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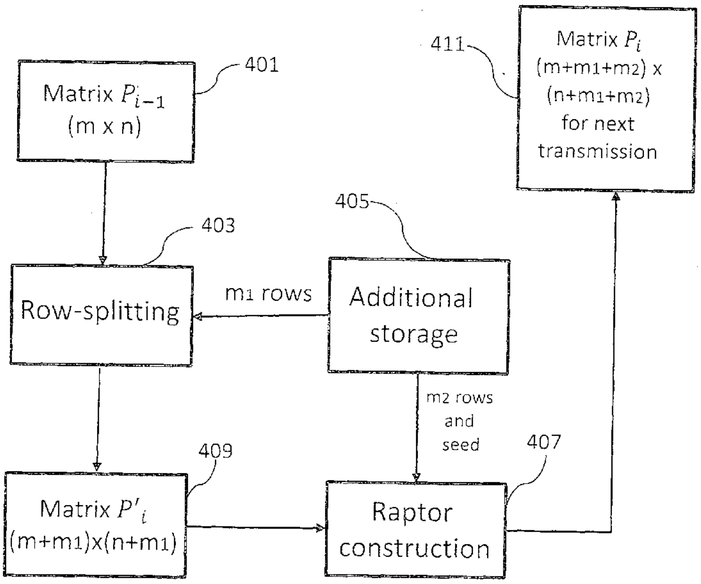

Fig. 4

(57) Abstract: The invention relates to a device (100) and method (1100) for generating on the basis of a first protograph matrix P_1 of size m x n, wherein the first protograph matrix P_1 defines a first code H_1 a second protograph matrix P_2 of size (m + d) x (n + d), wherein the second protograph matrix P_2 defines a second code H_2. The device (100) comprises a processor (102) configured to: (i) generate an auxiliary protograph matrix P' of size $(m + d_1)$ x $(n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting; (ii) generate d_2 random integer numbers, wherein $d_2 = d - d_1$; (iii) generate a binary matrix M of size d_2 x (n - m), wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers; (iv) generate a matrix M' by

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lifting the binary matrix M; (v) generate a matrix I of size d_2 x d_2, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements; (vi) generate a matrix C_1 of size (m + d_1) x d_2 and a matrix C_2 of size d_2 x (m + d_1), wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts; and (vii) generate the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C1 and the matrix C_2 wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

DEVICES AND METHODS FOR GENERATING A LOW DENSITY PARITY CHECK CODE FOR A INCREMENTAL REDUNDANCY HARQ COMMUNICATION APPARATUS

TECHNICAL FIELD

Generally, the present invention relates to the field of channel coding. More specifically, the present 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 an HARQ method of combination of 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). In particular, quasi cyclic low density parity check (QC-LDPC) codes can have a compact specification due to the fact that they can be defined by means of protograph matrices and circulant matrices.

US20110239075 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. However, this scheme is an offline HARQ scheme, wherein bits which are sent more than once are mapped to lower reliable bits in points of the constellation.

US2011138260 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 are disclosed, for instance, in US2007113147, US2010192037 and US2007220399. US2007113147 suggests arranging transmitted parity bits at regular intervals. In US2010192037 the transmission order of parity bits is based on their column degree. In US2007220399 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 for 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_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2. The device comprises a processor configured to generate an auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting, generate d_2 random integer numbers, wherein $d_2 = d - d_1$, generate a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers, generate a matrix M' by lifting the binary matrix M, generate a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements, generate a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts, and generate the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

In a first possible implementation form of the device according to the first aspect as such, the processor is further configured to generate the d_2 random integer numbers on the basis of a mean row weight λ of the auxiliary protograph matrix P', wherein the mean row weight λ is defined as a ratio of the number of nonempty circulants of the auxiliary matrix P' to $m + d_1$.

In a second possible implementation form the device according to the first implementation form of the first aspect, the processor is further configured to generate the d_2 random integer numbers on the basis of a Poisson distribution having a mean value λ.

In a third possible implementation form of the device according to the first aspect as such, the first or the second implementation form thereof, the auxiliary protograph matrix P' has a circulant size z and the processor is further configured to generate at most z random circulant shifts on the basis of a seed, wherein the z random circulant shifts have integer values lower than z or equal to z.

In a fourth possible implementation form of the device according to the third implementation form of the first aspect, the processor is further configured to lift the binary matrix M by replacing elements of the binary matrix M equal to 1 by one of the z random circulant shifts and by replacing the elements of the binary matrix M equal to 0 by -1.

In a fifth possible implementation form of the device according to the first aspect as such, or any one of the first to fourth implementation form thereof, the processor is further configured to set the elements $(1\mathrm{:m} + d_1, 1\mathrm{:n} + d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the auxiliary protograph matrix P'.

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 processor is further configured to set the elements $(1\mathrm{:m} + d_1, \mathrm{n} + d_1 + 1\mathrm{:n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_1.

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 processor is further configured to set the elements $(\mathrm{m} + d_1 + 1\mathrm{:m} + \mathrm{d}, 1\mathrm{:n} - \mathrm{m})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix M'.

In an eighth possible implementation form of the device according to the first aspect as such, or any one of the first to seventh implementation form thereof, the processor is further configured to set the elements $(\mathrm{m} + d_1 + 1{:}\,\mathrm{m} + \mathrm{d}, \mathrm{n} - \mathrm{m} + 1{:}\,\mathrm{n} + d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_2.

In a ninth possible implementation form of the device according to the first aspect as such, or any one of the first to eighth implementation form thereof, the processor is further configured to set the elements $(\mathrm{m} + d_1 + 1{:}\,\mathrm{m} + \mathrm{d}, \mathrm{n} + d_1 + 1{:}\,\mathrm{n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix I.

In a tenth possible implementation form of the device according to the first aspect as such, or any one of the first to ninth implementation form thereof, the first protograph matrix P_1 and/or the auxiliary protograph matrix P' and/or the second protograph matrix P_2 have the same circulant size.

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 as such or any one of the first to tenth implementation form thereof.

According to a third aspect the invention relates to a communication apparatus comprising a channel encoder comprising a first protograph matrix P_1 or a corresponding first code H_1 and a second protograph matrix P_2 or a corresponding second code H_2, wherein the channel encoder is configured to use the first code H_1 for a first transmission of a HARQ scheme and the second code H_2 for a retransmission of the HARQ scheme and wherein the first protograph matrix P_1 or the corresponding first code H_1 and the second protograph matrix P_2 or the corresponding second code H_2 have been provided by a device for generating a protograph matrix according to the first aspect as such or any one of the first to tenth implementation form thereof.

According to a fourth aspect the invention relates to a method for generating on the basis of a first protograph matrix P_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2. The method comprises the steps of: generating an auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting, generating d_2 random integer numbers, wherein $d_2 = d - d_1$, generating a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers, generating a matrix M' by lifting the binary matrix M, generating a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements, generating a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts, and generating the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

In a first possible implementation form of the method according to the fourth aspect as such, the method further comprises the step of: setting the elements $(1\!:\mathrm{m} + \mathrm{d1}, 1\!:\mathrm{n} + \mathrm{d1})$ of the second protograph matrix P_2 equal to the corresponding elements of the auxiliary matrix P'.

In a second possible implementation form of the method according to the fourth aspect as such or the first implementation form thereof, the method further comprises the step of: setting the elements $(1\!:\mathrm{m} + d_1, \mathrm{n} + d_1 + 1\!:\mathrm{n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_1.

In a third possible implementation form of the method according to the fourth aspect as such, the first or the second implementation form thereof, the method further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1\!:\mathrm{m} + \mathrm{d}, 1\!:\mathrm{n} - \mathrm{m})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix M'.

In a fourth possible implementation form of the method according to the fourth aspect as such or any one of the first to third implementation form thereof, the method further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1\!:\mathrm{m} + \mathrm{d}, \mathrm{n} - \mathrm{m} + 1\!:\mathrm{n} + d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_2.

In a fifth possible implementation form of the method according to the fourth aspect as such or any one of the first to fourth implementation form thereof, the method further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1\!:\mathrm{m} + \mathrm{d}, \mathrm{n} + d_1 + 1\!:\mathrm{n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix I.

According to a fifth aspect, the invention relates to a computer program comprising a program code for performing the method according to the fourth aspect as such or any one of the first to fifth possible implementation form thereof 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 a device for generating a code for a HARQ 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 some steps for a transmission in a HARQ communication apparatus according an embodiment;

Fig. 4 shows a schematic diagram illustrating some steps of an algorithm for generating a matrix by a device for generating a code according to an embodiment;

Fig. 5 shows a schematic diagram illustrating some steps of an algorithms for generating a matrix by a device for generating a code according to an embodiment;

Fig. 6 shows a schematic diagram illustrating a first protograph matrix and an auxiliary protograph matrix generated by a device for generating a code according to an embodiment;

Fig. 7 shows a schematic diagram illustrating a binary matrix and a lifted matrix generated by a device for generating a code according to an embodiment;

Fig. 8 shows a schematic diagram illustrating a second matrix generated by a device for generating a code according to an embodiment;

Fig. 9 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment;

Fig. 10 shows a schematic diagram illustrating the performance of a HARQ communication apparatus according to an embodiment; and

Figure 11 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 present invention. The following detailed description, therefore, is not to be taken in a limiting sense, as the scope of the present invention is defined by 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 its 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 $-1 \le p_{i,j} \le z-1$.

An LDPC code, in particular a 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:

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

wherein 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. The integers $p_{i,j}$ are usually called circulant shifts. If $p_{i,j} = -1$, then $p_{i,j}$ is called an empty circulant shift. If $p_{i,j} = 0$, then $p_{i,j}$ is called a zero circulant shift.

In embodiments of the invention, H represents a first LDPC code, in particular a first QC-LDPC code, which can be used for the first transmission of a HARQ scheme, in particular of 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:

$$P = \begin{array}{|c|c|c|c|c|c|c|c|c|c|}\hline & i_1 & i_2 & \cdots & i_{n-m} & p_1 & p_2 & \cdots & p_{m-1} & p_m \\ \hline r_1 & p_{1,1} & p_{1,2} & \cdots & p_{1,n-m} & 0 & -1 & \cdots & -1 & -1 \\ \hline r_2 & p_{2,1} & p_{2,2} & \cdots & p_{2,n-m} & 0 & 0 & \cdots & -1 & -1 \\ \hline \end{array}$$

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

In 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 a $m \cdot (z \times z)$ submatrix of $H(P)$, that is, i_j corresponds to a group of z information bits as well as p_j.

In other embodiments of the invention, the protograph matrix P is a repeat accumulate (RA), an extended irregular repeat-accumulate (eIRA) protograph matrix or a multi-edge protograph matrix.

The device 100 in figure 1 for generating a code for the HARQ communication apparatus 210 comprises a processor 102. The processor 102 of the device 100 is configured to generate on the basis of a first protograph matrix P_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2.

In a first stage, the processor 102 of the device 100 is configured to generate an auxiliary protograph matrix P′ of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting.

In a second stage, the processor 102 of the device 100 is configured to generate d_2 random integer numbers, wherein $d_2 = d - d_1$.

In a third stage, the processor 102 of the device 100 is configured to generate a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers.

In a fourth stage, the processor 102 of the device 100 is configured to generate a matrix M′ by lifting the binary matrix M.

In a fifth stage, the processor 102 of the device 100 is configured to generate a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements.

In a sixth stage, the processor 102 of the device 100 is configured to generate a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts; and

In a seventh stage, the processor 102 of the device 100 is configured to generate the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

The first protograph matrix P_1 and/or the corresponding first code H_1 and the second protograph matrix P_2 and/or the corresponding second code H_2 as described above can be beneficially used in a HARQ scheme. In an embodiment, the first protograph matrix P_1 and/or the corresponding first code H_1 and the second protograph matrix P_2 and/or the corresponding second code H_2 are implemented in the communication apparatus 210 of the communication system 200 shown in figure 2.

In an embodiment, the communication system 200 shown in figure 2 implements a reliability based HARQ (RB-HARQ) scheme. The communication system 200 comprises the transmitting communication apparatus 210 and the receiving communication apparatus 230. In an embodiment, the transmitting communication apparatus 210 and the receiving communication apparatus 230 could be a base station, a user equipment or the like.

A binary information sequence with attached cyclic redundancy check (CRC) 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 a transmission l, a binary code sequence $\boldsymbol{c}^{(l)} = \left(c^l(1), c^l(2), \dots, c^l(N_l)\right)$ is obtained, 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 $x^{(l)}$. 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:

$$r_i^{(l)} = h_i^{(l)} \cdot x_i^{(l)} + n_i^{(l)},$$

wherein $h_i^{(l)}$ 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) L, which can be implemented in a Max-Log-MAP (maximum a posteriori) fashion:

$$L_{i,k}^{(l)} = \max_{\theta_j \in A:\theta_{j,k}=1} \log F(r_i^{(l)}, \hat{h}_i^{(l)}, \hat{\sigma}_l, \boldsymbol{\theta}_j) - \max_{\theta_j \in A:\theta_{j,k}=0} \log F(r_i^{(l)}, \hat{h}_i^{(l)}, \hat{\sigma}_l, \boldsymbol{\theta}_j),$$

wherein

$$\log F\left(r_i^{(l)}, \hat{h}_i^{(l)}, \hat{\sigma}_l, \boldsymbol{\theta}_j\right) = -\frac{\left\| r_i^{(l)} - \hat{h}_i^{(l)} \cdot \boldsymbol{\theta}_j \right\|^2}{2 \cdot \hat{\sigma}_l^{\,2}},$$

wherein $\hat{h}_i^{(l)}$ and $\hat{\sigma}_l^{\,2}$ are estimations of a fading coefficient and of a noise variance respectively, 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 decoder. So, $L_{in}^{(l)}$ corresponds to input LLRs of the SISO decoder 231 at the l-th transmission and $L_{out}^{(l)}$ - soft output LLRs of the decoder 231. Generally, RB-HARQ algorithms take $L_{out}^{(l)}$ 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 configured to perform the steps illustrated in figure 3, which define a first stage of a HARQ scheme with $K \geq 2$ possible steps. Let n_i be the number of columns of a protograph matrix P_i, $n = n_1, n_{i+1} > n_i$. In the case of incremental redundancy, $n_i = i \cdot n$.

Let the circulant size be denoted by z and let the information bits (block 301) with attached CRC be denoted by $\boldsymbol{u}$. Then, by encoding $\boldsymbol{u}$ by means of an LDPC code $H(P_1)$, the codeword $\boldsymbol{c_1}$ of length $n_1 \cdot z$ for a current channel transmission (block 303) can be obtained, wherein P_1 is a protogrpah matrix of the first transmission (block 309), which can be used for the first transmission (block 311). After modulation of the codeword, the passage of the codeword through the communication channel 220, and the demodulation of the received signal (block 305), a soft information $\boldsymbol{L_1}$ consisting of LLR's corresponding to the bits of $\boldsymbol{c_1}$ can be obtained. Then, $\boldsymbol{L_1}$ can be decoded (block 315) by means of a parity-check matrix. After decoding, the CRC can be checked (block 317). If the information is confirmed, then the correct information bits have been received (block 318). Otherwise, the next stage with $iter = 2$ can be performed.

In the next stage, the protograph matrix P_{iter} for a next transmission is constructed (block 313). Then, $\boldsymbol{u}$ is encoded using a LDPC code $H(P_{iter})$ and a codeword $\boldsymbol{c_{iter}}$ of length $n_{iter} \cdot z$ is obtained (block 303). Since $\boldsymbol{c_{iter}}$ contains $\boldsymbol{c_{iter-1}}$ as a subword, only the remaining part of $\boldsymbol{c_{iter}}$ is transmitted, that is $\boldsymbol{c_{iter}} \backslash \boldsymbol{c_{iter-1}}$ is transmitted. After modulation of the codeword, the passage of the codeword through the communication channel 220, and the demodulation of the received signal (block 305), the soft information $\boldsymbol{L'_{iter}}$ consisting of LLR's corresponding to bits of $\boldsymbol{c_{iter}} \backslash \boldsymbol{c_{iter-1}}$ can be obtained. 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 $n_{iter} \cdot z$). By means of the parity-check matrix, $\boldsymbol{L_{iter}}$ can be decoded (block 315). After decoding, the CRC can be checked (block 317). If the information is confirmed, then the correct information bits have been received (block 318). Otherwise, if $iter < K$, the above next stage with $iter = iter + 1$ can be repeated.

Figure 4 shows a schematic diagram illustrating some steps of an algorithm for generating a matrix by the device 100 for generating a code according to an embodiment. In particular, in this embodiment, some steps of an algorithm for generating a protograph matrix P_i (block 411) used for generating a QC LDPC code $H_2 = H(P_i)$ of a next transmission on the basis of a protograph matrix P_{i-1} (block 401) used for generating a code $H_1 = H(P_{i-1})$ in a previous transmission are illustrated. The QC-LDPC code H_2 has a length $(n + m)z$, wherein z is a circulant size of the protograph matrix P_i, while the QC-LDPC code H_1 has a length nz such that the code H_1 is a subcode of the code H_2.

Moreover, some predefined parameters can be stored in a memory 405, which are used in a first row-splitting (RS) algorithm (block 403) and in a second algorithm, which is herein referred to as raptor-like construction (RLC) algorithm (block 407).

In a first step, the protograph matrix P_{i-1} of size $m \times n$ (block 401) is used as input in the row-splitting (RS) algorithm (block 403) in order to obtain the auxiliary protograph matrix P'_i (block 409) according to the following relation:

$$P'_i = RS(P_{i-1}, m_1)$$

wherein the auxiliary protograph matrix P'_i (block 409) has m_1 more rows and columns than the protograph matrix P_{i-1} (block 401), and wherein m_1 is stored in the additional storage unit 405.

In a next step, the auxiliary protograph matrix P'_i of size $(m + m_1) \times (n + m_1)$ (block 409) is used as input for the raptor like construction (RLC) algorithm (block 407) in order to obtain the protograph matrix P_i of size $(m + m_1 + m_2) \times (n + m_1 + m_2)$ (block 411) for the next transmission according to the following relation:

$$P_i = RLC(P'_i, m_2, seed)$$

wherein m_2 corresponds to the number of additional rows and columns of P_i compared to P'_i and $seed$ is a seed used in a pseudorandom algorithm. The input parameters m_1, m_2 and $seed$ can be stored in the additional storage unit 405. In embodiments of the invention, the parameters m_1, m_2 and $seed$ can be calculated offline and can be chosen in such a way that the HARQ scheme with these parameters provides the best performance among all possible parameters.

In general, in order to obtain a protograph matrix P_i of size $(m + d) \times (n + d)$, first $i - 2$ similar steps can be performed in order to get the protograph matrix P_{i-1} of size $m \times n$, and, then, the following steps can be performed:

$$P'_i = RS(P_{i-1}, d_i)$$

$$P_i = RLC(P'_i, d - d_i, seed_i),$$

wherein P'_i is a protograph matrix of size $(m + d_i) \times (n + d_i)$ and $seed_i$ is a seed used to generate $d - d_i$ random numbers.

In general, the algorithm used to generate protograph matrices used in HARQ schemes has as input a P_1 protograph matrix of size $m \times n$, a number K of maximum HARQ transmissions, a set of seeds $\{seed_2, seed_3, \dots, seed_K\}$, and a set of integers $\{d_2, d_3, \dots, d_K\}$, wherein $d_j \leq n$, and as output a set of K protograph matrices $P_1, \dots, P_K$, corresponding to each transmission according to the HARQ scheme, wherein the sizes of P_i is $(m + \sum_{j=2}^{i} d_{\mathrm{j}}) \times (n + \sum_{j=2}^{i} d_{\mathrm{j}})$.

As already described above, in embodiments of the invention, the RS algorithm can be used by the device 100 to generate the auxiliary protograph matrix P'. In an embodiment, the processor 102 of the device 100 is configured to generate the auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ with circulant size z on the basis of the first protograph matrix P_1 of size $m \times n$ with circulant size z using the following RS algorithm. In an embodiment, the first protograph matrix P_1 and/or the auxiliary protograph matrix P' are repeat accumulate (RA) matrices. In an embodiment, further input parameters for the RS algorithm are the integer number d_1, and an option $O \in \{A, B\}$, wherein the options A and B allow to control regularity or irregularity of the obtained QC-LDPC code $H(P')$.

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 $p_{i,j} \neq -1,\ 1 \leq j \leq n - m$.
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 $Weight < m + d_1$, and, if this is the case, the RS algorithm will be terminated.
If $O = A$, then a $m \times 1$ vector $\mathrm{splittingFactors}$ is defined, such that $\mathrm{splittingFactors(i)} \leq RowWeight(i)$, and all values of $\mathrm{splittingFactors}$ are close (may be equal) to each other, and $\sum \mathrm{splittingFactors(i)} = \mathrm{m} + d_1$.
If $O = B$, then a $m \times 1$ vector $\mathrm{splittingFactors}$ is defined, such that $\mathrm{splittingFactors(i)} \leq RowWeight(i)$ and all values given by $\frac{\mathrm{splittingFactors(i)}}{RowWeight(i)}$ are close (may be equal) to each other, and $\sum \mathrm{splittingFactors(i)} = \mathrm{m} + d_1$.

In particular, the vector $\mathrm{splittingFactors(i)}$ determines how many rows will appear in the auxiliary protograph matrix P' instead of the i-th row of the first protograph matrix P_1.
The auxiliary protograph matrix P' consists of m submatrices $P'(i)$

$$P' = \begin{array}{|c|} \hline P'(1) \\ \hline P'(2) \\ \hline \cdots \\ \hline \cdots \\ \hline P'(\mathrm{m}) \\ \hline \end{array}$$

The submatrix $P'(i)$ is obtained by splitting the i-th row of the first protograph matrix P_1 and by adding some new columns in the way, as expressed by the following pseudo code.

```
$P'(i)$ is predetermined as a $(\mathrm{splittingFactor(i)}) \times (n + d_1)$ matrix of -1's.
Residue = 0;
For any $j \in [n - m]$
    If $P(i,j) == -1$
        Continue;
    End If
    Residue = Residue + 1;
            Residue = mod(Residue, splittingFactor(i));
            $P'(i, \mathrm{Residue}) = P(i,j)$;
        End For
         $begPos(i) = n - m + \sum_{k=1}^{i-1} \mathrm{splittingFactor(k)}$ ;
Insert in $P'$(i, $begPos(i) + 1 : begPos(i) + \mathrm{splittingFactor(i)}$) a $(\mathrm{splittingFactor(i)}) \times \mathrm{splittingFactor(i)})$ ) matrix representing a RA part of LDPC code;
  End For
```

The auxiliary 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_1 with circulant size 5:

$P_1 =$

	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_1 and $d_1 = 4$;

1) $RowWeight = (3, 2, 3)^T$;

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

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 auxiliary protograph matrix P' are based on row r_1 of the first protograph matrix P_1. Rows r_{21} and r_{22} of the auxiliary protograph matrix P' are based on row r_2 of the first protograph matrix P_1. The rows r_{31}, r_{32} and r_{33} of the auxiliary matrix P' are based on the row r_3 of the first protograph matrix P_1.

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

The rows r_{11}, r_{12} and r_{13} of the auxiliary protograph matrix P' are based on the row r_1 of the first protograph matrix P_1. The row r_{21} of the auxiliary protograph matrix P' is based on the row r_2 of the first protograph matrix P_1. The rows r_{31} and r_{32} of the auxiliary protograph matrix P' are based on the row r_3 of the first protograph matrix P_1.

The RS approach described above leads to a coherent first protograph matrix P_1 and to a coherent auxiliary protograph P', as well as to coherent corresponding LDPC codes. Indeed, since $r_i = \sum_j r_{ij}$, the rows in each layer of the auxiliary matrix P' (using the rule (-1+k) = k and (k+k) = -1) can be summed and a matrix P'', which could be the same as P, can be obtained, if columns with zero weight, i.e. columns consisting of -1's only, are excluded, wherein the matrix P'' is given by:

$P'' =$

	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

In other words, if information bits (i_1, i_2, i_3) are encoded with the LDPC code corresponding to the auxiliary 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_1 with the same information bits (i_1, i_2, i_3).

In embodiments of the invention, the raptor-like construction (RLC) algorithm can be used by the device 100 to generate the second protograph matrix P_2. In an embodiment, the processor 102 of the device 100 is configured to generate the second protograph matrix P_2 of size $(m + d\ ) \times (n + d)$ with circulant size z on the basis of the auxiliary protograph matrix P' of size $(m + d_1)\ \times (n + d_1)$ with circulant size z using the following RLC algorithm. In an embodiment, the first protograph matrix P_1 and/or the second protograph matrix P_2 are RA matrices.

In a first step of the RLC algorithm illustrated in figure 5, an average row weight of the auxiliary protograph matrix P' is computed (block 503), wherein the row weight is defined according to the following formula:

$$\lambda = \frac{number\ of\ nonempty\ circulants\ in\ P}{m+d_1},$$

wherein $m + d_1$ corresponds to the number of rows of the auxiliary protograph matrix P'.

In a further step of the RLC algorithm, a Poisson random number generator (PRNG) (block 505) having a mean value λ is initialized with a seed $seed$ (block 507).

In a further step of the RLC algorithm, d_2 random integer numbers $X_1, X_2, \dots X_{d_2}$ (block 515) having a Poisson distribution are generated using the PRNG, wherein $d_2 = d - d_1$.

In a further step of the RLC algorithm, a uniform k-subset of t-set generator ($U(k,t)$) is initialized (block 511) with the seed $seed$.

In a further step of the RLC algorithm, a binary matrix M of size $d_2 \times (n - m)$ is constructed (block 513), wherein the i-th row of the binary matrix M can be considered as a subset of a $(n - m)$-set. For each $i \in d_2$, the i-th row of the binary matrix M is generated using $U(X_i, n - m)$.

In a further step of the RLC algorithm, a random number generator (RNG) taking values $[0,1 \dots z - 1]$ is initialized with the seed $seed$. Furthermore, the binary matrix M is randomly lifted (block 517) on the basis of the RNG, i.e., instead of 1-s random circulant shift are put in the binary matrix M, and instead of 0-s, -1 are put in the binary matrix M. By randomly lifting the binary matrix M, a matrix M' is obtained.

The outcome of the RLC algorithm is the second protograph matrix P_2 (block 519).

According to an embodiment of the invention, the second protograph matrix P_2 can be written as follows:

$$P_2 = \begin{array}{|c|c|c|} \hline P'_{inf} & P'_{par} & -1 \\ \hline M' & -1 & I(d_2) \\ \hline \end{array}$$

wherein the auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ (block 501) can be represented in the form $P' = [P'_{inf} P'_{par}]$, wherein P'_{par} is a $(m + d_1) \times (m + d_1)$ matrix corresponding to the parity bits, P'_{inf} is a $(m + d_1) \times (n - m)$ matrix corresponding to the information bits, $I(d_2)$ is a $d_2 \times d_2$ matrix having zero circulant shifts as diagonal elements, and only empty circulant shifts as non-diagonal elements. Finally, -1 corresponds to the part of matrix containing only empty circulant shifts.

In embodiments of the invention, the second protograph matrix P_2 (block 519) can be represented in the following way: $P_2 = [P_{2,inf}\ P_{2,par}]$, wherein:

$$P_{2,inf} \quad \begin{array}{|c|}\hline P'_{inf} \\ \hline M' \\ \hline \end{array} \quad =$$

and

$$P_{2,par} = \begin{array}{|c|c|}\hline P'_{par} & \mathbf{-1} \\ \hline \mathbf{-1} & I(d_2) \\ \hline \end{array}$$

Since the matrix $I(d_2)$ has a diagonal form and P'_{par} has an easy form for encoding, the second protograph matrix P_2 (block 519) can be used for easy (linear-time) encoding.

In order to better illustrate the above mentioned steps of the RS algorithm and of the RLC algorithm, we provide an exemplary first protograph matrix P_1 and a corresponding exemplary auxiliary matrix P' in figure 6, an exemplary binary matrix M and an exemplary lifted matrix M' in figure 7, and an exemplary second protograph matrix P_2 in figure 8.

P_1 is a first protograph matrix of size 3 × 6, that is $m = 3$, $n = 6$, and of circulant size $z = 10$ (see figure 6). The matrix P_1 corresponds to the first transmission in a HARQ scheme. On the basis of the above described RS algorithm and RLC algorithm, a second protograph matrix P_2 of size 9 × 12, namely $d = 6$, corresponding to a second transmission in HARQ scheme can be constructed.

Let d_1 be equal 3 (i.e., $d_1 = 3$ is the parameter chosen offline among all possible parameters which optimizes the performance of the code) and, therefore, $d_2 = d - d_1 = 3$. By applying the RS algorithm to the first protograph matrix P_1, the resulting auxiliary protograph matrix P' can be obtained (see figure 6):

$$P' = RS(P_1, d_1).$$

In order to generate the second protograph matrix P_2 of size 9 × 12, a mean row weight λ of the auxiliary protograph matrix P' is computed:

$$\lambda = \frac{\text{number of nonempty circulants in } P'}{\text{number of rows in } P'} = \frac{20}{6} \approx 3{,}33.$$

Afterwards, $d_2 = 3$ random numbers X_1, X_2, and X_3 are generated by means of a seed *seed* and of a Poisson distribution $\wp$ having mean value λ, wherein a variable X has a Poisson distribution $\wp$, if:

$$\wp(X = k) = \frac{\lambda^k e^{-\lambda}}{k!},$$

wherein k is an integer number. For example, the Poisson random number generator gives the following result: $X_1 = 3,\ X_2 = 4$, and $X_3 = 2$.

Then, the binary matrix M of size 3 × 3 is generated using a uniform k-subset of a t-set random generator, wherein a random variable X with a uniform k-subset of a t-set distribution is defined as follows. Let A be a set of t elements, namely $|A| = \mathrm{t}$. Then, for any B (subset of A), and $|\mathrm{B}| = \mathrm{k}$, the following probability distribution holds:

$$\mathcal{F}(X = B) = \frac{1}{\{t\ \text{choose}\ k\}},$$

wherein $\{t\ \text{choose}\ k\}$ corresponds to a binomial coefficient. Since, in embodiments of the invention, the weights of the new rows of the second protograph matrix P_2 are equal to $X_1 = 3,\ X_2 = 4$, and $X_3 = 2$, respectively, and the matrix $I(d_2)$ (also called raptor part) has row weights and column weights equal to 1, then, for constructing the binary matrix M, a 2-subset of a 3-set generator can be used to get the first row of the binary matrix M, a 3-subset of a 3-set generator can be used to get the second row of the binary matrix M, and a 1-subset of a 3-set generator can be used to get the third row binary matrix M (see figure 7).

Once the binary matrix M is generated, the matrix M' can also be obtained (see figure 7) by randomly lifting the binary matrix M, i.e., instead of 1-s, random circulant shifts (not more than the circulant size 10) can be placed. Finally, the second protograph matrix P_2:

$$P_2 = RLC(P', 3, seed),$$

can be obtained (see figure 8), wherein the second protograph matrix P_2 has three more rows and three more columns than the auxiliary protograph matrix P'. Moreover, the weights of new rows of the second protograph matrix P_2 are equal to $X_1 = 3$, $X_2 = 4$, and $X_3 = 2$, respectively.

Advantageously, the specific form of the second protograph matrix P_2 allows to perform easy (linear time) encoding.

Figures 9 and 10 show a schematic diagram illustrating the performance of a HARQ communication apparatus 230 according to an embodiment. In this embodiment, the first protograph matrix P_1 used for the first transmission in HARQ scheme corresponds to a multi-edge protograph matrix of size 6×21, the coding rate is 3/4, the number of information bits is 2000, and the first protograph matrix P_1 contains 49 nonempty circulant shifts. For the 4-th transmission in HARQ scheme, the code is generated by a 66×81 fourth protograph matrix having 206 nonempty circulant shifts. For every circulant, the following bits can be stored: for each circulant shift value – 9 bits, for its position in a corresponding protograph matrix: for rows and columns – 7 + 7 bits for offline HARQ scheme, 5+5 for online HARQ scheme. Additional memory (less than or equal to 25 bits) for the seeds and the HARQ scheme parameters for online calculations can be taken into account. The total amount of memory for the offline storage of the protograph matrices in HARQ schemes is: $23 \times 206 = 4738$ bits, while the total amount of memory for the on-the-fly generation of the protograph matrices in the HARQ schemes according to embodiments of the invention is: $19 \times 49 + 25 = 956$ bits. In this example, we need 4.96 times less memory for matrix storage and HARQ parameters.

Furthermore, embodiments of the invention have a better performance (block error rate and throughput) than LTE HARQ schemes of different rates, and they also have a performance comparable to the one of offline HARQ schemes for LDPC codes. These results are also verified in different channel conditions, as shown in figures 9 and 10.

In particular, figure 9 shows the block error rate (BLER) as a function of the signal to noise ration E_b/N_0 in dB of a communication apparatus, wherein the case ME LDPC IR (solid lines) refers to a multi-edge LDPC on-the-fly code used in HARQ schemes according to embodiment of the present invention which is compared to a LTE TURBO code with 8 iterations and scaled Max Log MAP decoding (scale factor = 0.75 for all iterations) used in HARQ schemes. By way of example, a CRC of length 24, a code rate equal to 2/3, a number of transmissions equal to 4, a QPSK modulation, an additive white Gaussian noise (AWGN) channel, and an information length of 1000 bits are chosen. Moreover, the number of iteration of the layered min-sum decoder or communication apparatus for the LDPC code simulation is set to 50. As it can be taken from figure 9, for the same value of E_b/N_0, the BLER in the ME LDPC IR cases (solid lines) is much lower than in the other cases. Therefore, the performance of the LDPC on-the-fly code used in HARQ schemes according to embodiments of the present invention is significantly higher compared to the performance of other codes used in HARQ schemes.

In figure 10, the performance of a multi-edge LDPC offline HARQ scheme proposed by Qualcomm is compared to the performance of a multi-edge LDPC on-the-fly HARQ scheme according to embodiments of the present invention. In this embodiment, a code of rate 0.83, a number of transmissions equal to 2, a QPSK modulation, an AWGN channel, an information length of 2000 bits, and a number of iteration of layered min-sum decoder for LDPC simulation of 50 are chosen.

Some advantages of embodiments of the device 100 for generating on-the-fly LDPC matrices for HARQ schemes according to embodiment of the invention include: very good performance (similar to the one of offline HARQ schemes and better than the one of LTE TURBO schemes), saving memory for the matrix storage (only seeds and parameters for the row-splitting algorithm are kept in the memory), and a low complexity of constructing extended codes (they are linear on the number of nonempty circulant shifts). Therefore, embodiments of the present invention can be realized in real time systems.

Figure 11 shows a schematic diagram illustrating a method 1100 for generating a code for a HAQR communication apparatus 210, wherein the method 1100 generates on the basis of a first protograph matrix P_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2. The method 1100 comprises the following steps: generating 1102 an auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting; generating 1104 d_2 random integer numbers, wherein $d_2 = d - d_1$; generating 1106 a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers; generating 1108 a matrix M' by lifting the binary matrix M; generating 1110 a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements; generating 1112 a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts; and generating 1114 the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P′, the matrix M′, the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

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 present 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 present 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_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2, wherein the device (100) comprises:

a processor (102) configured to:

(i) generate an auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting;

(ii) generate d_2 random integer numbers, wherein $d_2 = d - d_1$;

(iii) generate a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers;

(iv) generate a matrix M' by lifting the binary matrix M;

(v) generate a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements;

(vi) generate a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts; and

(vii) generate the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

2. The device (100) of claim 1, wherein the processor (102) is further configured to generate the d_2 random integer numbers on the basis of a mean row weight λ of the auxiliary protograph matrix P', wherein the mean row weight λ is defined as a ratio of the number of nonempty circulants of the auxiliary matrix P' to $m + d_1$.

3. The device (100) of claim 2, wherein the processor (102) is further configured to generate the d_2 random integer numbers on the basis of a Poisson distribution having a mean value λ.

4. The device (100) of any one of the preceding claims, wherein the auxiliary protograph matrix P' has a circulant size z and wherein the processor (102) is further configured to generate at most z random circulant shifts on the basis of a seed, wherein the z random circulant shifts have integer values lower than z or equal to z.

5. The device (100) of claim 4, wherein the processor (102) is further configured to lift the binary matrix M by replacing elements of the binary matrix M equal to 1 by one of the z random circulant shifts and by replacing the elements of the binary matrix M equal to 0 by -1.

6. The device (100) of any one of the preceding claims, wherein the processor (102) is further configured to set the elements $(1{:}\mathrm{m}+d_1, 1{:}\mathrm{n}+d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the auxiliary protograph matrix P'.

7. The device (100) of any one of the preceding claims, wherein the processor (102) is further configured to set the elements $(1{:}\mathrm{m}+d_1, \mathrm{n}+d_1+1{:}\mathrm{n}+\mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_1.

8. The device (100) of any one of the preceding claims, wherein the processor (102) is further configured to set the elements $(\mathrm{m}+d_1+1{:}\mathrm{m}+\mathrm{d}, 1{:}\mathrm{n}-\mathrm{m})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix M'.

9. The device (100) of any one of the preceding claims, wherein the processor (102) is further configured to set the elements $(\mathrm{m}+d_1+1{:}\mathrm{m}+\mathrm{d}, \mathrm{n}-\mathrm{m}+1{:}\mathrm{n}+d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_2.

10. The device (100) of any one of the preceding claims, wherein the processor (102) is further configured to set the elements $(\mathrm{m}+d_1+1{:}\mathrm{m}+\mathrm{d}, \mathrm{n}+d_1+1{:}\mathrm{n}+\mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix I.

11. The device (100) of any one of the preceding claims, wherein the first protograph matrix P_1 and/or the auxiliary protograph matrix P' and/or the second protograph matrix P_2 have the same circulant size.

12. 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.

13. A communication apparatus (210) comprising a channel encoder (213) comprising a first protograph matrix P_1 or a corresponding first code H_1 and a second protograph matrix P_2 or a corresponding second code H_2, wherein the channel encoder (213) is configured to use the first code H_1 for a first transmission of a HARQ scheme and the second code H_2 for a retransmission of the HARQ scheme and wherein the first protograph matrix P_1 or the corresponding first code H_1 and the second protograph matrix P_2 or the corresponding second code H_2 have been provided by a device (100) for generating a protograph matrix according to any one of claims 1 to 11.

14. A method (1100) for generating on the basis of a first protograph matrix P_1 of size $m \times n$, wherein the first protograph matrix P_1 defines a first code H_1, a second protograph matrix P_2 of size $(m + d) \times (n + d)$, wherein the second protograph matrix P_2 defines a second code H_2, wherein the method (1100) comprises:

generating (1102) an auxiliary protograph matrix P' of size $(m + d_1) \times (n + d_1)$ on the basis of the first protograph matrix P_1 using row splitting;

generating (1104) d_2 random integer numbers, wherein $d_2 = d - d_1$;

generating (1106) a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers;

generating (1108) a matrix M' by lifting the binary matrix M;

generating (1110) a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements;

generating (1112) a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts; and

generating (1114) the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P', the matrix M', the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers.

15. The method (1100) of claim 14, wherein the method (1100) further comprises the step of: setting the elements $(1{:}\,\mathrm{m} + d_1, 1{:}\,\mathrm{n} + d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the auxiliary matrix P'.

16. The method (1100) of claim 14 or 15, wherein the method (1100) further comprises the step of: setting the elements $(1{:}\,\mathrm{m} + d_1, \mathrm{n} + d_1 + 1{:}\,\mathrm{n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_1.

17. The method (1100) of any one of the claims 14 to 16, wherein the method (1100) further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1{:}\,\mathrm{m} + \mathrm{d}, 1{:}\,\mathrm{n} - \mathrm{m})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix M'.

18. The method (1100) of any one of the claims 14 to 17, wherein the method (1100) further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1{:}\,\mathrm{m} + \mathrm{d}, \mathrm{n} - \mathrm{m} + 1{:}\,\mathrm{n} + d_1)$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix C_2.

19. The method (1100) of any one of the claims 14 to 18, wherein the method (1100) further comprises the step of: setting the elements $(\mathrm{m} + d_1 + 1{:}\,\mathrm{m} + \mathrm{d}, \mathrm{n} + d_1 + 1{:}\,\mathrm{n} + \mathrm{d})$ of the second protograph matrix P_2 equal to the corresponding elements of the matrix I.

20. A computer program comprising a program code for performing the method (1100) of any one of the claims 14 to 19 when executed on a computer.

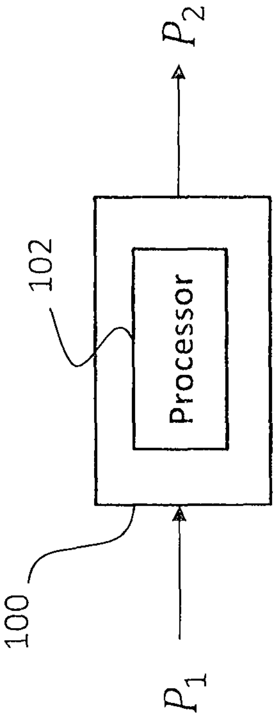

Fig. 1

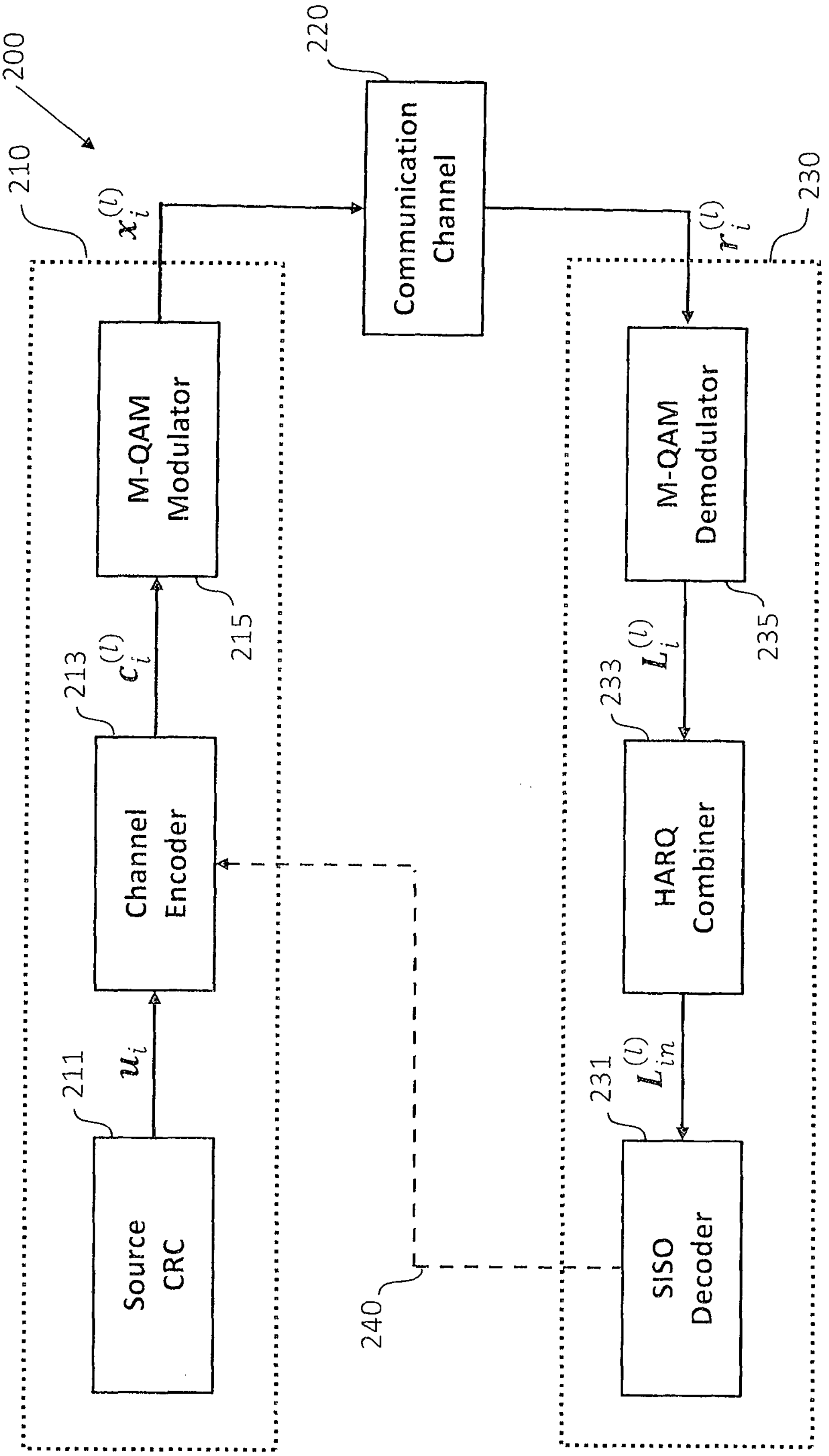
200
220
Communication Channel
210
$x_i^{(l)}$
230
$r_i^{(l)}$
M-QAM Modulator
215
M-QAM Demodulator
235
213
$c_i^{(l)}$
233
$L_i^{(l)}$
Channel Encoder
HARQ Combiner
211
u_i
231
$L_{in}^{(l)}$
Source CRC
SISO Decoder
240

Fig. 2

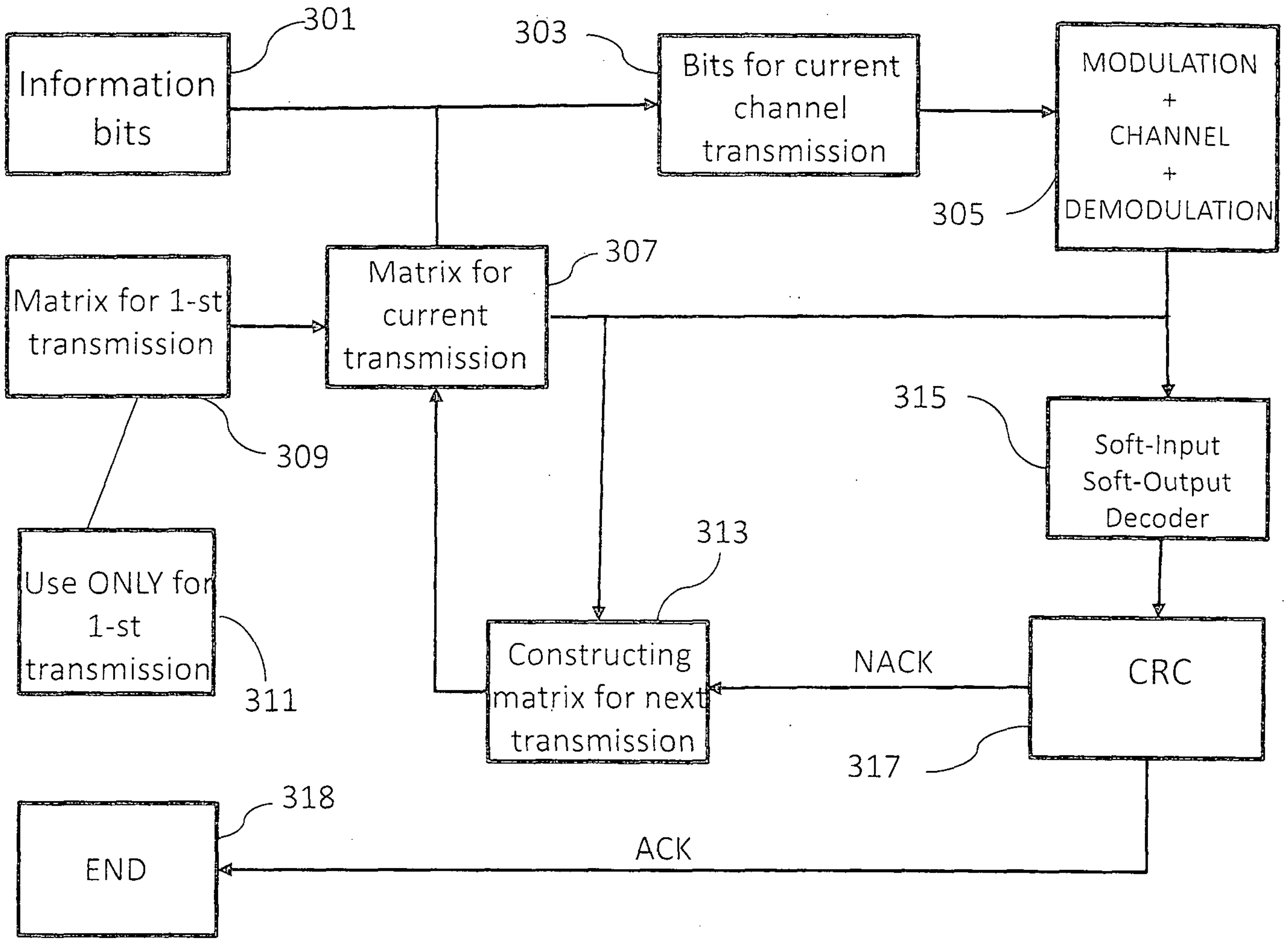
Information bits
301
303
Bits for current channel transmission
MODULATION + CHANNEL + DEMODULATION
305
Matrix for 1-st transmission
Matrix for current transmission
307
309
315
Soft-Input Soft-Output Decoder
Use ONLY for 1-st transmission
311
313
Constructing matrix for next transmission
NACK
CRC
317
318
END
ACK

Fig. 3

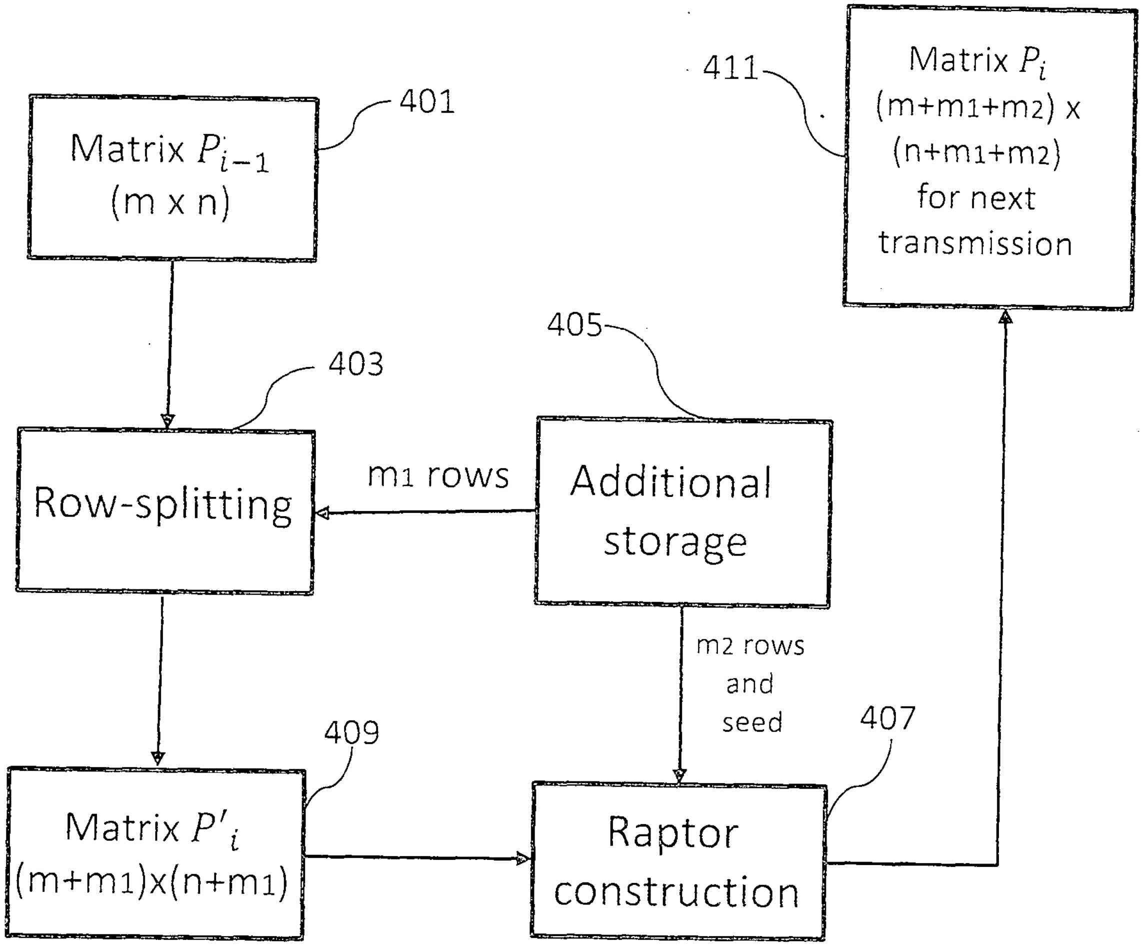
Matrix P_{i-1}
(m x n)
401
403
Row-splitting
m1 rows
405
Additional storage
m2 rows and seed
409
Matrix P'_i
(m+m1)x(n+m1)
407
Raptor construction
411
Matrix P_i
(m+m1+m2) x
(n+m1+m2)
for next transmission

Fig. 4

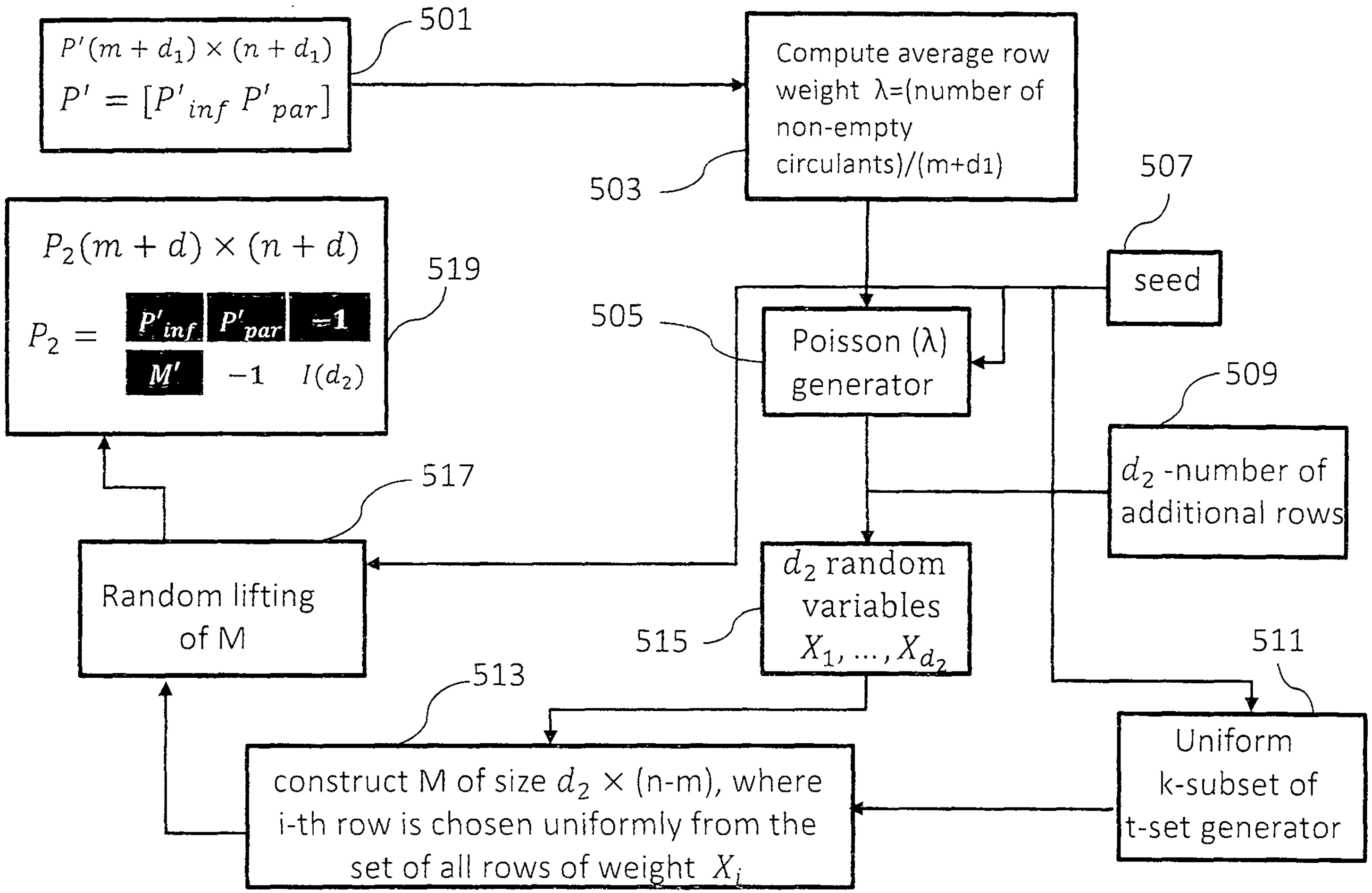
$P'(m + d_1) \times (n + d_1)$
$P' = [P'_{inf}\ P'_{par}]$
501
Compute average row weight λ=(number of non-empty circulants)/(m+d1)
503
507
seed
505
Poisson (λ) generator
509
d_2 -number of additional rows
$P_2(m + d) \times (n + d)$
$P_2 =$
P'_{inf}
P'_{par}
-1
M'
-1
$I(d_2)$
519
517
Random lifting of M
515
d_2 random variables $X_1, \ldots, X_{d_2}$
511
513
Uniform k-subset of t-set generator
construct M of size $d_2 \times$ (n-m), where i-th row is chosen uniformly from the set of all rows of weight X_i

Fig. 5

$P_1 =$

7	5	3	0	-1	-1
6	1	8	0	0	-1
1	4	9	-1	0	0

$P' =$

7	-1	3	0	-1	-1	-1	-1	-1
-1	5	-1	0	0	-1	-1	-1	-1
6	-1	8	-1	0	0	-1	-1	-1
-1	1	-1	-1	-1	0	0	-1	-1
1	-1	9	-1	-1	-1	0	0	-1
-1	4	-1	-1	-1	-1	-1	0	0

Fig. 6

$$M = \begin{array}{|c|c|c|}\hline 1 & 1 & 0 \\ \hline 1 & 1 & 1 \\ \hline 0 & 1 & 0 \\ \hline \end{array}$$

$$M' = \begin{array}{|c|c|c|}\hline 8 & 3 & -1 \\ \hline 4 & 3 & 6 \\ \hline -1 & 5 & -1 \\ \hline \end{array}$$

Fig. 7

$P_2 =$

7	-1	3	0	-1	-1	-1	-1	-1	-1	-1	-1
-1	5	-1	0	0	-1	-1	-1	-1	-1	-1	-1
6	-1	8	-1	0	0	-1	-1	-1	-1	-1	-1
-1	1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
1	-1	9	-1	-1	-1	0	0	-1	-1	-1	-1
-1	4	-1	-1	-1	-1	-1	0	0	-1	-1	-1
8	3	-1	-1	-1	-1	-1	-1	-1	0	-1	-1
4	3	6	-1	-1	-1	-1	-1	-1	-1	0	-1
-1	5	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

M`-part

I(3)-raptor part

Fig. 8

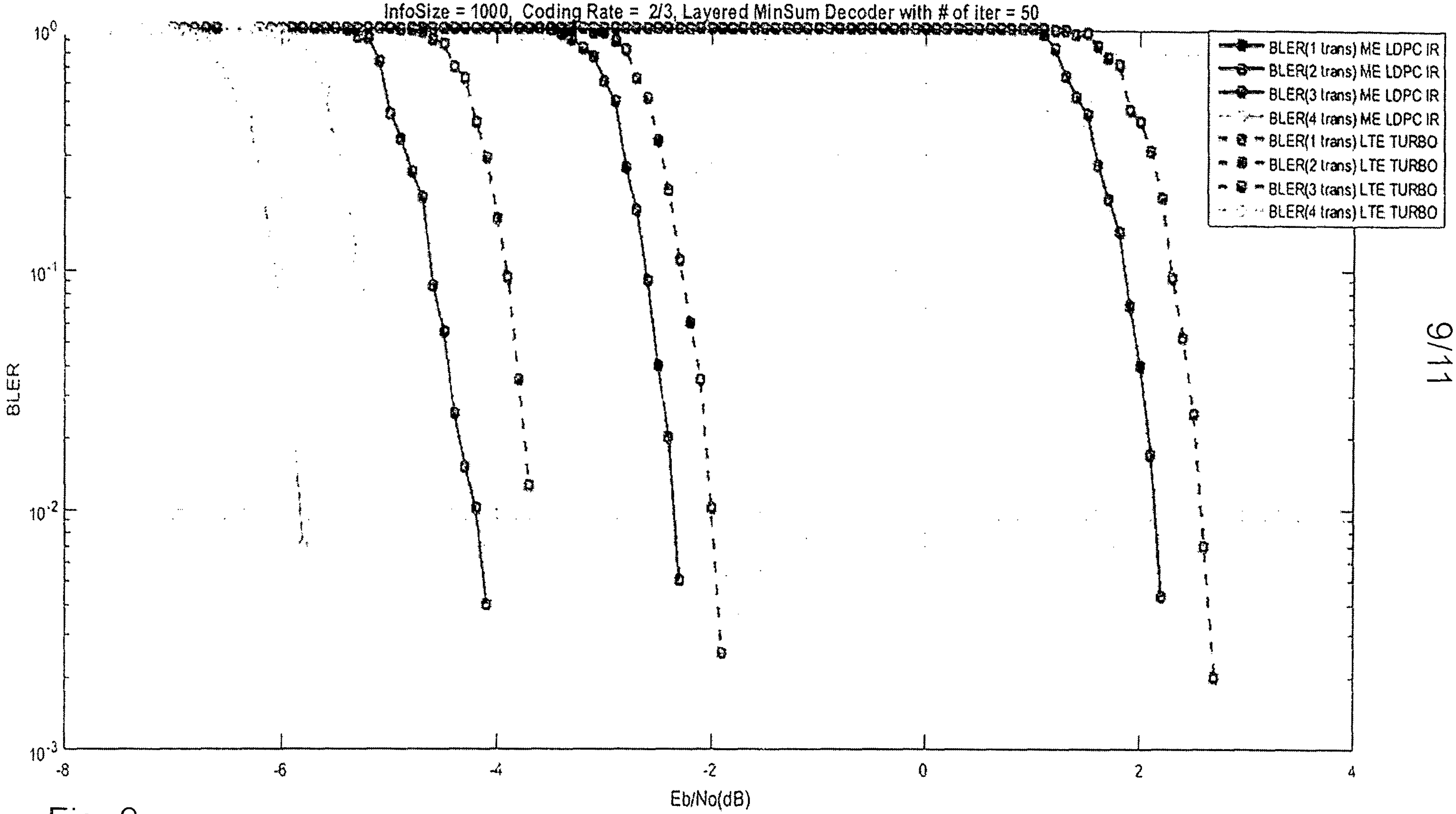
InfoSize = 1000, Coding Rate = 2/3, Layered MinSum Decoder with # of iter = 50
BLER(1 trans) ME LDPC IR
BLER(2 trans) ME LDPC IR
BLER(3 trans) ME LDPC IR
BLER(4 trans) ME LDPC IR
BLER(1 trans) LTE TURBO
BLER(2 trans) LTE TURBO
BLER(3 trans) LTE TURBO
BLER(4 trans) LTE TURBO
BLER
10^0
10^{-1}
10^{-2}
10^{-3}
-8
-6
-4
-2
0
2
4
Eb/No(dB)

Fig. 9

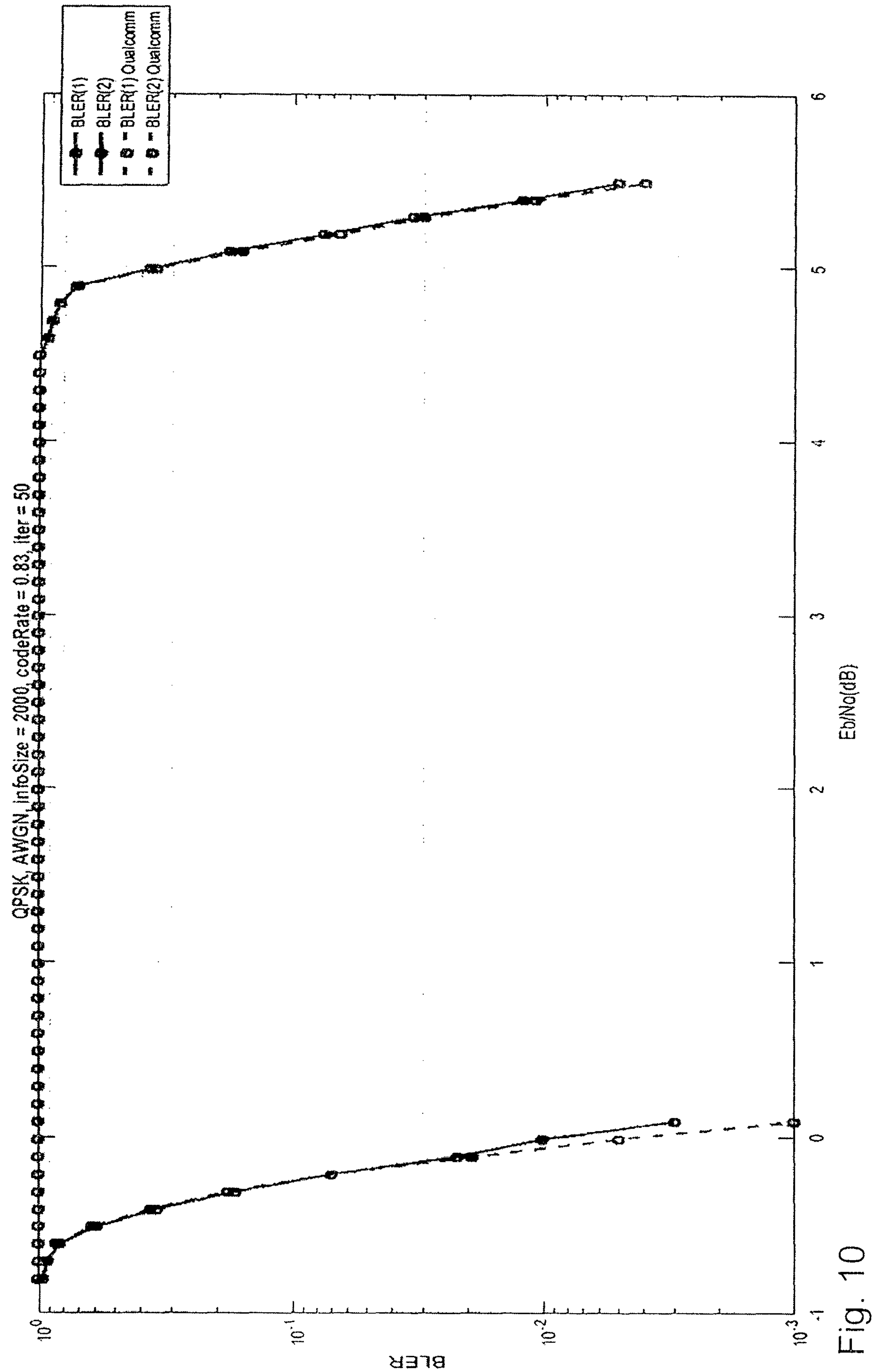
QPSK, AWGN, infoSize = 2000, codeRate = 0.83, Iter = 50
BLER(1)
BLER(2)
BLER(1) Qualcomm
BLER(2) Qualcomm
BLER
10^0
10^{-1}
10^{-2}
10^{-3}
-1
0
1
2
3
4
5
6
Eb/No(dB)

Fig. 10

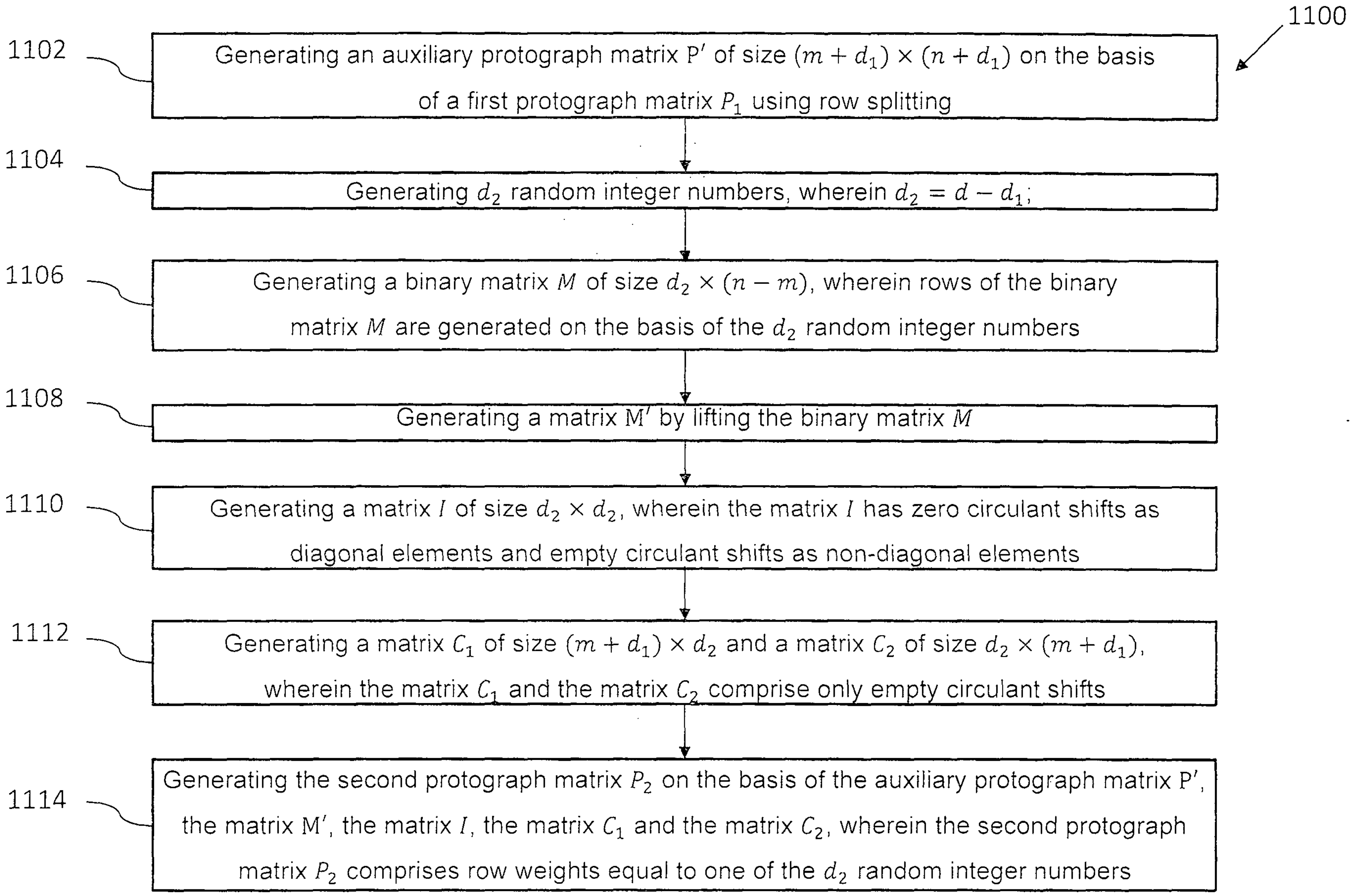
1100
1102
Generating an auxiliary protograph matrix P′ of size $(m + d_1) \times (n + d_1)$ on the basis of a first protograph matrix P_1 using row splitting
1104
Generating d_2 random integer numbers, wherein $d_2 = d - d_1$;
1106
Generating a binary matrix M of size $d_2 \times (n - m)$, wherein rows of the binary matrix M are generated on the basis of the d_2 random integer numbers
1108
Generating a matrix M′ by lifting the binary matrix M
1110
Generating a matrix I of size $d_2 \times d_2$, wherein the matrix I has zero circulant shifts as diagonal elements and empty circulant shifts as non-diagonal elements
1112
Generating a matrix C_1 of size $(m + d_1) \times d_2$ and a matrix C_2 of size $d_2 \times (m + d_1)$, wherein the matrix C_1 and the matrix C_2 comprise only empty circulant shifts
1114
Generating the second protograph matrix P_2 on the basis of the auxiliary protograph matrix P′, the matrix M′, the matrix I, the matrix C_1 and the matrix C_2, wherein the second protograph matrix P_2 comprises row weights equal to one of the d_2 random integer numbers

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2016/000869

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

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)
H04L H03M

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/126916 A1 (CHUNG JI WOOK [KR] ET AL) 29 May 2008 (2008-05-29) page 6, right-hand column, paragraph 111 - page 9, right-hand column, paragraph 152; figures 12,20-30 -----	1-20
A	WO 2008/069460 A1 (KOREA ELECTRONICS TELECOMM [KR]; OH JONG-EE [KR]; YOON CHANHO [KR]; CH) 12 June 2008 (2008-06-12) abstract page 12, paragraph 90 - page 17, paragraph 123; figures 1-15 -----	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

"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
30 August 2017	11/09/2017

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	Courville, Nicolas

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/RU2016/000869

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008126916 A1	29-05-2008	NONE	
WO 2008069460 A1	12-06-2008	NONE	