685, the number of resource blocks (RB) is 30, the total length of codeword is 24840. In this case the rate of the first transmission is moderate. As consequence, the RS approach is chosen for generating the LDPC matrix for the second transmission in such a way that at the second transmission only new parity-check bits are transmitted. In Figure 6 the lock error rate for each transmission is shown. In Figure 7 the throughput for IR-HARQ LTE protocol and IR-HARQ LDPC protocol is shown.

Figure 8 shows a schematic diagram of a method 800 for generating on the basis of a first protograph matrix P of size $(m \times n)$, wherein the first protograph matrix P defines a first code H, a second protograph matrix P' of size $(m + d \times n + d)$, wherein the second protograph matrix P' defines a second code H'. The method 800 comprises the steps of: setting 801 the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P; setting 803 the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1; pre-setting 805 the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1; setting 807 selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1; and setting 809 the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0.

Embodiments of the invention allow constructing an extended low-density parity check (LDPC) code H_2 with a lower code rate (CR) from an LDPC code H_1 with a higher CR. Embodiments of the invention can be used in an IR HARQ scheme. Embodiments of the invention address shortcomings of known methods and the performance thereof was verified in a communication system with an Additive White Gauss Noise (AWGN) channel.

Embodiments of the invention propose a beneficial alternative to the HARQ protocol currently used in LTE systems. Embodiments of the invention provide two exact algorithms which can be used to design QC-LDPC code H_2 of dimension $(m + d)z \times (n + d)z$ from the QC-LDPC code H_1 of dimension $mz \times nz$ such that the code H_1 is a subcode of H_2. In embodiments of the invention the first algorithm is used in case H_1 has either low or moderate rate, while the second algorithm is appropriate in case H_1 has either moderate or high rate.

Embodiments of the invention outperform currently used in LTE systems in terms of block error rate (BLER) for each transmission and, as a consequence, in terms of throughput. Embodiments of the invention can be easily implemented and can work online. Additional overhead in complexity of decoding of the second transmission does not exceed complexity of decoding of the first transmission.

While a particular feature or aspect of the disclosure may have been disclosed with respect to only one of several implementations or embodiments, such feature or aspect may be combined with one or more other features or aspects of the other implementations or embodiments as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "include", "have", "with", or other variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprise". Also, the terms "exemplary", "for example" and "e.g." are merely meant as an example, rather than the best or optimal. The terms “coupled” and “connected”, along with derivatives may have been used. It should be understood that these terms may have been used to indicate that two elements cooperate or interact with each other regardless whether they are in direct physical or electrical contact, or they are not in direct contact with each other.

Although specific aspects have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific aspects shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific aspects discussed herein.

Although the elements in the following claims are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.

Many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the above teachings. Of course, those skilled in the art readily recognize that there are numerous applications of the invention beyond those described herein. While the invention has been described with reference to one or more particular embodiments, those skilled in the art recognize that many changes may be made thereto without departing from the scope of the invention. It is therefore to be understood that within the scope of the appended claims and their equivalents, the invention may be practiced otherwise than as specifically described herein.

CLAIMS

1. A device (100) for generating on the basis of a first protograph matrix P of size $(m \times n)$, wherein the first protograph matrix P defines a first code H, a second protograph matrix P' of size $(m + d \times n + d)$, wherein the second protograph matrix P' defines a second code H', wherein the device (100) comprises:

a processor (101) configured to generate the second protograph matrix P' by:

(i) setting the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P;

(ii) setting the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1;

(iii) pre-setting the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1;

(iv) setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1; and

(v) setting the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0.

2. The device (100) of claim 1, wherein the processor (101) is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to 0.

3. The device (100) of claim 1, wherein the processor (101) is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to p.

4. The device (100) of claim 1, wherein the first protograph matrix has a circulant size z and wherein the processor (101) is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to (-1-zero block circulant).

5. The device (100) of any one of the preceding claims, wherein a parameter D is associated with the number of diagonals of the first protograph matrix P and wherein the processor (101) is configured to set the selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1 by (i) determining a $(1 \times n)$ vector $ColWeight$ such that $ColWeight(j)$ is equal to the number of elements of the j-th column of the first protograph matrix P, which are not equal to -1, (ii) determining a sequence $i_1, i_2, \dots, i_n$ such that $ColWeight(i_1) \leq ColWeight(i_2) \dots \leq ColWeight(i_n)$, and (iii) generating for each value of the index j from 1 to d a set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ including all indices with k > 0 and setting for the respective value of the index j for each k being element of the set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ the respective element of the second protograph matrix identified by j and k to a value different from -1.

6. The device (100) of claim 5, wherein the following relation holds between the parameter D and the values d and : $D \leq d \leq n$.

7. The device (100) of any one of the preceding claims, wherein the first protograph matrix P and the second protograph matrix P' have the same circulant size z.

8. The device (100) of any one of the preceding claims, wherein the first protograph matrix P and the second protograph matrix P' are repeat accumulate matrices.

9. A communication apparatus (210) comprising a channel encoder (213) comprising a device (100) for generating a protograph matrix according to any one of the preceding claims.

10. A communication apparatus (210) comprising a channel encoder (213) comprising a first protograph matrix P or a corresponding first code H and a second protograph matrix P' or a corresponding second code H', wherein the channel encoder (213) is configured to use the first code H for a first transmission of a HARQ scheme and the second code H' for a retransmission of the HARQ scheme and wherein the first protograph matrix P or the corresponding first code H and the second protograph matrix P' or the corresponding second code H' have been provided by a device (100) for generating a protograph matrix according to any one of claims 1 to 8.

11. The communication apparatus (210) of claim 9 or 10, wherein the channel encoder (213) is configured to use the first code H for a first transmission of the HARQ scheme and the second code H' for a retransmission of the HARQ scheme for code rates smaller than a code rate threshold and to use a third code H* for a retransmission of the HARQ scheme for code rates larger than a code rate threshold, wherein the third code H* is based on a third protograph matrix, which has been derived from the first protograph matrix using a row splitting scheme.

12. The communication apparatus (210) of claim 11, wherein the code rate threshold has a value of 0.6.

13. A method (800) for generating on the basis of a first protograph matrix P of size $(m \times n)$, wherein the first protograph matrix P defines a first code H, a second protograph matrix P' of size $(m + d \times n + d)$, wherein the second protograph matrix P' defines a second code H', wherein the method (800) comprises:

setting (801) the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P;

setting (803) the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1;

pre-setting (805) the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1;

setting (807) selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1; and

setting (809) the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0.

14. The method (800) of claim 13, wherein a parameter D is associated with the number of diagonals of the first protograph matrix P and wherein the step (807) of setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different from -1 comprises the following steps:

(i) determining a $(1 \times n)$ vector $ColWeight$ such that $ColWeight(j)$ is equal to the number of elements of the j-th column of the first protograph matrix P, which are not equal to -1;

(ii) determining a sequence $i_1, i_2, \dots, i_n$ such that $ColWeight(i_1) \leq ColWeight(i_2) \dots \leq ColWeight(i_n)$; and

(iii) generating for each value of the index j from 1 to d a set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ including all indices with k > 0 and setting for the respective value of the index j for each k being element of the set of indices $\{i_{j-D+1}, i_{j-D+2}, \dots, i_j\}$ the respective element of the second protograph matrix identified by j and k to a value different from -1.

15. A computer program comprising program code for performing the method of claim 13 or 14 when executed on a computer.

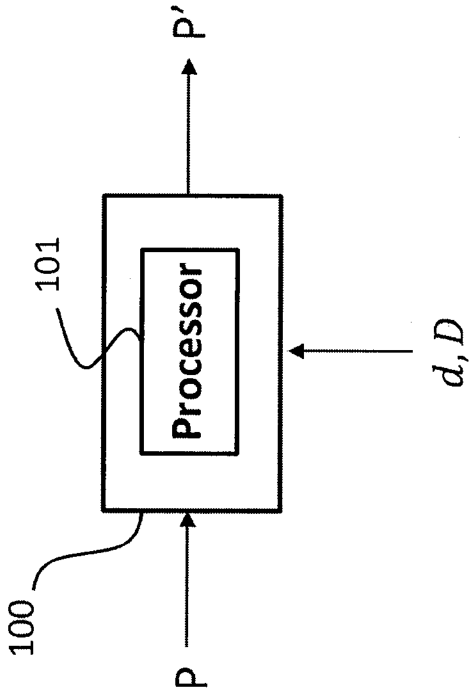


Fig. 1

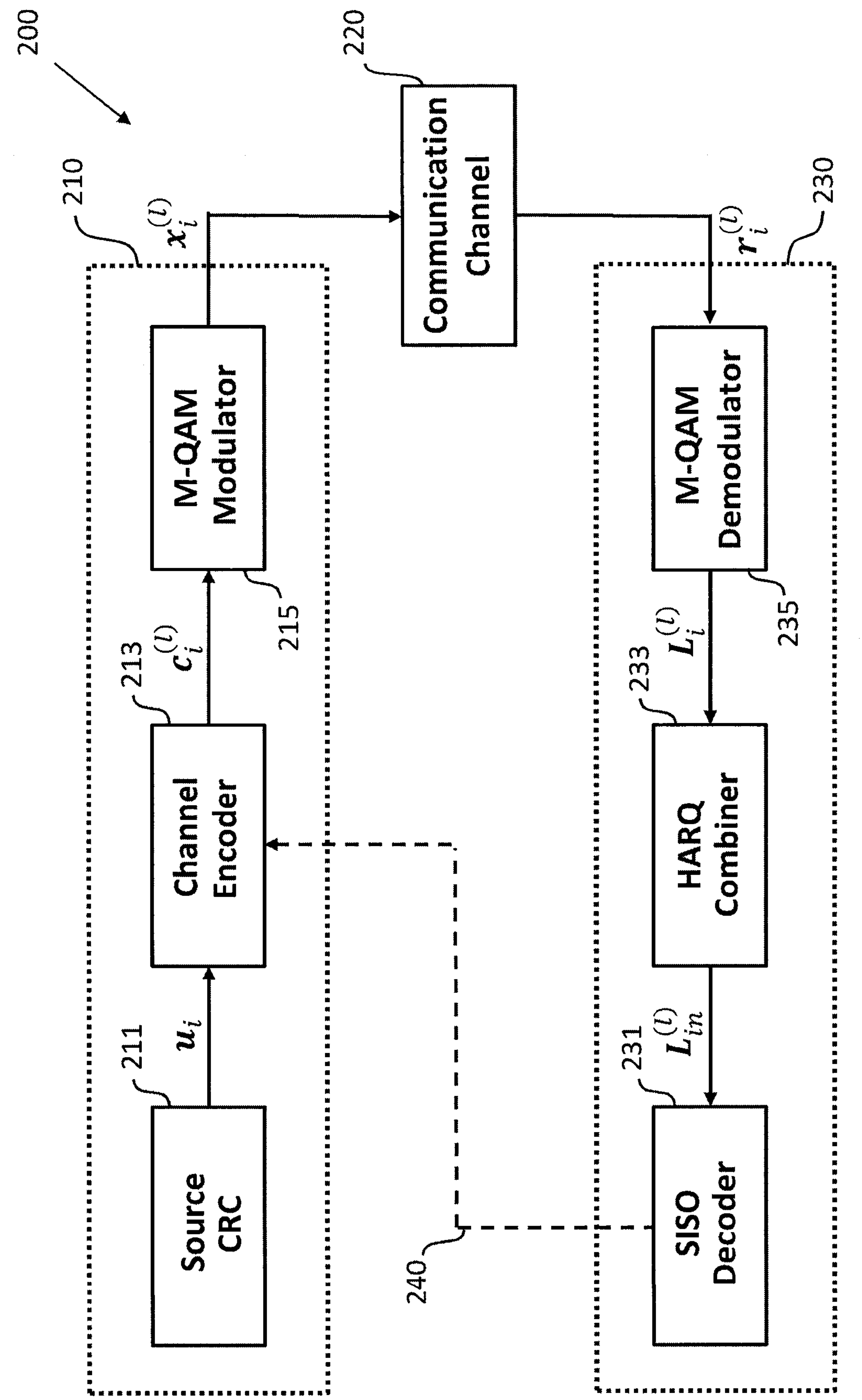

200
210
220
Communication Channel
230
$x_i^{(l)}$
$r_i^{(l)}$
M-QAM Modulator
M-QAM Demodulator
215
235
213
$c_i^{(l)}$
233
$L_i^{(l)}$
Channel Encoder
HARQ Combiner
211
u_i
231
$L_{in}^{(l)}$
Source CRC
SISO Decoder
240

Fig. 2

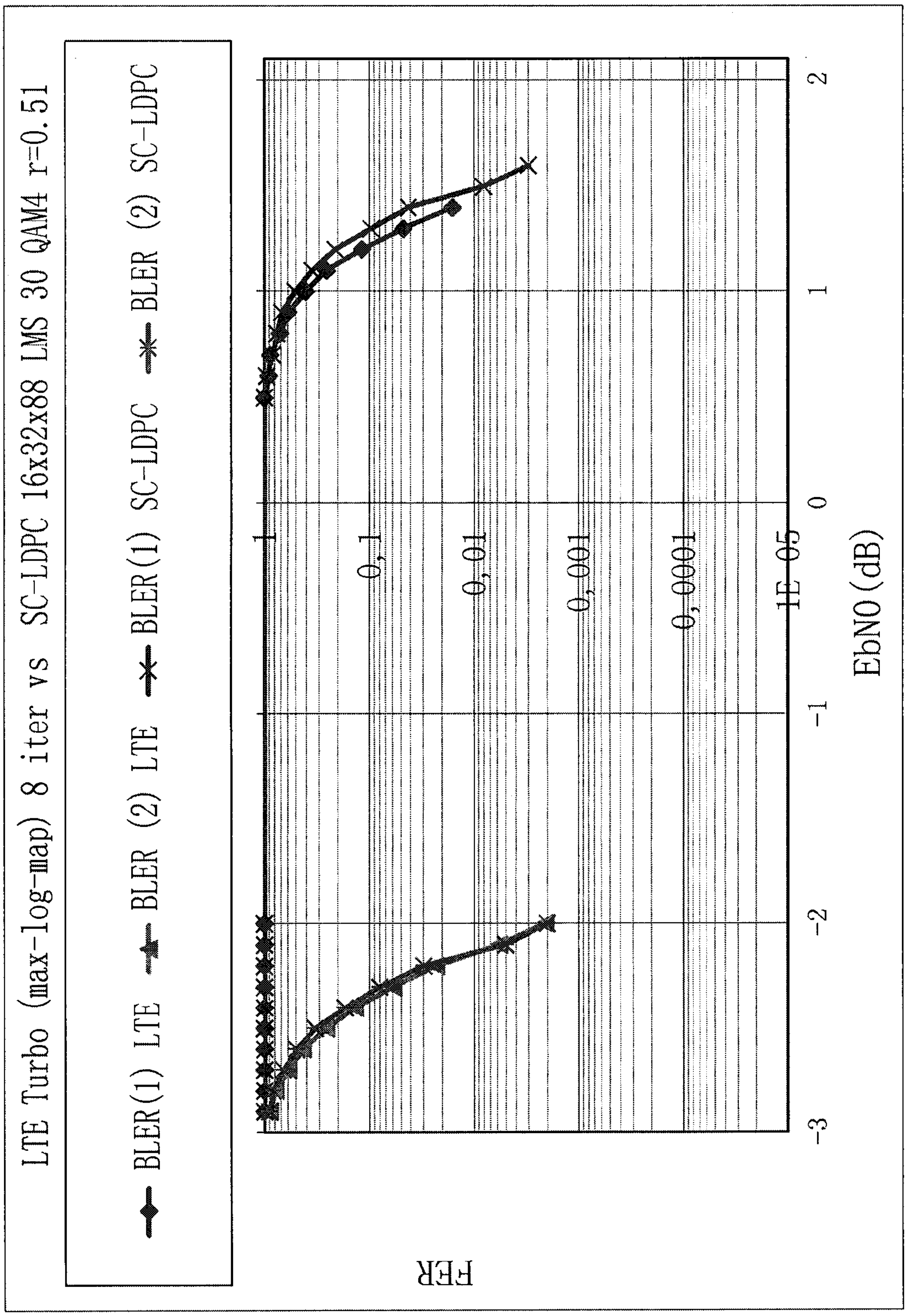

LTE Turbo (max-log-map) 8 iter vs SC-LDPC 16x32x88 LMS 30 QAM4 r=0.51
BLER(1) LTE
BLER (2) LTE
BLER(1) SC-LDPC
BLER (2) SC-LDPC
FER
1
0,1
0,01
0,001
0,0001
1E-05
-3
-2
-1
0
1
2
EbN0(dB)

Fig. 3

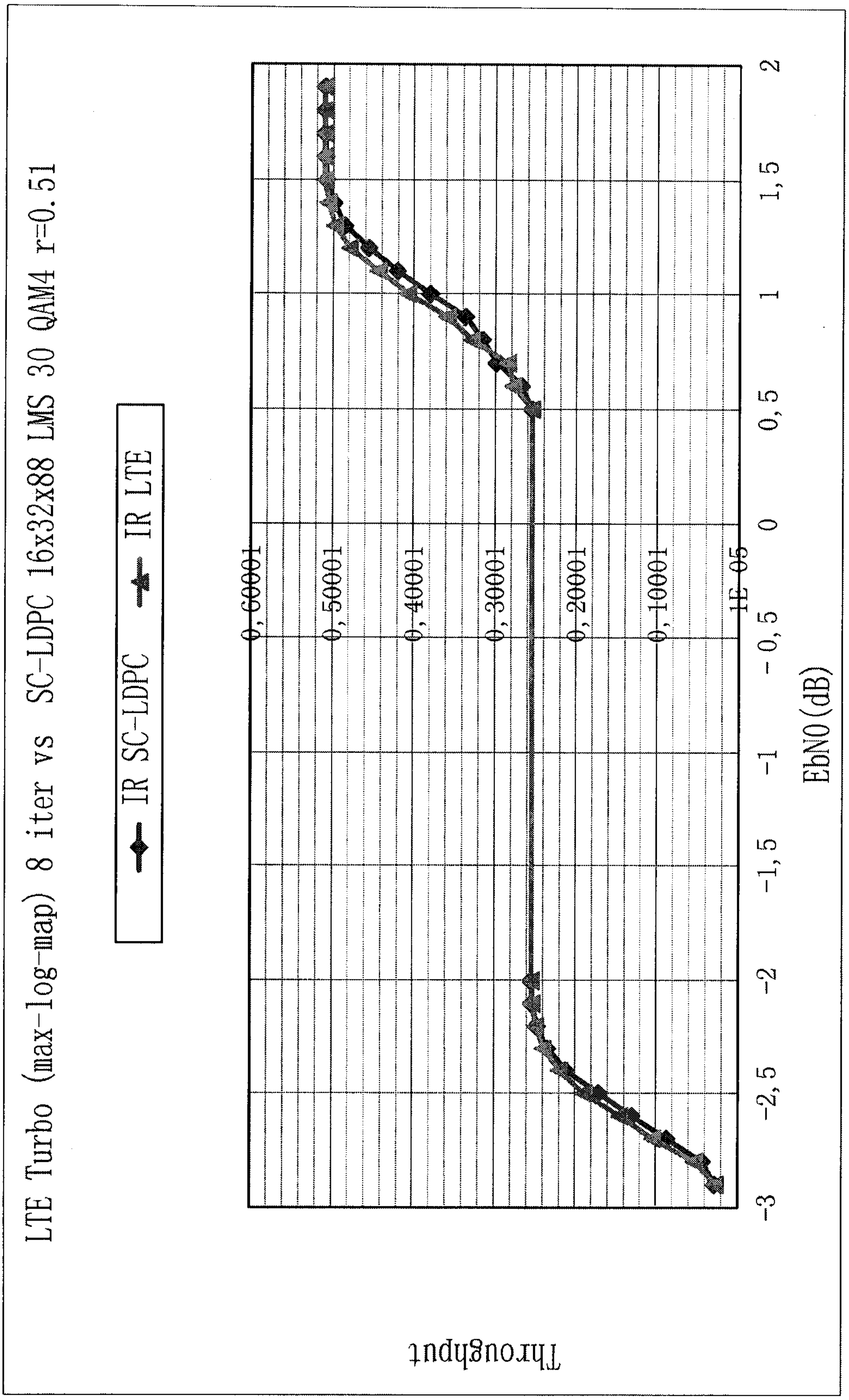

LTE Turbo (max-log-map) 8 iter vs SC-LDPC 16x32x88 LMS 30 QAM4 r=0.51
IR SC-LDPC
IR LTE
Throughput
EbN0(dB)
-3
-2,5
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
1E-05
0,10001
0,20001
0,30001
0,40001
0,50001
0,60001

Fig. 4

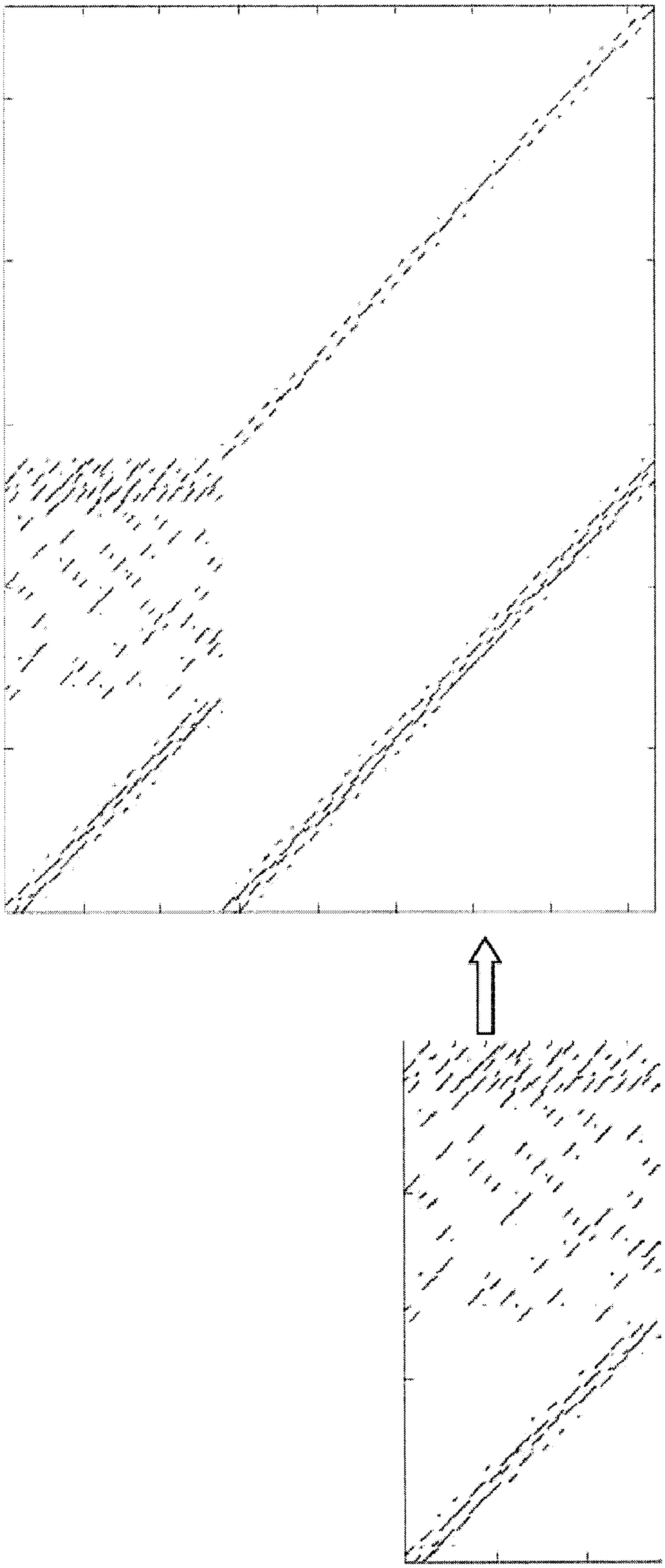


Fig. 5

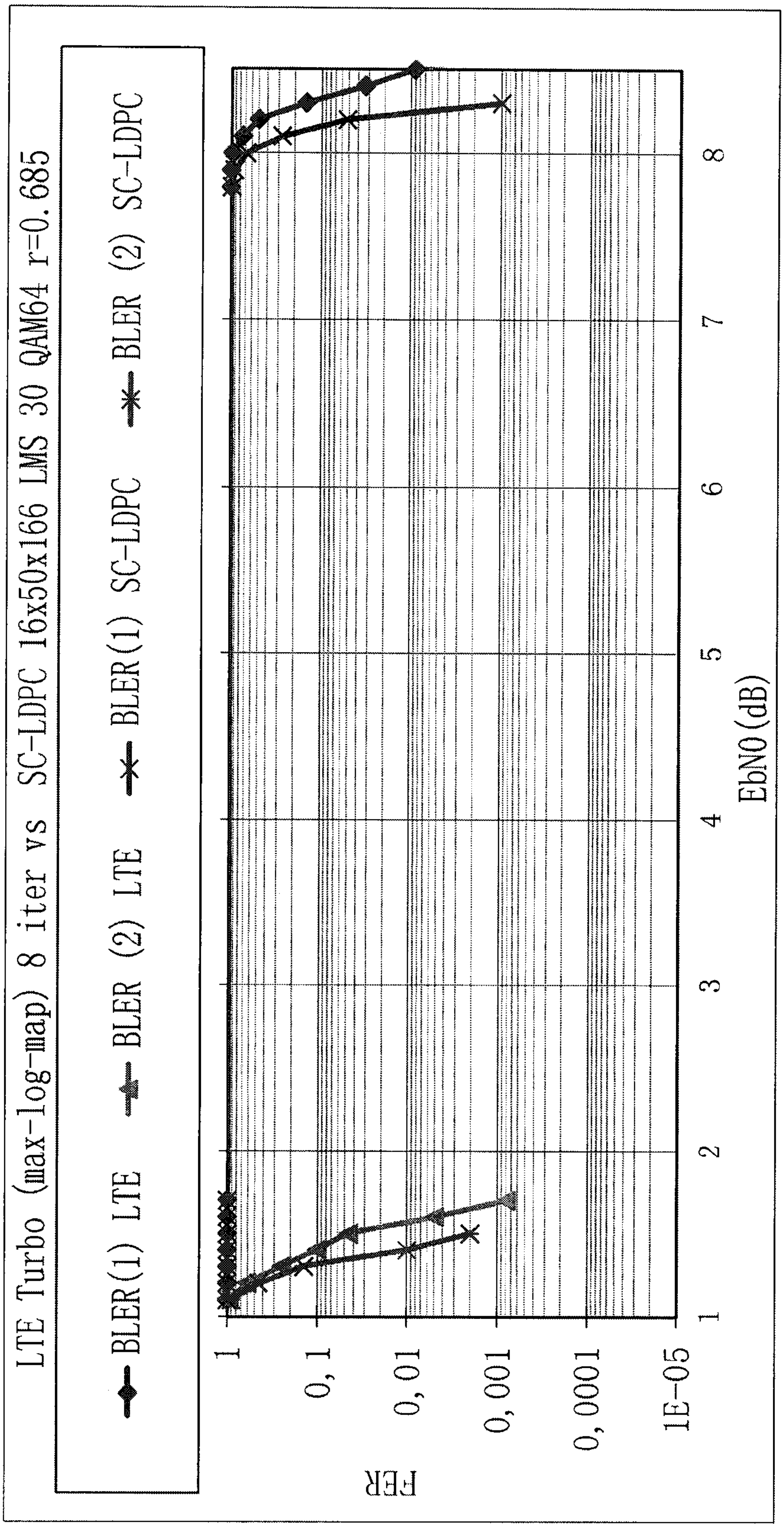
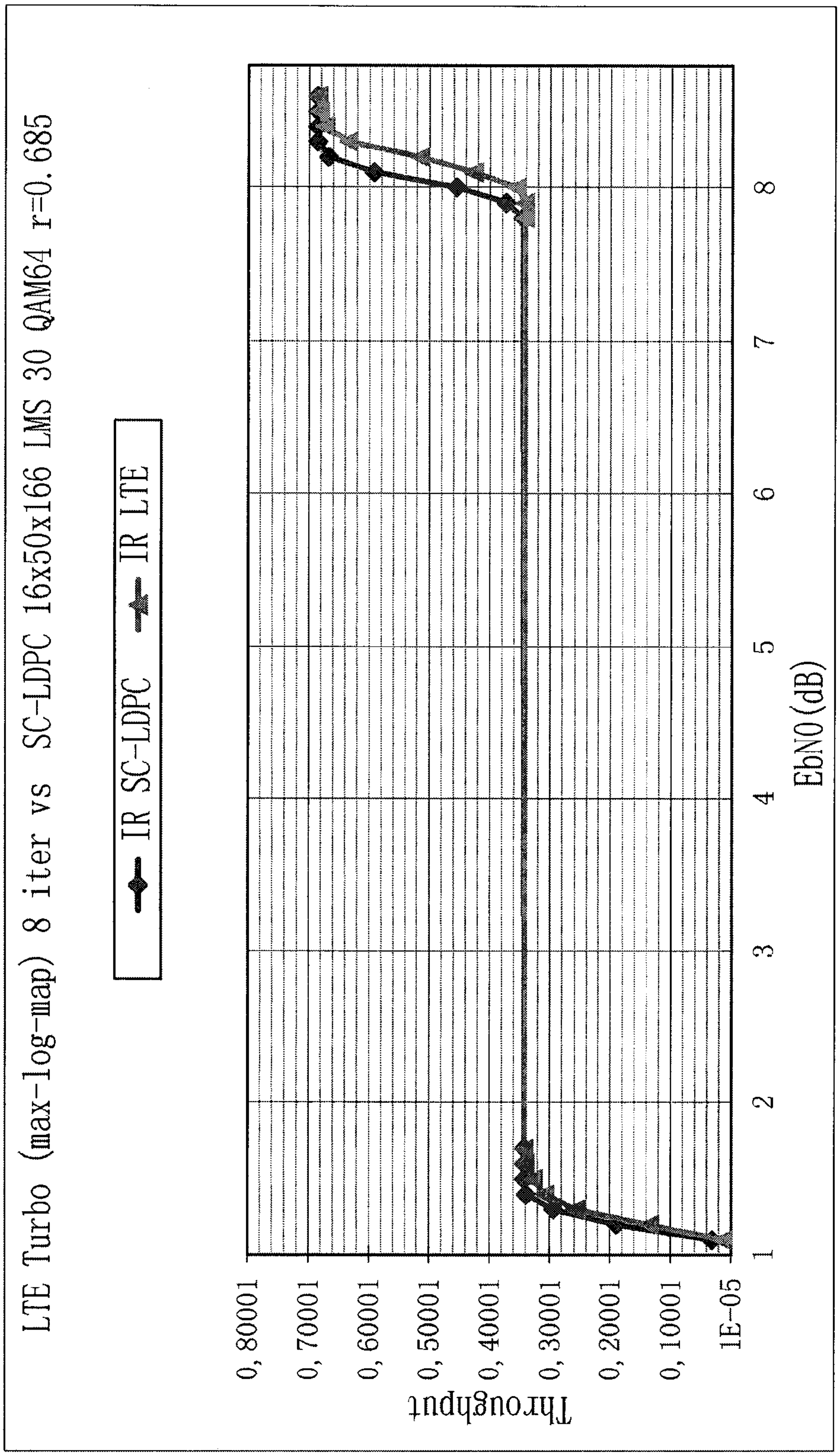

LTE Turbo (max-log-map) 8 iter vs SC-LDPC 16x50x166 LMS 30 QAM64 r=0.685
BLER(1) LTE
BLER (2) LTE
BLER(1) SC-LDPC
BLER (2) SC-LDPC
FER
1
0,1
0,01
0,001
0,0001
1E-05
1
2
3
4
5
6
7
8
EbN0(dB)

Fig. 6



LTE Turbo (max-log-map) 8 iter vs SC-LDPC 16x50x166 LMS 30 QAM64 r=0.685
IR SC-LDPC
IR LTE
Throughput
0,80001
0,70001
0,60001
0,50001
0,40001
0,30001
0,20001
0,10001
1E-05
1
2
3
4
5
6
7
8
EbN0(dB)

Fig. 7

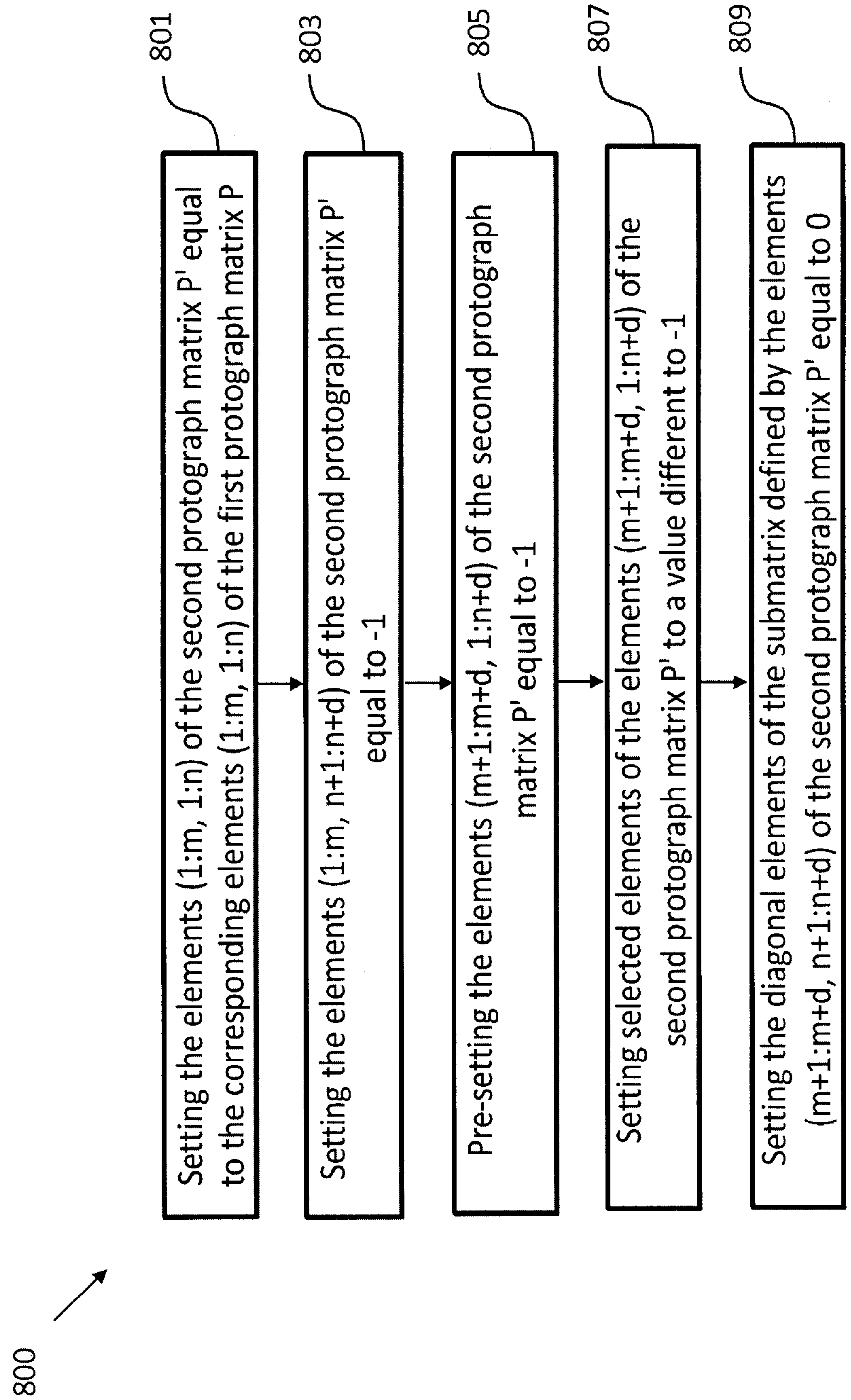

800
801
Setting the elements (1:m, 1:n) of the second protograph matrix P' equal to the corresponding elements (1:m, 1:n) of the first protograph matrix P
803
Setting the elements (1:m, n+1:n+d) of the second protograph matrix P' equal to -1
805
Pre-setting the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' equal to -1
807
Setting selected elements of the elements (m+1:m+d, 1:n+d) of the second protograph matrix P' to a value different to -1
809
Setting the diagonal elements of the submatrix defined by the elements (m+1:m+d, n+1:n+d) of the second protograph matrix P' equal to 0

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2016/000534

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03M13/11 H03M13/03 H04L1/00 H04L1/18
ADD. H03M13/09 H03M13/2906

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03M H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/155385 A1 (JEONG HONG-SIL [KR] ET AL) 26 June 2008 (2008-06-26)	1-3,5-9, 15
A	figures 6-16 paragraph [0004] - paragraph [0008] paragraph [0040] - paragraph [0043] paragraph [0059] - paragraph [0067] claims 1,28 -----	11,12
X	EP 1 868 294 A1 (SAMSUNG ELECTRONICS CO LTD [KR]; POSTECH FOUNDATION [KR]) 19 December 2007 (2007-12-19)	1-3,5-9, 15
A	paragraph [0001] - paragraph [0004]; figures 1-7 claims 1-7 -----	11,12
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 July 2017	27/07/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Offer, Elke

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INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2016/000534

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2008/178065 A1 (KHANDEKAR AAMOD [US] ET AL) 24 July 2008 (2008-07-24) paragraph [0083] - paragraph [0086]; figure 8 -----	1-3,5-9, 15 11,12
X A	US 2005/283709 A1 (KYUNG GYU-BUM [KR] ET AL) 22 December 2005 (2005-12-22) figures 1,13 claim 1 paragraph [0117] - paragraph [0123] -----	1-3,5-9, 15 11,12
X A	US 2007/162822 A1 (CHOI SEUNG-HOON [KR] ET AL) 12 July 2007 (2007-07-12) paragraph [0025] - paragraph [0026] paragraph [0043] - paragraph [0069]; figure 2 -----	1-3,5-9, 15 11,12
X A	DAVID BENMAYOR ET AL: "Design of Efficiently Encodable Rate-Compatible LDPC Codes Using Vandermonde Extension Matrices", WIRELESS PERSONAL COMMUNICATIONS, KLUWER ACADEMIC PUBLISHERS, DO, vol. 60, no. 4, 8 May 2010 (2010-05-08), pages 695-708, XP019961217, ISSN: 1572-834X, DOI: 10.1007/S11277-010-9969-8 the whole document -----	1-3,5-9, 15 11,12
X A	WENWEN LI ET AL: "Novel Extending Scheme for the Construction of Rate-Compatible IRA-Like Codes", PROC., IEEE 81ST VEHICULAR TECHNOLOGY CONFERENCE (VTC SPRING 2015), GLASGOW, SCOTLAND, UNITED KINGDOM, 11 May 2015 (2015-05-11), - 14 May 2015 (2015-05-14), pages 1-5, XP055374699, Piscataway, NJ DOI: 10.1109/VTCSpring.2015.7145956 ISBN: 978-1-4799-8088-8 the whole document -----	1-3,5-9, 15 11,12

-/--

7

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TOSHIHIKO OKAMURA: "A Hybrid ARQ Scheme Based on Rate-Compatible Low-Density Parity-Check Codes by Shortening and Extending", IEICE TRANSACTIONS ON FUNDAMENTALS OF ELECTRONICS,COMMUNICATIONS AND COMPUTER SCIENCES, ENGINEERING SCIENCES SOCIETY, TOKYO, JP, vol. E92A, no. 11, 1 November 2009 (2009-11-01), pages 2883-2890, XP001550892, ISSN: 0916-8508, DOI: 10.1587/TRANSFUN.E92.A.2883	1-3,5-9, 15
A	page 2887	11,12
A	HYEUNG-GUN JOO ET AL: "Design of rate-compatible RA-type low-density parity-check codes using splitting", IEEE TRANSACTIONS ON COMMUNICATIONS, IEEE SERVICE CENTER, PISCATAWAY, NJ. USA, vol. 57, no. 12, 1 December 2009 (2009-12-01), pages 3524-3528, XP011285974, ISSN: 0090-6778, DOI: 10.1109/TCOMM.2009.12.0603462 the whole document	11,12
A	WO 2008/069460 A1 (KOREA ELECTRONICS TELECOMM [KR]; OH JONG-EE [KR]; YOON CHANHO [KR]; CH) 12 June 2008 (2008-06-12) the whole document	11,12
A	ZHAO PEIYAO ET AL: "Construction of Multiple-Rate QC-LDPC Codes Using Hierarchical Row-Splitting", IEEE COMMUNICATIONS LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 20, no. 6, 1 June 2016 (2016-06-01), pages 1068-1071, XP011613031, ISSN: 1089-7798, DOI: 10.1109/LCOMM.2016.2553658 [retrieved on 2016-06-08] the whole document	11,12

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/RU2016/000534

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

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

1. [X] Claims Nos.: 13, 14
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

see additional sheet

1. [X] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10, 15(completely); 11, 12(partially)

    Device to generate a second protograph defining a second code H' based on a first protograph defining a first code H. The first protograph is part of the second protograph and the extended part of the second protograph comprises a diagonal submatrix (basic definition for the so-called generalized repeat accumulate GRA construction). Focus on a selection rule for determining positions of non-zero elements in the extension part of the second parity protograph (details of the GRA construction). Communication apparatus comprising a channel encoder comprising a first and a second protograph generated accordingly.

    ---

2. claims: 11, 12(partially)

    Communication apparatus for a HARQ scheme where the channel encoder uses either a code extension according to claim 1 (defining the basics of the GRA rule) or a code extension using a row-splitting scheme depending of the code rate.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 13, 14

Rule 39.1(i) PCT - Mathematical method
The subject-matter of claims 13-14 does not have a technical character but constitute purely mathematical methods. In particular, independent claim 13 specifies a method for generating a second protograph matrix P' defining a second code H' comprising solely mathematical method steps related to the extension of a first protograph matrix P defining a first code H. It is noted that a code is composed of codewords with length n and is a subset of all binary vectors of length n. Consequently, a code and its corresponding protograph matrix as such are purely mathematical constructions which have no technical character and this applies also to the code generation (i.e. the generation of the corresponding protograph) itself. It is further noted that a method for generating a protograph defining a code only fulfils the requirements of Rule 39 PCT if technical means for carrying out the method are claimed (see claims 8-15) or if an additional method step of using the generated protograph (i.e. the generated code) to determine the symbols to be transmitted or retransmitted within an HARQ system would be additionally claimed.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/RU2016/000534

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008155385 A1	26-06-2008	NONE	
EP 1868294 A1	19-12-2007	EP 1868294 A1	19-12-2007
		KR 20070119580 A	20-12-2007
		US 2008028273 A1	31-01-2008
		WO 2007145491 A1	21-12-2007
US 2008178065 A1	24-07-2008	AU 2008207799 A1	31-07-2008
		BR PI0806757 A2	13-09-2011
		CA 2674719 A1	31-07-2008
		CN 101601187 A	09-12-2009
		CN 102904583 A	30-01-2013
		EP 2106635 A2	07-10-2009
		EP 2568612 A1	13-03-2013
		JP 5231453 B2	10-07-2013
		JP 5551209 B2	16-07-2014
		JP 5559246 B2	23-07-2014
		JP 2010517444 A	20-05-2010
		JP 2012231473 A	22-11-2012
		JP 2012231474 A	22-11-2012
		KR 20090113869 A	02-11-2009
		KR 20120076382 A	09-07-2012
		KR 20130023375 A	07-03-2013
		KR 20130026525 A	13-03-2013
		KR 20130081324 A	16-07-2013
		RU 2009131711 A	27-02-2011
		TW 200838159 A	16-09-2008
		TW 201334425 A	16-08-2013
		US 2008178065 A1	24-07-2008
		US 2012166914 A1	28-06-2012
		WO 2008092040 A2	31-07-2008
US 2005283709 A1	22-12-2005	KR 20060048403 A	18-05-2006
		US 2005283709 A1	22-12-2005
US 2007162822 A1	12-07-2007	KR 20070059696 A	12-06-2007
		US 2007162822 A1	12-07-2007
WO 2008069460 A1	12-06-2008	NONE	