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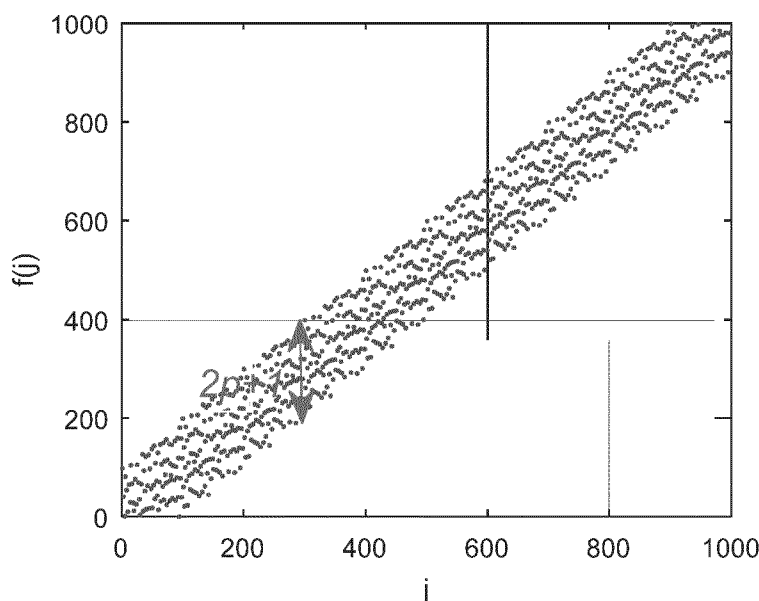


Fig. 6

(57) Abstract: The present invention relates to an interleaver (104), particularly for a turbo encoder (100), for mapping an input sequence of k indexed input symbols (101) to an output sequence of k indexed output symbols (105), k being a positive integer, comprising means for mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function, wherein, for a particular subset of k input indices, a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k . This interleaver may be advantageously applied in combination with sliding-window decoding.



WINDOW-INTERLEAVED TURBO (WI-TURBO) CODES

TECHNICAL FIELD

5 The present invention generally relates to the field of interleaver design, and specifically relates to an interleaver and to an interleaving method having a band structure. The present invention relates further to obtaining such an interleaver and using such an interleaver in a communication system, e.g. for channel encoding and decoding.

10 BACKGROUND

In the followings, the background regarding delay or latency in communication systems and its relation to cannel codes is presented.

15 In each communication system, there is a delay or latency caused by the channel encoder or decoder. Depending on the application, the delay may have a big influence on the quality of service (QoS) and the quality of experience (QoE).

20 There are several causes for such a delay in communication systems. A structural delay may be seen as the cause of the latency that depends on the system design and not on the processing power and memory of transmitter or receiver. One aspect that causes large structural delay is the block-wise processing of the signals in the transmitter and receiver chains. Especially, forward error correction (FEC) schemes cause large structural delays.

25 In general, the channel decoder requires coded symbols corresponding to the whole codeword in order to start the decoding operation. Coded symbols may relate to both binary and non-binary symbols, wherein in case of a binary code, a symbol is a bit. Hence the decoder cannot start as long as the whole codeword is not received. For long codewords, this may cause a
30 large delay.

Certain channel codes have special structures that allow the decoder to start the decoding operation even if the whole codeword is not available. This kind of codes may be decoded

with a so-called sliding window decoder (SWD), where the availability of only a part of the codeword is enough to start the decoding process.

If a sliding window decoder SWD is used, the decoding is performed over the symbols within a window, said window having a length w . After the decoding of m targeted symbols inside the window ($m < w$) is completed, the window is shifted to a new location, where new targeted symbols are then decoded. This procedure is repeated until the whole codeword is decoded. Despite its sub-optimality in terms of error correction performance, the sliding window decoder SWD allows more flexibility in latency: The decoder may indeed start decoding the first targeted symbols as soon as the symbols within a certain window are available.

Convolutional codes may be given as an example for codes that may be decoded with a sliding window decoder SWD, wherein each encoded symbol only depends on certain previously encoded symbols. Another example of convolutional codes may be the low-density parity-check convolutional codes (LDPC-CC) that have a parity check matrix with a band diagonal structure, which also allows using a sliding window decoder SWD. LDPC-CC is known for example from A. J. Felström, and K. S. Zigangirov, "Time-varying periodic convolutional codes with low-density parity-check matrix" *IEEE Transactions on Information Theory*, 45.6 (1999): 2181-2191.

In the followings, the background regarding interleavers is presented.

An interleaver is a deterministic function that takes a sequence as input and outputs the same sequence with a different order. Interleaving is a technique that is usually used to improve the performance of channel codes.

An interleaver of length k , in particular a block interleaver, can be described by a bijective function $f(j)$ with j and $f(j)$ taking integer values from 0 to $k - 1$. The function $f(j)$ defines the order that the samples or symbols are read from the input vector, i.e., the j^{th} output of the interleaver is read from the location $f(j)$ in the input vector.

In the followings, the background regarding turbo codes is presented.

Turbo codes, as parallel concatenated convolutional codes, are powerful error correction codes first introduced in C. Berrou, A. Glavieux. "Near optimum error correcting coding and decoding: Turbo-codes", *IEEE Transactions on Communications*, 44.10 (1996): 1261-1271.

The encoder of a turbo code used e.g., in 3GPP WCDMA or LTE, consists of two
5 convolutional encoders (constituent encoders), and an interleaver $f(\cdot)$.

Known interleavers used in turbo codes, i.e. the turbo interleavers, are usually designed in a way such that the input is shuffled as much randomly as possible. It is indeed desired to have interleavers with large spread factors. The spread S_f of an interleaver with interleaving
10 function $f(j)$ is defined as the minimum distance of any two different indices:

$$S_f = \min_{\substack{i,j \\ i \neq j}} D_{i,j} \quad (1)$$

where $D_{i,j}$ is the distance metric between the indices i and j defined as:

$$D_{i,j} = |i - j| + |f(i) - f(j)| \quad (2)$$

For turbo codes, usually interleavers with large spreads are desired due to their better error correction performance. Therefore, during the design of an interleaver for a turbo code, one
20 normally tries to build interleavers where the spread is maximized.

For example, an LTE turbo code is constructed using two constituent convolutional codes with 8 states, i.e. with the generators 15 and 13 (in octal) for feedforward and feedback, respectively. As interleaver, the quadratic permutation polynomials (QPP) in the form $f(j) = (f_1 j + f_2 j^2) \bmod k$ is used, where k is the interleaver length and mod is the modulo operation.
25 The parameters f_1, f_2 and k are specified in 3GPP Technical Specification, TS 36.212 v12.6.0, 2015.

The decoder of a turbo code consists of two Soft-In-Soft-Out (SISO) decoders, i.e. one SISO
30 decoder for each constituent convolutional code. The two SISO decoders are connected via an interleaver $f(\cdot)$ and a deinterleaver $f^{-1}(\cdot)$.

The decoding operation occurs in an iterative way, such that extrinsic information is exchanged between the constituent decoders during each iteration.

However, turbo codes in general cannot be decoded with a sliding window decoder SWD.

5 Indeed, the interleaver and the deinterleaver connecting both SISO decoders make the use of a sliding window decoder SWD impossible or at least difficult. It has to be noted that the sliding window decoder SWD may be used to decode the constituent convolutional codes, however the focus here is the sliding window decoding of the turbo codewords.

10 If a sliding window decoder SWD is used with a turbo code, the following problem occurs. Assume a window with w symbols, where the first m symbols are the targeted symbols. The first SISO decoder may process the first w symbols and produce extrinsic information about those symbols. However, after interleaving, these symbols are usually interleaved to locations that are outside the window. Similarly, the interleaver might require input from symbols
15 outside the window to feed in to the second SISO decoder. Therefore, the extrinsic information exchange is limited due to the interleaving operation, and a window decoding is not possible.

SUMMARY OF INVENTION

20 Having recognized the above-mentioned disadvantages and problems, the present invention aims to improve the state of the art. In particular, the object of the present invention is to provide an improved interleaver with the distance between input sequence and output sequence limited in a pre-defined range, so that turbo codes can be interleaved in such way
25 that it can be decoded by using sliding window decoding. In this way, a latency caused by interleaver and decoding can be reduced.

The above-mentioned object of the present invention is achieved by the solution provided in the enclosed independent claims. Advantageous implementations of the present invention are
30 further defined in the respective dependent claims.

A first aspect of the present invention provides an interleaver, particularly for channel coding, for mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, k being a positive integer,

comprising means for mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function,

wherein, for the input indices $b, \dots, k-b-1$, b being a nonnegative integer smaller than $k/2$

(excluding the first and the last b indices), a distance between the input index and the output

index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k . Typically, $b \leq \lceil k/4 \rceil$ where $\lceil \cdot \rceil$ denotes the ceiling operator.

This also implies the same property for the corresponding deinterleaver, since the

deinterleaver can be defined by the inverse of the interleaving function, i.e., it is an interleaver

with the interleaving function $f^{-1}(\cdot)$.

Thereby, the interleaver is advantageous in that it shows a band structure, such that a sliding

window decoder may be used for a decoder for reducing the decoder latency. The interleaver

may particularly be an interleaver for a channel encoder or decoder, especially as for forward

error correction (FEC).

The k input symbols of the input sequence are indexed in that the order of the k input symbols in the input sequence is determined by respective input indices. In other words, the k input

symbols have an order that is determined by their respective input index. Similarly, the k

output symbols of the output sequence are indexed in that the order of the k output symbols in

the output sequence is determined by respective output indices. In other words, the k output

symbols have an order that is determined by their respective output index.

In an implementation form of the interleaver, the interleaver is configured for turbo codes or

turbo codewords.

In an implementation form of the interleaver, the distance between the input index and the

output index defined by the interleaving function is smaller than or equal to the threshold p

for all k input indices.

Particularly, the distance between the input index and the output index may relate to the

absolute value of the difference between the input index and the output index.

Particularly, the interleaving function may fulfill the condition $|f_p(j) - j| \leq p$ for all k input indices,

wherein $f_p(j)$ is the input index, and j is the output index. The same condition is also fulfilled for the deinterleaver, as a deinterleaver is an interleaver with the interleaving function $f^{-1}(j)$.

- 5 In fact, it can be shown that when $|f(j) - j| \leq p$, then we have $|f^{-1}(j) - j| \leq p$. Therefore, we may not differentiate $f(\cdot)$ and f^{-1} unless otherwise stated.

- 10 In an implementation form of the interleaver, the distance between the input index and the output index defined by the interleaving function is smaller than or equal to the threshold p only for a subset of all k input indices.

Particularly, the distance between the input index and the output index may relate to the absolute value of the difference between the input index and the output index.

- 15 A second aspect of the present invention provides an interleaving method, particularly for channel coding, for mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, k being a positive integer, comprising mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function,
- 20 wherein, for the input indices $b, \dots, k-b-1$, b being a nonnegative integer smaller than $k/2$ (excluding the first and the last b indices), a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k . Typically, $b \leq \lceil k/4 \rceil$ where $\lceil \cdot \rceil$ denotes the ceiling operator.

- 25 A third aspect of the present invention provides a channel encoder comprising at least one interleaver according to the first aspect of the present invention.

Particularly, the channel encoder may be a turbo encoder.

- 30 Particularly, the interleaver may be used in any channel code that can be decoded with the turbo principle. This includes the classical turbo codes, i.e. parallel concatenated convolutional codes, as well as other types of codes like repeat-accumulate codes (Jin, Hui, Aamod Khandekar, and Robert McEliece. "Irregular repeat-accumulate codes." *Proc. 2nd Int. Symp. Turbo codes and related topics*. 2000.),, accumulate-repeat-accumulate codes

(Abbasfar, Aliazam, Dariush Divsalar, and Kung Yao. "Accumulate-repeat-accumulate codes." *IEEE Transactions on Communications* 55.4 (2007): 692-702) and other kind of serial and parallel concatenated codes connected via an interleaver where the constituent codes may be any block code or convolutional code. Moreover, the proposed interleavers may also be used as interleavers between the channel code and the symbol mapper in any bit interleaved coded modulation (BICM) system (Caire, Giuseppe, Giorgio Taricco, and Ezio Biglieri. "Bit-interleaved coded modulation," *IEEE Transactions on Information Theory*, 44.3 (1998): 927-946), where the second constituent code is a symbol mapper. Note that in a "general turbo code", a constituent code can be any channel code, including the conventional turbo code, convolutional code, LDPC code, or LDPC-convolutional code.

In an implementation form of the channel encoder for encoding the input sequence into an encoded sequence, the channel encoder is a turbo encoder further comprising:

- first and second constituent encoders,
- the first constituent encoder being adapted to generate a first constituent codeword from the input sequence, and
- the second constituent encoder being adapted to generate a second constituent codeword from the output sequence of the interleaver, and
- a combination unit adapted to combine the input sequence, the first constituent codeword and the second constituent codeword into the encoded sequence.

In an implementation form of the channel encoder, the channel encoder comprises:

- an identification unit adapted to identify, from among all k input indices, the input indices for which the distance between the input index and the output index defined by the interleaving function is above the threshold p , and
- a computing unit adapted to set to known symbols the input symbols located at the identified input indices in the input sequence.

In an implementation form of the channel encoder the channel encoder comprises:

- an identification unit adapted to identify, from among all k input indices, the input indices for which the distance between the input index and the output index defined by the interleaving function is above the threshold p , and
- a puncturing unit adapted to puncture the identified input indices in the encoded sequence.

A fourth aspect of the present invention provides a channel decoder for decoding a received encoded sequence codeword into a sequence of decoded symbols, comprising at least one interleaver according to the first aspect of the present invention.

5 In an implementation form of the channel decoder for decoding a received encoded sequence into a sequence of decoded symbols, the channel decoder is a turbo decoder further comprising a first and a second concatenated constituent decoders, the first and second constituent decoders being connected by the interleaver.

10 In an implementation form of the channel decoder, the first and second constituent decoders are sliding window decoders.

In an implementation form of the channel decoder, the first constituent decoder is adapted to perform soft output decoding of the received encoded codeword so as to generate the
15 sequence of decoded symbols and a first extrinsic information, and the second constituent decoder is adapted to perform soft output decoding of the received encoded codeword so as to generate second extrinsic information, wherein the interleaver is adapted to map the first extrinsic information to side information for the second constituent decoder, and
20 a deinterleaver is adapted to map the second extrinsic information to side information for the first constituent decoder according to the opposite function of the interleaving function.

In an implementation form of the channel decoder, the channel decoder is adapted to decode an encoded sequence encoded by a channel encoder according to the third aspect of the
25 present invention in that the first and second constituent decoders of the channel decoder are adapted to use perfect a-priori information about the known symbols. Particularly, the first and second constituent decoders of the channel decoder are adapted to use perfect a-priori information about the known symbols set by the computing unit of the channel encoder.

30 A fifth aspect of the present invention provides a method for obtaining the interleaving function according to any of the claims 1 to 5, said interleaving function being adapted to be used in a turbo encoder or turbo decoder, the method comprising:

- randomly or pseudo-randomly generating a plurality of input interleaving functions respectively satisfying the condition that, for at least a subset of the set of all k input indices, a distance between the input index and an output index defined by the input interleaving function is smaller than or equal to the threshold p ,
 - 5 wherein k is a positive integer and p is a positive integer smaller than k ,
 - selecting the best performing interleavers in terms of the performance of turbo coding from the generated input interleavers, and
 - choosing one of the selected interleavers so as to obtain the interleaving function.
- 10 A sixth aspect of the present invention provides a method that may be referred to as s-random construction method for obtaining the interleaving function according to any of the claims 1 to 5, said interleaving function being adapted to be used in a turbo encoder or turbo decoder, the method comprising:
- A. defining a set $J = \{0, 1, \dots, k - 1\}$ of all k indices, and setting $j=0$, and
 - 15 the method further comprising recursively performing following steps:
 - B. selecting from the set J an input value (index) A fulfilling the following criteria:
 - i. $|i - j| + |f(i) - A| \geq s$ for all nonnegative integers i fulfilling $(j - s) \leq i < j$, wherein $f(i)$ is the input index mapped to the output index i according to the interleaving function f ,
 - 20 ii. $|A - j| \leq p$,
 - C. defining the interleaving function f so as to map the input value $f(j) = A$ to the output value j ,
 - D. removing the selected input value A from the set J .
 - E incrementing j by 1 and repeating the steps starting from step B, unless j equals $k-1$.
 - 25 Particularly, the steps B to E are performed recursively until the input set J is empty. In this case, the distance between the input index and the output index defined by the interleaving function is smaller than or equal to the threshold p for all k input indices.

Alternatively, the steps B to E are performed recursively until no input value A from the input set J fulfils the criteria i. and ii., wherein the input set J is not empty. In such a case, the steps B to E may be further performed recursively by ignoring the condition ii. In this case, the distance between the input index and the output index defined by the interleaving function may be smaller than or equal to the threshold p only for a subset of all k input indices.

Alternatively, the steps B to E are performed recursively until no input value A from the input set J fulfils the criteria i. and ii., wherein the input set J is not empty. In such a case, the interleaving function is obtained by performing again the step A and the recursive steps B to E.

5

A seventh aspect of the present invention provides a method that may be referred to as base interleaver construction method for obtaining an interleaving function $f_{p,d}$, said interleaving function being adapted to be used in a turbo encoder (100) or turbo decoder (200), the method comprising:

- 10 - providing a positive integer parameter L and a base interleaver f_b of length k' defined by a corresponding base interleaver function $f_b(j)$, k' being a positive integer,
- building a helper function $h(j) = f_b(j) + t_j k' \quad \forall j = \{0, 1, \dots, k' - 1\}$ with t_j being an integer, and
- constructing the interleaving function $f_{p,d}$ according to the equation:

15
$$f_{p,d}(j + lk') = [h(j) + lk'] \bmod(Lk') \quad j = \{0, \dots, k' - 1\}, \quad l = \{0, \dots, L - 1\}.$$

Particularly, the base interleaver f_b may be chosen as an LTE turbo interleaver.

Particularly, the helper function $h(j)$ may be chosen according to the following equation:

20
$$h_z(j) = \begin{cases} f_b(j) - k' & \text{if } j \in J^z \\ f_b(j) & \text{otherwise} \end{cases}$$

wherein $J^z \subseteq J = \{0, 1, \dots, k' - 1\}$. Here, $\subseteq$ is the subset or equal to operator. In this case, the obtained interleaving function defines a zigzag-window interleaver.

Particularly, the helper function $h(j)$ may be chosen according to the following equation:

25
$$h_s(j) = \begin{cases} f_b(j) - k' & \text{if } j \in J_1^s \\ f_b(j) + k' & \text{if } j \in J_2^s \\ f_b(j) & \text{otherwise} \end{cases}$$

wherein J_1^s and J_2^s are two non-overlapping subsets of $J = \{0, 1, \dots, k' - 1\}$ defined as either:

- $J_1^s = \{j: j < k'/2 \wedge f_b(j) > j + k'/2\}$ and $J_2^s = \{j: j > 3k'/2 \wedge f_b(j) < j - k'/2\}$, or

- any J_1^s and J_2^s such that $J_1^s \subset \{j: j \geq f_b(j)\}$ and $J_2^s \subset \{j: j < f_b(j)\}$. Here, $\subset$ and $\wedge$ are subset and logical and operators, respectively. In this case, the obtained interleaving function defines

30 a smoothed window interleaver.

An eight aspect of the present invention provides an interleaving device comprising:

- a serial to parallel converter to write the input sequence to a matrix M of size L by k' ,
- a base interleaver to be applied on each row of M , where the output is written to the
5 corresponding rows of a matrix R of the same size,
- a cyclic shift operator to be applied on each column of R in the vertical dimension to
obtain a matrix S of the same size where the shift values t_j for each column is
determined by the integers $t_j, j=0, \dots, k'-1$,
- a parallel to serial converter to read the matrix S row by row to generate the
10 interleaved output of length $k'L$.

Particularly, the base interleaver may be chosen as LTE interleaver.

Particularly, the base interleaver may be a Quadratic Permutation Polynomial (QPP)
15 interleaver.

A ninth aspect of the present invention provides a channel encoder for encoding an input
sequence into an encoded sequence,

the channel encoder comprising at least one interleaver,

20 wherein the interleaver is defined such that the encoded sequence is adapted to be decoded by
a channel decoder comprising concatenated constituent decoders in the form of sliding
window decoders.

A tenth aspect of the present invention provides a computer program having a program code
25 for performing the method according to the second, fifth, sixth or seventh aspect of the
present invention, when the computer program runs on a computing device.

It has to be noted that all devices, units and means described in the present application could
be implemented by software or hardware elements or any kind of combination thereof. All
30 steps which are performed by the various entities described in the present application as well
as the functionalities described to be performed by the various entities are intended to mean
that the respective entity is adapted to or configured to perform the respective steps and
functionalities. Even if, in the following description of specific embodiments, a specific
functionality or step to be full formed by eternal entities not reflected in the description of a

specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective software or hardware elements, or any kind of combination thereof.

5 BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 shows a turbo encoder according to an embodiment of the present invention,

Fig. 2 shows a turbo decoder according to an embodiment of the present invention,

10

Fig. 3 shows a turbo encoder according to a further embodiment of the present invention,

Fig. 4 shows a turbo decoder according to a further embodiment of the present invention,

15 Fig. 5 shows an interleaving function of an interleaver according to the state of the art,

Fig. 6 shows an interleaving function of an interleaver according to an embodiment of the present invention,

20 Fig. 7 shows an interleaving function of an interleaver according to another embodiment of the present invention,

Fig. 8 shows a zigzag window interleaver according to an embodiment of the present invention,

25

Fig. 9 shows a smoothed window interleaver according to an embodiment of the present invention,

Fig. 10 shows a smoothed window interleaver according to another embodiment of the present invention,

30

Fig. 11 shows a sliding window decoding according to an embodiment of the present invention,

Fig. 12 shows performance results of wi-turbo codes with smoothed window interleavers according to an embodiment of the present invention,

Fig. 13 shows performance results of wi-turbo codes with zigzag window interleavers according to an embodiment of the present invention,

Fig. 14 shows performance results of wi-turbo codes with smoothed-window interleavers according to an embodiment of the present invention,

Fig. 15 shows possible gains due to the flexible latency adjustment according to the present invention, and

Fig. 16 shows an interleaving device with an interleaving function according to an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

The present invention will be explained in details in the following.

The present invention proposes an interleaver, particularly for channel coding, for mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, k being a positive integer.

The interleaver comprises means for mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function. For at least a part of all k input indices, a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , k and the threshold p being positive integer.

The k input symbols of the input sequence are indexed in that the order of the k input symbols in the input sequence is determined by respective input indices. In other words, the k input symbols have an order that is determined by their respective input index. Similarly, the k output symbols of the output sequence are indexed in that the order of the k output symbols in

the output sequence is determined by respective output indices. In other words, the k output symbols have an order that is determined by their respective output indices.

The means for mapping may e.g. be a computing unit adapted to map the input index of the input sequence to the output index of the output sequence according to the interleaving function.

The input symbols and output symbols of the respective input sequence and output sequence may be values or coded symbols related to either binary and non-binary codes. Particularly, in case of a binary code, a symbol may be a bit.

The threshold p may be a positive integer. The threshold p may be set such that $2p+1$ is smaller than the value k , the value k reflecting the total length of input sequence or the total number of input symbols of the input sequence. In other words, the threshold p may verify or fulfill the equation $p < (k-1)/2$, with p and k being positive integers. To achieve low latency, p can be typically chosen as $p < (k-1)/4$.

The proposed interleaver may be an interleaver for turbo codes, i.e. a turbo code interleaver.

Figs. 1 and 2 show two embodiments for using the interleaver according to the present invention.

Fig. 1 shows a turbo encoder 100 according to an embodiment of the present invention. The turbo encoder 100 comprises an interleaver 104 according to the present invention.

Particularly, Fig. 1 shows the interleaver 104, particularly for channel coding, for mapping an input sequence 101 of k indexed input symbols to an output sequence 105 of k indexed output symbols, k being a positive integer.

The interleaver 104 comprises means for mapping an input index of the input sequence 101 to an output index of the output sequence 105 according to an interleaving function. For the input indices $b, \dots, k-b-1$, (b being a nonnegative integer smaller than $k/2$), a distance between the input index and the output index defined by the interleaving function is smaller than or

equal to a threshold p , p being a positive integer smaller than k . The said means may be implemented through a module, unit or on a software basis.

The input of the turbo encoder 100 is the sequence of information symbols to be encoded 101 corresponding to the input sequence 101 of k indexed input symbols. Output of the encoder contains systematic symbols 101 – i.e. the sequence of information symbols itself –, parity symbols 103 generated by a first constituent encoder 102, and parity symbols 107 generated by a second encoder 106 after interleaving 104.

The turbo encoder 100 is adapted to encode the input sequence 101 into an encoded sequence or codeword 109. The turbo encoder 100 comprises the interleaver 104, as well as first 102 and second 106 concatenated constituent encoders. The first constituent encoder 102 is adapted to generate a first constituent codeword 103 from the input sequence 101, and the second constituent encoder 106 is adapted to generate a second constituent codeword 107 from the output sequence 105 of the interleaver 104.

The turbo encoder 100 also comprises a combination unit, like a serial/parallel unit 108, adapted to combine the first constituent codeword 103 and the second constituent codeword 107 into the encoded sequence 109. Particularly, the combination unit 108 may be adapted to combine the input sequence 101, the first constituent codeword 103, and the second constituent codeword 107 into the encoded sequence 109.

Particularly, the first and second constituent encoders 102, 106 of the turbo encoder 100 may be respectively in the form of convolutional encoders as shown in Fig. 1.

Fig. 2 shows a turbo decoder 200 according to an embodiment of the present invention. The turbo decoder 200 comprises an interleaver 205 according to the present invention.

Particularly, Fig. 2 shows the interleaver 205, particularly for channel coding, for mapping an input sequence 204 of k indexed input symbols to an output sequence 206 of k indexed output symbols, k being a positive integer.

The interleaver 205 comprising means for mapping an input index of the input sequence 204 to an output index of the output sequence 206 according to an interleaving function. For the

input indices $b, \dots, k-b-1$, (b being a nonnegative integer smaller than $k/2$), a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , the threshold p being a positive integer smaller than k . The said means may be implemented through a module, unit or on a software basis.

5

The input of the turbo decoder 200 is the received symbols 201 in form of reliability values, e.g. log-likelihood values or L-values, or soft values. The output 210 corresponds to the decoded symbols.

10 The turbo decoder 200 comprises first and second constituent decoders 202, 203 that are connected by the interleaver 205. The two constituent decoders 202, 203 are also connected by a de-interleaver 208 corresponding to interleaver 205, i.e. being the opposite of the interleaver 205. The two constituent decoders 202, 203 perform a soft output decoding, and generate respective extrinsic information 204, 207 about each symbol of the information
15 sequence 201.

The extrinsic information 204 of the first constituent decoder 202 is then interleaved by the interleaver 205 and fed 206 to the second constituent decoder 203 as side information.

Likewise, the extrinsic information 207 of the second constituent decoder 203 is de-
20 interleaved by the de-interleaver 208 and fed 209 to the first constituent decoder 202 as side information. The respective extrinsic information 204, 207 of one constituent decoder is fed iteratively to the other constituent decoder.

This iterative procedure is repeated a certain amount of times before making a final decision
25 on the decoded symbols 210. If decoding is successful, the decoded symbols 210 are equivalent to the transmitted information sequence 101.

The channel encoder and channel decoder of Figs. 1 and 2 comprise respectively constituent encoders 102, 106 and constituent decoders 202, 203 that are parallel concatenated.

30 Specifically, Figs. 1 and 2 show parallel concatenated turbo codes in form of parallel concatenated binary convolutional codes.

The invention is also applicable to channel encoder and channel decoder having alternative structures, see for example Figs. 3 and 4. For example, the invention is also applicable to non-

binary and/or to serially concatenated codes. Also the invention may be used with parallel or serially concatenated codes containing more constituent codes, i.e. containing more than the two constituent encoders 102, 106 of Fig. 1 and more than the two constituent decoders 202, 203 of Fig. 2. A parallel or serial concatenated code according to the invention may then be a turbo code consisting of at least two constituent codes and at least one interleaver. The interleaver may be referred to as the turbo interleaver.

In the followings, the structural delay or latency of channel encoders and decoders according to the present invention is presented with respect to the structural delay or latency of known channel encoders and decoders.

It is assumed that the symbols $b_0 b_1 \dots b_{K-1}$ are the input 101 to the channel encoder 100, and the symbols $c_0 c_1 \dots c_{N-1}$ are the output 109 of the channel encoder, i.e. the encoded sequence 109, or the input 201 of the channel decoder 200, i.e. the received encoded sequence 201, wherein k and n are time indices and $R = K/N$ is usually called the channel code rate and K and N are positive integers. According to the state of the art, to produce the encoded sequence, all of the K symbols of the input sequence have to be available at the input of the channel encoder, such that the N encoded symbols can be generated. This may cause a large delay if the input sequence is long.

The present invention is advantageous in that the encoded symbols c_i may be generated even if only a part of the input sequence is available. We make the following definitions. The output symbol c_n is called the *delay- d and window- w encoded*, if c_n may be generated using $b_{[R \cdot (n+d-w+1)]}, \dots, b_{[R \cdot n]}, \dots, b_{[R \cdot (n+d)]}$ with $w > d \geq 0$. Further on, when c_n is *delay- d and window- w encoded* for all n , then the channel code is called *delay- d and window- w encodable*, and the corresponding encoder is called *delay- d and window- w encoder*.

Obviously, if a code is *delay- d and window- w encodable*, then it is also *delay- $(d+1)$ and window- $(w+1)$ encodable*. Since we are interested only in the minimum of d and w , unless otherwise stated, the *delay- d and window- w encodable* channel code is referred to as the code which is not *delay- $(d-1)$ and window- $(w-1)$ encodable*. Thus, without considering the processing delay, the delay d is dependent only on the structural delay of the channel encoder.

Similar definitions can be made for the decoders, too. The symbol b_k is called the *delay- d and window- w decodable*, if b_k can be decoded using $c_{[(k+d-w+1)/R]}, \dots, c_{[k/R]}, \dots, c_{[(n+d)/R]}$ with

$w > d \geq 0$. Further on, when b_k is *delay- d and window- w decodable* for all k , the channel code is called the *delay- d and window- w decodable*, and the corresponding decoder is called the *delay- d and window- w decoder*. Since any *delay- d and window- w decodable* code is also *delay- $(d+1)$ and window- $(w+1)$ decodable*, unless otherwise stated, d and w are the minimum delay d and window w of the *delay- d and window- w code*, respectively. With unlimited processing power and memory, and for a given channel and a target decoder performance (e.g. BER or BLER), the delay d is dependent only on the structural delay of the channel decoder, and may serve as a structure delay parameter.

For example, a known non-recursive convolutional encoder may consist of s memory elements – shift registers – and the output at each time instant may be a linear combination of the values in the memory elements. The input sequence is fed to the memory elements and shifted by one symbol after the outputs are generated. Due to this structure, one can say that a non-recursive convolutional code with s memory elements is *delay- s window- s encodable*.

Recursive convolutional codes are similar to non-recursive codes, except their output may also depend on the previous outputs due to the feedback connection. For recursive convolutional codes, the encoding delay is the same as the non-recursive codes, but as the output depends also on the previous outputs, the window size may be regarded as infinity. In general, one can decode a convolutional code with the same delay and window parameters as they are required for the encoding, i.e., if no errors are occurred during the transmission, the symbols can be decoded correctly with the same delay as the encoding delay. This corresponds to making a decision on the decoder output after the reception of each trellis section of the Viterbi decoder. However, as the channel conditions degrade, this would decrease the error correction performance. To improve the performance, one usually makes the decision after receiving τ trellis segments. Therefore, the decoder can be regarded as *delay- τs window- τs decoder*.

For example, for known encoders and decoders, the turbo codes respectively use unconstrained interleavers, such that the input and the output order of the interleaver may be arbitrary. Therefore, a known encoder requires the whole input sequence in order to produce its encoded sequence. Similarly, a known decoder requires the whole input sequence in order to start decoding. With these constraints, one can say that a turbo code is *delay- k window- k encodable* and *delay- k window- k decodable*. It can be noted that in general the constituent codes of a turbo code can be any kind of codes (like block codes or convolutional codes),

however one usually uses convolutional codes as constituent codes with parallel concatenated turbo codes due to their advantages such as performance and simplicity.

The invention proposes particularly a new interleaver, a new channel encoder and channel decoder and new turbo codes generated by using the new interleaver having band characteristics. Such kind of turbo codes according to the present invention may be called window interleaved turbo codes, i. e. Wi-Turbo or wi-turbo codes. The proposed interleaver having band structure or properties may be referred to as Window Interleaver.

The concept of delay- d and window- w encoder can be extended to many devices, including the (de)interleavers. In their most general case, an interleaver of length k can be interleaved/deinterleaved with a delay of k symbols. However, interleavers with special structures (such as window interleavers, WI) can be (de)interleaved with smaller delay values.

The proposed new Wi-Turbo codes provide better performances with regard to the conventional turbo codes approaching the theoretical bounds. Moreover, due to the proposed interleaver structure, such as the band interleaver structure, the Wi-Turbo encoder or decoder has a reduced structural latency or delay, i.e. a reduced waiting time for encoding or decoding. The proposed new coding method allows the generated codewords to be encoded or decoded using a sliding window encoder or decoder. In other words, their encoding or decoding time is dependent on the chosen WI parameters. Moreover, Wi-Turbo codes are more flexible in supporting rate matching and incremental redundancy, compared to other modern codes such as the LDPC-CC.

The proposed Wi-turbo codes according to the present invention have special interleavers, like window interleavers, that allow them to be decoded using a sliding window decoder. A window interleaver is defined by the parameter p that defines the maximum distance between the input and the output of the interleaver. Therefore, assuming that the convolutional encoders of the turbo code, i.e. of the turbo encoder, has s memory elements, the encoding delay of the wi-turbo codes can be regarded as $s+p < k$. Note that s is usually small compared to p and can be neglected.

The main advantage of the present invention, i.e. of the wi-turbo codes compared to conventional turbo codes is their suitability to sliding window decoder (SWD). If an SWD is

used, the decoding latency can be as small as p symbols, similar to the encoder. However to obtain good error correction performance, one usually defines a number of target symbols m – number of symbols to be decoded in each window – and chooses a window of size greater than $m+p$. Experimental evaluations suggest that, for example, choosing $m=p$ and the window size $w \approx 5m$ usually leads to good results.

Figs. 3 and 4 show two embodiments for using the interleaver according to the present invention in respectively a turbo encoder and a turbo decoder having an alternative structure.

Fig. 3 shows a turbo encoder 300 according to a further embodiment of the present invention. The turbo encoder 300 comprise an interleaver 304 according to the present invention.

The turbo encoder 300 is a serial concatenated encoder. Two constituent codes 302, 306 are connected serially with the interleaver 304. Repeat-accumulate codes, wherein the first constituent code 302 is a repetition code and the second one 306 is an accumulator, and accumulate-repeat-accumulate codes, wherein the first constituent code 302 is an accumulator/repetition code and the second one 306 is an accumulator, can be given as examples for serially concatenated codes.

The turbo encoder 300 of Fig. 3 generates an encoded sequence or encoded symbols 309 from an input sequence or input symbols 301. The input sequence 301 is applied to a first constituent code, i.e. a first constituent encoder 302, to obtain a first constituent codeword 303. The interleaver of the present invention generates an output sequence 305 from the first constituent codeword 303. The output sequence 305 is applied to a second constituent code, i.e. a second constituent encoder 306, to obtain a second constituent codeword 307. A combination unit 308 is adapted to combine the input sequence 301 and the second constituent codeword 307 into the encoded sequence 309.

Fig. 4 shows a turbo decoder 400 according to a further embodiment of the present invention.

The turbo decoder 400 comprise an interleaver 405 according to the present invention.

The turbo decoder 400 of Fig. 4 may be used to decode the encoded sequence 309, 401 generated by the turbo encoder 300 of Fig. 3 so as to obtain decoded symbols 410. Similarly to the turbo decoder 200 of Fig. 2, the turbo decoder 400 comprises a first 403 and a second

constituent decoder 402 that are connected by the interleaver 405 and by a de-interleaver 408 being the opposite of the interleaver 405. The input sequence 401 of the turbo decoder 400 is applied to the second constituent decoder 402 and the decoded symbols 410 is generated by the first constituent decoder 403.

5

By using the interleaver according to the present invention, the distance between the input and the output of the interleaver is limited. Since both constituent codes 302, 306 may be chosen as codes with low latency – like accumulators, for example memory-1 convolutional codes, and repeaters –, the overall latency may be characterized by the interleaver latency. Therefore, if a window interleaver with parameter p is used, the encoder latency may be regarded as p , and is reduced with respect to known interleavers.

10

The interleaver according to the present invention may be realized by several constrained interleavers. In the followings, two embodiments for the interleaver are presented, as well as two interleaver construction methods.

15

Fig. 6 shows an interleaving function of an interleaver according to a first embodiment of the interleaver. The first proposed interleaver shown in Fig. 6 is called $f_p(j)$ -window interleaver, or $f_p(j)$ -WI. It is defined with the interleaving function $f_p(j)$ of length k , where the absolute difference $|f_p(j) - j|$ is smaller than or equal to a predefined threshold or number p for all k input indices.

20

The interleaving function $f_p(j)$ defines the order that the samples or values are read from the input vector or sequence, i.e., the j^{th} output of the interleaver is read from the location $f_p(j)$ in the input vector. The interleaving function $f_p(j)$ has a length k , and the values j and $f_p(j)$ are integer values between 0 and $k - 1$. In this way, the distance between the input and the output indices are limited by p for all j .

25

The embodiment shown in Fig. 6 correspondingly presents an interleaver function having a band structure with a width of $2p+1$. In comparison, Fig. 5 shows an interleaving function of an interleaver according to the state of the art that does not have such a band structure.

30

Due to the structure of the $f_p(j)$ -WI, a sliding window decoder with the following parameters can be utilized for channel coding: window size w ($w > p$) and number of targeted symbols m

($m \leq w - p$), where the target symbols are the first m symbols within the window. The structure of the interleaver prevents the extrinsic information of the targeted symbols to be interleaved to locations that are located outside the current or previous windows.

- 5 The $f_p(j)$ -window interleaver of length k according to the embodiment of Fig. 6 is a constrained interleaver with the interleaving function $f_p(j)$, wherein the following condition holds, k and p being positive integers:

$$|f_p(j) - j| \leq p \quad j, f_p(j) \in J := \{0, 1, \dots, k - 1\} \quad (3)$$

- 10 Here, $J := \{0, 1, \dots, k - 1\}$ means that J is defined as the set consisting of elements $0, 1, \dots, k - 1$. Also, $j, f_p(j) \in J$ means that $j, f_p(j)$ is respectively an element of the set J . The value $f_p(j)$ is the interleaving function, and p ($p = 0, 1, \dots, k - 1$) is the threshold or parameter defining the maximum distance between input and the output of the interleaving
15 function. It is proportional to the interleaver size and has an influence on the possible window sizes if this interleaver is used as the turbo interleaver of a wi-turbo code. As shown previously, $m \leq w - p$ should hold, wherein m is the number of targeted symbols and w is the window size.

- 20 Fig. 7 shows an interleaving function of an interleaver according to a second embodiment of the interleaver. The interleaver of the second embodiment may be called $f_{p,d}(j)$ -window interleaver or $f_{p,d}(j)$ -WI. It is defined with the interleaving function $f_{p,d}(j)$ of length k , wherein the absolute difference $|f_{p,d}(j) - j|$ is not greater than a predefined number p for the input indices $b, \dots, k-b-1$, b being a nonnegative integer, and d being a nonnegative integer
25 defining the number of indices where the condition is not fulfilled. In this way, the distance between the input and the output indices is limited by the threshold p for only a subset of all possible input indices. In the example shown in Fig. 7, the distance between the input and the output indices is limited by p for only the input indices comprised between $f_{p,d}(j) = 1000$ and $f_{p,d}(j) = 9000$.

- 30 The $f_{p,d}(j)$ -WI has the advantage of a simple construction. However, it has to be noted that when used with a turbo code, it may experience problems in exchanging extrinsic information corresponding to symbols located at the d indices that do not fulfill the distance constraints.

One solution to overcome this problem is to transmit known bits – e.g., zeros – over the d known locations, such that during iterative decoding, no extrinsic information exchange is needed, as those bits are already known perfectly at the receiver.

5 The $f_{p,d}(j)$ -window interleaver of length k according to the embodiment of Fig. 7 is a constrained interleaver with the interleaving function $f_{p,d}(j)$ wherein the following condition holds, k and p being positive integers, d being a nonnegative integer:

$$10 \quad |f_{p,d}(j) - j| \leq p \quad \forall j \in J_d \quad (4)$$

wherein J_d is a subset of J with cardinality $k-d$. Here, d is the parameter specifying the number that shows at how many input indices of the interleaving function do not fulfill the constraint given in equation (4). It is desired to have a small d – because for these indices other measures
15 have to be taken during decoding, like setting systematic bits to known values or puncturing systematic bits corresponding to these known values, as explained below –, but its value mainly depends on the construction methods explained in the next sections. Note that the d indices are located in the first or in the last b locations.

20 A $f_{p,d}(j)$ -window interleaver fulfills the same conditions as a $f_p(j)$ -window interleaver except for d indices. For $d=0$, both definitions are equivalent.

In the followings, a first construction method for constructing the interleaver according to the present invention is presented. This first construction method may be called random
25 construction method.

The first proposed construction method is a brute force method to construct a random WI. With this method, one basically generates a large number of length- k random or pseudo random interleavers such that enough number of WIs can be also generated. Later, the best
30 performing WI may be selected among the generated interleavers. One option to select the best performing one is to evaluate the performance of turbo codes constructed with the stored interleavers in terms of bit error rate (BER) or block error rate (BLER) and then select the interleaver that give the best error correction performance.

As a common practice for engineers in the area of channel coding, one can do computer simulations by using a simulation chain consisting of Wi-Turbo encoder, channel and Wi-Turbo decoder. By alternating the selected WIs employed in Wi-Turbo encoder and decoder, different BLERs (block error rates) or BERs (bit error rates) can be measured at the Wi-Turbo decoder. The best performing WIs are then the WIs – used in Wi-Turbo – which lead to the lowest FER or BER.

Alternatively, one can truncate the best performing length- k interleaver to obtain an interleaver of smaller length.

In the followings, a second construction method for constructing the interleaver according to the present invention is presented. This second construction method may be called s-random construction method, and is based on the method proposed by S. Dolinar, D. Divsalar, “Weight distributions for turbo codes using random and nonrandom permutations,” *TDA Progress Report 42.122*, 1995, with the modification that during the construction of the interleaving function $f(j)$ the constraint $|f_p(j) - j| \leq p$ is also considered.

This second method describes how to construct a window interleaver of length k with a modified s-random construction method. The inputs of the following algorithm are interleaver length k , minimum spread s of the interleaver and the threshold p – being a constraint for SWD –, where all of the inputs are non-negative integers. The second construction method comprises:

1. Define the set $J = \{0, 1, \dots, k - 1\}$
2. Set $j = 0$, assign a random index from the set J to $f(j)$ such that the following two criteria are fulfilled:

$$D_{i,j} \geq s \text{ for all nonnegative } i \text{ fulfilling } (j - s) \leq i < j \quad (5)$$

$$|f_p(j) - j| \leq p \quad (6)$$

3. Remove the assigned index from J , increase j by 1 and go to step 2 until

- 3a either the set J is empty (in this case, one obtains a $f_p(j)$ -window interleaver), or
- 3b there are no indices left in J that can fulfill the conditions in step 2.

If the case 3b, continue by considering only the condition (5) and not the condition (6). In this case, one obtains a $f_{p,d}(j)$ -window interleaver. Otherwise, if there is still no index left, start again from the beginning, i.e. from step 1.

In the followings, a third construction method for constructing the interleaver according to the present invention is presented. This second construction method may be called base interleaver construction method.

According to this third construction method, one may use an unconstrained interleaver $f_b(j)$ of length k' – called here the base interleaver – to build a larger interleaver of length $L \cdot k'$, where L is a positive integer. For the construction, first a helper function is generated by modifying the base interleaver function, which is then concatenated L times using a deterministic method to obtain a $f_{p,d}(j)$ -WI. Theoretically, L can approach infinity such that the encoder/decoder can work for infinite size of data streams.

Depending on the construction of the helper function, the obtained $f_{p,d}(j)$ -WI can have a zigzag form – zigzag-WI – or a smooth form – smoothed-WI.

According to this third construction method from a base interleaver, it is possible to build an $f_{p,d}(j)$ -window interleaver of length $k'L - k'$ and L are positive integers – by using an unconstrained base interleaver $f_b(j)$ of length k' .

For the construction, first the following helper function is defined

$$h(j) = f_b(j) + t_j k' \quad \forall j = \{0, 1, \dots, k' - 1\}, \quad (7)$$

wherein t_j is an integer.

Then, $h(j)$ is used to construct the function $f_{p,d}(j)$ in the following way:

$$f_{p,d}(j + lk') = [h(j) + lk'] \bmod(Lk') \quad j = \{0, \dots, k' - 1\}, \quad l = \{0, \dots, L - 1\} \quad (8)$$

This method can be seen as concatenating the base interleaver L times where the connection between each interleaver is defined by the helper function.

- 5 Similar to this construction method, the interleaving method for mapping an input sequence of $k'L$ indexed input symbols to an output sequence of $k'L$ indexed output symbols, k' and L being positive integers, can be defined. Accordingly, the interleaving function will be
- $$f_{p,d}(j + lk') = [h(j) + lk'] \bmod(Lk'), \quad j = \{0, \dots, k' - 1\}, \quad l = \{0, \dots, L - 1\}, \text{ and } h(j) =$$
- 10 $f_b(j) + t_j$ with $f_b(j)$ being the interleaving function of the base interleaver of length k' , and $t_j, j = \{0, \dots, k' - 1\}$ being integers.

In the followings, a first example of the third construction method from a base interleaver is presented together with Fig. 8. According to this first example, a Zigzag Window Interleaver may be constructed, as shown in the right diagram of Fig. 8.

- 15 It is proposed to construct the zigzag window interleaver with the third construction method, using the following helper function:

$$h_z(j) = \begin{cases} f_b(j) - k' & \text{if } j \in J^z \\ f_b(j) & \text{otherwise} \end{cases} \quad (9)$$

- 20 Here, J^z is a subset of $J = \{0, 1, \dots, k' - 1\}$.

The left diagram of Fig. 8 shows the helper function and the right diagram shows the resulting zigzag window interleaver, wherein $k' = 256$, $L = 10$ and J^z is a randomly selected subset of J with cardinality $k'/4$. The indices of J^z are depicted with red markers.

- 25 If a zigzag window interleaver is used with a turbo code, resulting in a wi-turbo code, a SWD with window size $w = k'l$, $l = \{2, \dots, L - 1\}$ can be used. Thus, the codeword can be decoded with a latency that is equal to an integer multiple of the base interleaver length.

In the followings, a second example of the third construction method from a base interleaver is presented together with Fig. 9. According to this second example, a smoothed Window Interleaver may be constructed, as shown in the right diagram of Fig. 9.

- 5 It is proposed to construct the smoothed window interleaver with the third construction method, using the following helper function:

$$h_s(j) = \begin{cases} f_b(j) - k' & \text{if } j \in J_1^s \\ f_b(j) + k' & \text{if } j \in J_2^s \\ f_b(j) & \text{otherwise} \end{cases} \quad (10)$$

where J_1^s and J_2^s are two non-overlapping subsets of $J = \{0, 1, \dots, k' - 1\}$ defined as follows:

10

$$J_1^s = \{j: j < k'/2 \wedge f_b(j) > j + k'/2\} \quad (11)$$

$$J_2^s = \{j: j > 3k'/2 \wedge f_b(j) < j - k'/2\} \quad (12)$$

15

Figure 9 shows an example of this construction, in that the left diagram the helper function and the right diagram shows the resulting smoothed window interleaver, wherein $k' = 256$ and $L = 5$. J_1^s and J_2^s are obtained according to equations (11) and (12) and are depicted with red and green markers, respectively.

In the followings, a third example of the third construction method from a base interleaver is presented together with Fig. 10. According to this third example, a smoothed Window Interleaver may be constructed, as shown in the right diagram of Fig. 10.

20

It is proposed to construct this smoothed window interleaver with the third construction method, using the helper function defined in equation (10). However, J_1^s and J_2^s are not defined according to equations (11) and (12) like for the second example, but alternatively it is proposed to use any J_1^s and J_2^s such that the following criteria are fulfilled:

25

$$J_1^s \subset \{j: j \geq f_b(j)\} \quad (13)$$

$$J_2^s \subset \{j: j < f_b(j)\} \quad (14)$$

This third example also yields a smoothed window interleaver, as depicted in Fig. 10. The left diagram of Fig. 10 shows the helper function while the resulting smoothed window

interleaver is presented in the right diagram of Fig. 10, wherein $k' = 256$ and $L = 5$. J_1^s and J_2^s are obtained according to equations (13) and (14) and are depicted with red and green markers, respectively.

- 5 If a smoothed window interleaver is used with a turbo code, resulting in a wi-turbo code, an SWD with any window size between $2p$ and k can be used. Compared to the zigzag-WI, this gives a higher flexibility in terms of decoding latency.

10 In the followings, the choice of the base interleaver for the third construction method is presented.

Although one can use any unconstrained interleaver as a base interleaver, the choice can have an influence in the performance and in the implementation.

- 15 It may be shown that if an interleaver is used as base interleaver that is contention-free for an integer c , the resulting WI is also contention-free for c . This may be shown by using equation (8) and rewriting the definition of contention-free interleavers for this special structure of the interleavers.

- 20 It may numerically be verified that if the base interleaver is a Quadratic Permutation Polynomial (QPP) interleaver – see J. Sun, Y. O. Takeshita. "Interleavers for turbo codes using permutation polynomials over integer rings." *IEEE Transactions on Information Theory*, 51.1 (2005): 101-119 – with spread S_f , the resulting WI has a spread no smaller than S_f .

- 25 As the interleavers used in LTE turbo codes – see O. Y. Takeshita. "On maximum contention-free interleavers and permutation polynomials over integer rings." *IEEE Transactions on Information Theory*, 52.3 (2006): 1249-1253 – are contention-free QPP interleavers, one can construct contention free WIs with good spread factor by using LTE Turbo code interleavers
30 as base interleavers.

In the followings, a Sliding Window Decoding for Turbo Codes using an $f_p(j)$ -Window Interleaver is presented.

It is proposed to define the sliding window decoder with window length w for the turbo codes with a $f_p(j)$ -WI as follows:

1. Decoding starts by processing the first w systematic bits and their corresponding parity bits, where the first m systematic bits in the window are the targeted symbols.
2. The symbols inside the window are decoded using standard turbo decoding technique with the following modification: During interleaving/deinterleaving, if extrinsic information – e.g., in terms of log-likelihood value, also referred to as soft value – in the range $(-\infty, +\infty)$ from an unknown symbol from outside the window is required, it is set to 0.
3. After a certain number of iterations is reached, the following parameters are stored:
 - The state of the constituent decoders at the m^{th} index.
 - The extrinsic information of the first m systematic bits in the window, which will be needed for the next window.
4. The window is then shifted by m , such that the new window starts with the $(m+1)$ -th systematic bit of the previous window.
5. The symbols inside the window are decoded similar to the first window, except the following modification:
 - The constituent decoders start with the states, which were stored in the previous step.
 - Due to the interleaver structure, extrinsic information of some symbols from the previous window might be needed. This information is taken from the stored values in the last step.
6. Go to step 3, unless the end of the current window corresponds to the end of the codeword.

This procedure is shown in Fig. 11. In each window, w systematic bits are processed, where only the first m bits are the targeted symbols. After the processing of the current window is finished, the window is shifted by m .

In the followings, encoding and decoding of a turbo codes using an $f_p(j)$ -Window Interleaver are presented.

Turbo codes with an $f_{p,a}(j)$ -WI may be decoded by using the same method in the previous part, i.e. may be decoded by a Sliding Window Decoding for Turbo Codes using an $f_p(j)$ -Window Interleaver. However, there may be a performance loss due to the d indices of the interleaver, which do not fulfill the condition (4) and hence will lie outside of the window.

5

To solve this problem, the following modification is proposed:

10

1. At the encoder, the systematic bits corresponding to d indices are set to known values – e.g., zeros, whose corresponding log-likelihood value equals $+\infty$ –, such that no information is transmitted over these indices.
2. At the output of the encoder, the systematic bits corresponding to these known values are punctured, i.e. not transmitted.
3. At the decoder, a sliding window decoder is used with the following modification. During iterative decoding, the known values of the d indices are fed to the decoder as perfect a-priori information – e.g., with a log-likelihood value of $+\infty$.

15

This solution causes a small rate loss. However, for $d \ll k$ the rate loss will be small.

20

Fig. 16 shows an interleaver or an interleaving device 1600 with an interleaving function according to an embodiment of the present invention. The interleaving device 1600 is adapted to generate an output sequence or interleaved sequence 1609 from the input sequence 1601. The input sequence 1601 and the output sequence 1609 have a length Lk' .

25

The interleaving device 1600 comprises a serial to parallel converter 1602 to write the input sequence 1601 to a matrix M 1603 of size L by k' . The serial to parallel converter 1602 is adapted to reshape the input sequence 1601 into the matrix M 1603.

30

The interleaving device 1600 comprises a base interleaver 1604 to be applied on each row of M 1603, wherein the output of the base interleaver 1604 is written to the corresponding rows of the matrix R 1605 of the same size. Each row is interleaved using the base interleaver 1604.

The interleaving device 1600 comprises a cyclic shift operator 1606 to be applied on each column of R 1605 in the vertical dimension to obtain the matrix S 1607 of the same size,

wherein the shift values t_j for each column is determined by the integers $t_j, j=0, \dots, k'-1$. The cyclic shift operator 1606 performs a cyclic shift in vertical dimension according to t_j .

The interleaving device 1600 comprises a parallel to serial converter 1608 to read the matrix S 1607 row by row so as to generate the interleaved output 1609 of length $k'L$.

Particularly, the base interleaver 1604 may be an LTE interleaver.

In the followings, performance results are presented together with Figs. 12 to 15.

Fig. 12 shows performance results of wi-turbo codes – in terms of required E_b/N_0 to achieve a target error probability – with smoothed window interleavers according to the present invention. LTE QPP interleavers with lengths $k' = 64, \dots, 2048$ are used as base interleavers.

The performance of the wi-turbo codes decoded with a sliding window decoder is shown in Fig. 12. The window-interleavers are generated by using the third construction method and using the LTE QPP interleavers of different lengths as base interleavers. Here, latency is defined as the number of required symbols to start decoding, i.e. for SWD the latency equals the window length. The performance metric is the required SNR or E_b/N_0 to reach a target error bit probability of 0.0001. One can observe that for each of eight codes the performance gets better with increasing window length (latency).

For comparison the performance of LTE turbo codes are also given. Each square marker in Fig. 12 corresponds to the performance of an LTE Turbo code with different interleaver lengths. It may be noted that, for providing a fair comparison, the decoding latency of the LTE turbo codes where no SWD is possible are considered as the message length, i.e. interleaver length. It may be observed that the performance of LTE turbo codes and wi-turbo codes are comparable. However, the wi-turbo codes can be decoded with flexible latency. One LTE turbo code can be decoded only with a fixed latency value because they are not suitable for SWD. Advantageously, the decoding latency of wi-turbo codes according to the present invention can be adjusted at the receiver to obtain the desired latency, without changing the code itself.

Fig. 13 shows performance results of wi-turbo codes – in terms of required E_b/N_0 to achieve a target error probability – with zigzag window interleavers according to the present invention. S-random interleavers with lengths $k' = 200, \dots, 1000$ are used as base interleavers. Again, the results are comparable with LTE turbo codes.

5

Fig. 14 shows the bit error rate (BER) performance of wi-turbo codes with smoothed-window interleavers constructed from LTE QPP interleavers, i.e. constructed from different LTE QPP interleaver lengths k and different values L . For each curve, the length of the window interleaver is the same, but the length of the base interleaver is different. One can observe that for the same interleaver length, the performance gets better as the size of the base interleaver increases.

10

Fig. 15 shows an example scenario where the wi-turbo codes can have a significant advantage compared to LTE turbo codes. Assume that the receiver has to wait for τ seconds due to some other processing tasks, where it receives additional 750 symbols. Traditional turbo decoder would not be able to use this information to improve the decoding performance, but wi-turbo code can make use of these symbols to increase the performance, in this example by up to 0.41dB. Note that due to the special structure, any latency can be supported such that the decoder can work with nearly no idle periods.

20

The present invention is advantageous in that, by using the turbo codes with the proposed interleaver, the transmitter and receiver can have lower latency in channel encoding and decoding. One can adjust its decoding latency easily according to its latency budget by changing the window size of e.g. an SWD. This is not possible if a conventional interleaver is used because in known communication systems utilizing turbo codes, the latency cannot be adjusted at the transmitter or receiver side.

25

The present invention is advantageous in that, by using the proposed wi-turbo codes, the same codeword can be decoded with low latency in case of a good channel realization, and hence if a small window is enough for successful decoding.

30

The present invention is advantageous in that, by using the proposed wi-turbo codes, the latency can be increased by the transmitter or by the receiver to improve the error correction performance.

The present invention is advantageous in that, by using the third construction method, one can build WIs that can have some good properties of the base interleaver, like contention-free property and the spread factor.

5

The present invention is advantageous in that, by using the third construction method, one can build WIs with a periodic structure, such that the storage need for the interleaver function does not increase with the interleaver length.

10 The present invention is advantageous in that, by using the third construction method, one can build WIs of any length that are integer multiples of base interleaver length.

The present invention may be implemented in hardware and/or software. The proposed wi-turbo codes and interleaver may be used in optical, wireline or wireless

15 communications.

The present invention has been described in conjunction with various embodiments as examples as well as implementations. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the independent claims. In the claims as well as in
20 the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a
25 combination of these measures cannot be used in an advantageous implementation.

CLAIMS

1. Interleaver, in particular block interleaver, for mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, k being a positive integer, comprising means for mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function, wherein, for a subset of all k input indices, comprising the input indices $b, \dots, k-b-1$, b being a nonnegative integer smaller than $k/2$, a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k .
2. Interleaver according to claim 1, wherein the interleaver is configured for turbo codes.
3. Interleaver according to claim 1 or 2, wherein the distance between the input index and the output index defined by the interleaving function is smaller than or equal to the threshold p for all k input indices.
4. Interleaver according to claim 1, 2 or 3, where the interleaver is an s -random interleaver with s being a positive integer smaller than p .
5. Interleaving method, particularly for channel coding, for mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, k being a positive integer, comprising mapping an input index of the input sequence to an output index of the output sequence according to an interleaving function, wherein, for a subset of all k input indices, comprising the input indices $b, \dots, k-b-1$, b being a nonnegative integer smaller than $k/2$, a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k .
6. Channel encoder for encoding the input sequence into an encoded sequence, said channel encoder comprising at least one interleaver according to any of the claims 1 to 4.

7. Channel encoder according to claim 6,

wherein the channel encoder is a turbo encoder further comprising:

- first and second constituent encoders,

the first constituent encoder being adapted to generate a first constituent codeword from the

input sequence, and

the second constituent encoder being adapted to generate a second constituent codeword from the output sequence of the interleaver, and

- a combination unit adapted to combine the input sequence, the first constituent codeword and the second constituent codeword into the encoded sequence.

8. Channel encoder according to claim 7,

comprising:

- an identification unit adapted to identify, from among all k input indices, the input indices for which the distance between the input index and the output index defined by the

interleaving function is above the threshold p , and

- a computing unit adapted to set to known symbols the input symbols located at the identified input indices in the input sequence.

9. Channel encoder according to any of the claims 7 to 8,

wherein the channel encoder comprises:

- an identification unit adapted to identify, from among all k input indices, the input indices for which the distance between the input index and the output index defined by the

interleaving function is above the threshold p , and

- a puncturing unit adapted to puncture the identified input indices in the encoded sequence.

10. Channel decoder for decoding a received encoded sequence into a sequence of decoded symbols,

comprising at least one interleaver according to any of the claims 1 to 4.

11. Channel decoder according to claim 10,

wherein the channel decoder is a turbo decoder further comprising a first and a second constituent decoder,

the first and second constituent decoders being connected by the interleaver.

12. Channel decoder according to claim 11,
wherein the first and second constituent decoders are sliding window decoders.

13. Channel decoder according to claim 11 or 12,

- 5 wherein the first constituent decoder is adapted to perform soft output decoding of the received encoded codeword so as to generate the sequence of decoded symbols and a first extrinsic information, and
the second constituent decoder is adapted to perform soft output decoding of the received encoded codeword so as to generate second extrinsic information,
10 wherein the interleaver is adapted to map the first extrinsic information to side information for the second constituent decoder, and
a deinterleaver is adapted to map the second extrinsic information to side information for the first constituent decoder according to the opposite function of the interleaving function.

- 15 14. Channel decoder according to any of claims 11 to 13,
wherein the channel decoder is adapted to decode an encoded sequence encoded by a channel encoder according to claim 8 in that the first and second constituent decoders of the channel decoder are adapted to use perfect a-priori information about the known symbols.

- 20 15. Method for obtaining the interleaving function according to any of the claims 1 to 5, said interleaving function being adapted to be used in a turbo encoder (100) or turbo decoder (200),

the method comprising:

- randomly or pseudo-randomly generating a plurality of input interleaving functions
- 25 respectively satisfying the condition that, for at least a subset of the set of all k input indices, a distance between the input index and an output index defined by the input interleaving function is smaller than or equal to the threshold p ,
wherein k is a positive integer and p is a positive integer smaller than k ,
- selecting the best performing interleavers in terms of the performance of turbo coding from
- 30 the generated input interleavers, and
- choosing one of the selected interleavers so as to obtain the interleaving function.

16. Method for obtaining the interleaving function according to any of the claims 1 to 5, said interleaving function being adapted to be used in a turbo encoder (100) or turbo decoder (200),

the method comprising:

- 5 - A. defining a set $J = \{0, 1, \dots, k - 1\}$ of all k indices, initializing $j=0$, and the method further comprising recursively performing following steps:
 - B. selecting from the set J an input value A fulfilling the following criteria:
 - 10 iii. $|i - j| + |f(i) - A| \geq s$ for all nonnegative integers i fulfilling $(j - s) \leq i < j$, wherein $f(i)$ is the input index mapped to the output index i according to the interleaving function f ,
 - iv. $|A - j| \leq p$,
 - C. defining the interleaving function f so as to map the input value $f(j) = A$ to the output value j ,
 - D. removing the selected input value A from the set J ,
 - 15 - E. incrementing j by 1 and repeating the steps starting from step B, until J is an empty set, or until there is no indices left fulfilling the conditions iv, in which the steps starting from step B are repeated without considering the condition iv.

17. Method for obtaining an interleaving function $f_{p,d}$, said interleaving function being

20 adapted to be used in a turbo encoder (100) or turbo decoder (200),

the method comprising:

- providing a positive integer parameter L and a base interleaver f_b of length k' defined by a corresponding base interleaver function $f_b(j)$, k' being a positive integer,
- building a helper function $h(j) = f_b(j) + t_j k' \quad \forall j = \{0, 1, \dots, k' - 1\}$ with t_j being an
- 25 integer, and
- constructing the interleaving function $f_{p,d}$ according to the equation:

$$f_{p,d}(j + lk') = [h(j) + lk'] \bmod(Lk') \quad j = \{0, \dots, k' - 1\}, \quad l = \{0, \dots, L - 1\}.$$

18. Interleaving method, particularly for channel coding, for mapping an input sequence of
 30 $k'L$ indexed input symbols to an output sequence of $k'L$ indexed output symbols, k' and L being positive integers,

comprising the interleaving function $f_{p,d}(j + lk') = [h(j) + lk'] \bmod (Lk')$, $j = \{0, \dots, k' - 1\}$, $l = \{0, \dots, L - 1\}$, and $h(j) = f_b(j) + t_j$ with f_b being the interleaving function of the base interleaver of length k' , and t_j $j = \{0, \dots, k' - 1\}$ being integers.

- 5 19. Interleaving device (1600) comprising:
- a serial to parallel converter (1602) to write an input sequence (1601) to a matrix M (1603) of size L by k' ,
 - a base interleaver (1604) to be applied on each row of M (1603), wherein the output of the base interleaver (1604) is written to the corresponding rows of a matrix R (1605)
 - 10 of the same size,
 - a cyclic shift operator (1606) to be applied on each column of R (1605) in the vertical dimension to obtain a matrix S (1607) of the same size, wherein shift values t_j for each column of R is determined by the integers $t_j, j=0, \dots, k'-1$,
 - a parallel to serial converter (1608) to read the matrix S (1607) row by row to generate
 - 15 an interleaved output (1609) of length $k'L$.

20. Method according to claim 17 or 18 or interleaving device according to claim 19, wherein the base interleaver is chosen as LTE interleaver.

- 20 21. Method according to claim 17 or 18 or interleaving device according to claim 19, wherein the base interleaver is a Quadratic Permutation Polynomial (QPP) interleaver.

22. Channel encoder for encoding an input sequence into an encoded sequence,
the channel encoder comprising at least one interleaver and at least two constituent encoders,
25 wherein the interleaver, particularly block interleaver, is defined such that the encoded sequence is adapted to be decoded by a channel decoder in the form of a sliding window decoder.

23. Computer program having a program code for performing the method according to claim
30 5, 15, 16, 17, 18, 20 or 21, when the computer program runs on a computing device.

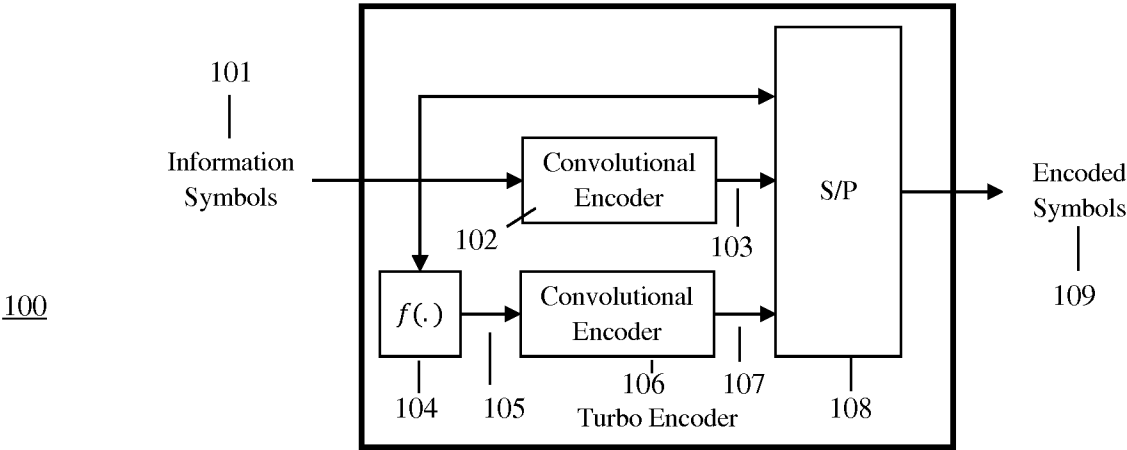


Fig. 1

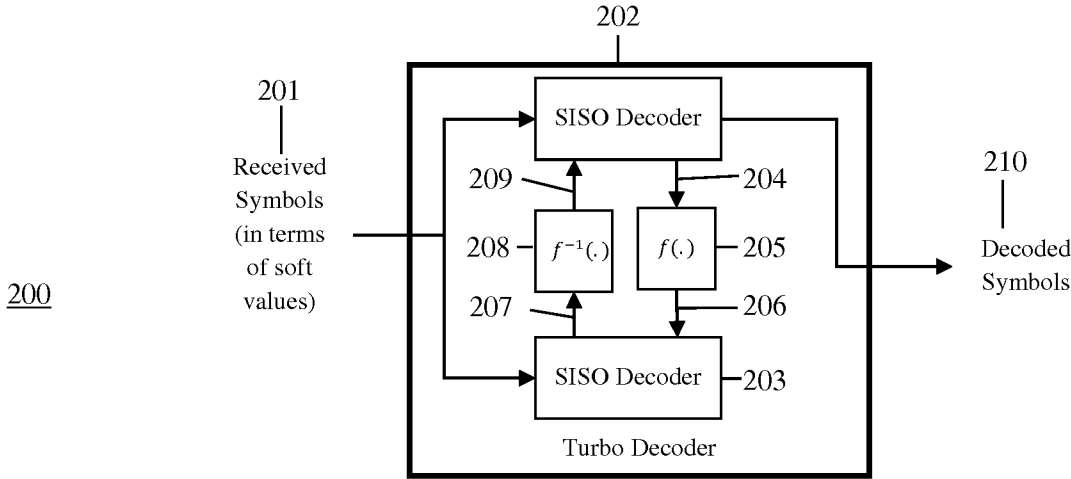


Fig. 2

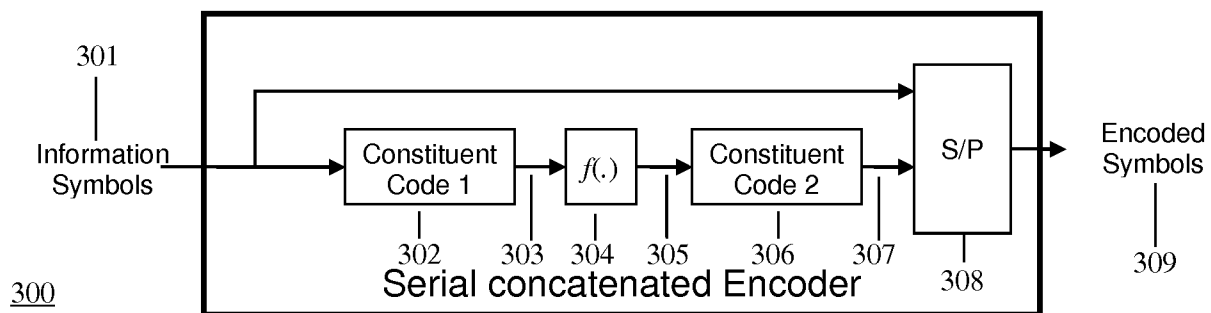


Fig. 3

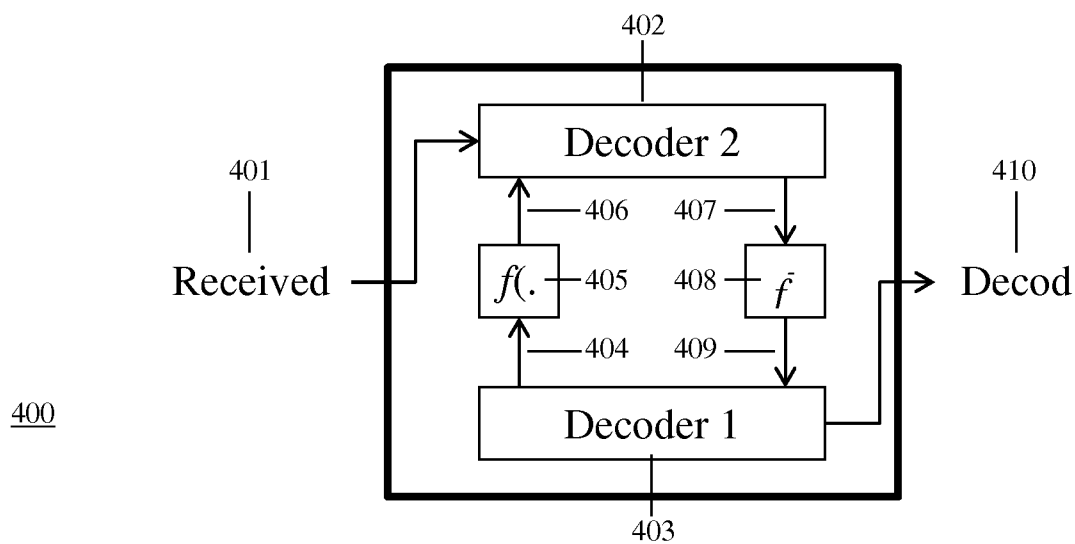


Fig. 4

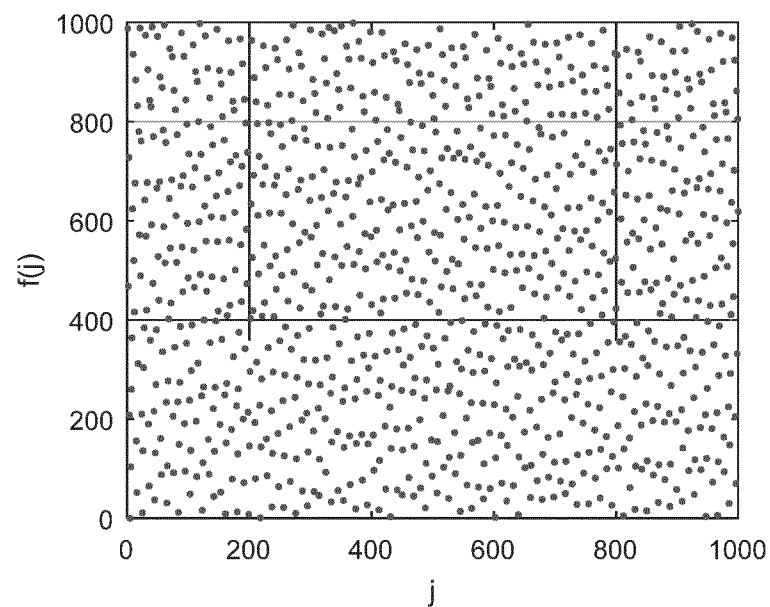


Fig. 5

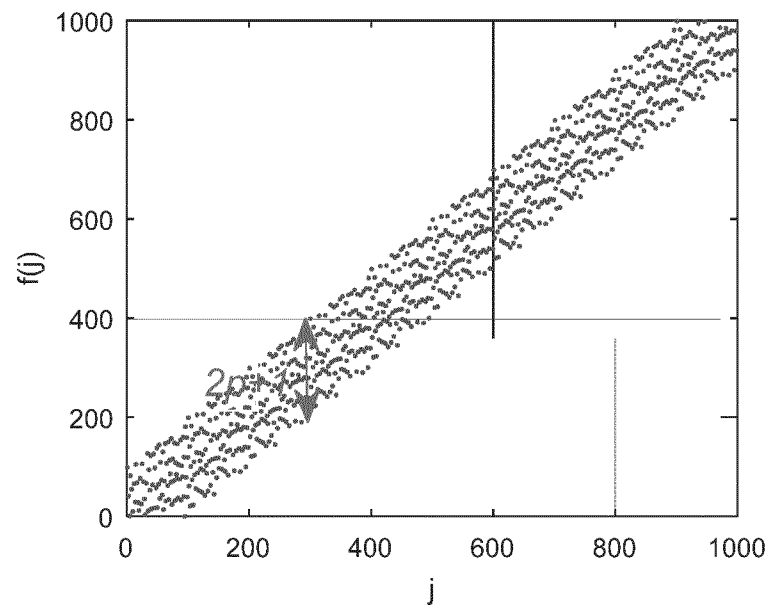


Fig. 6

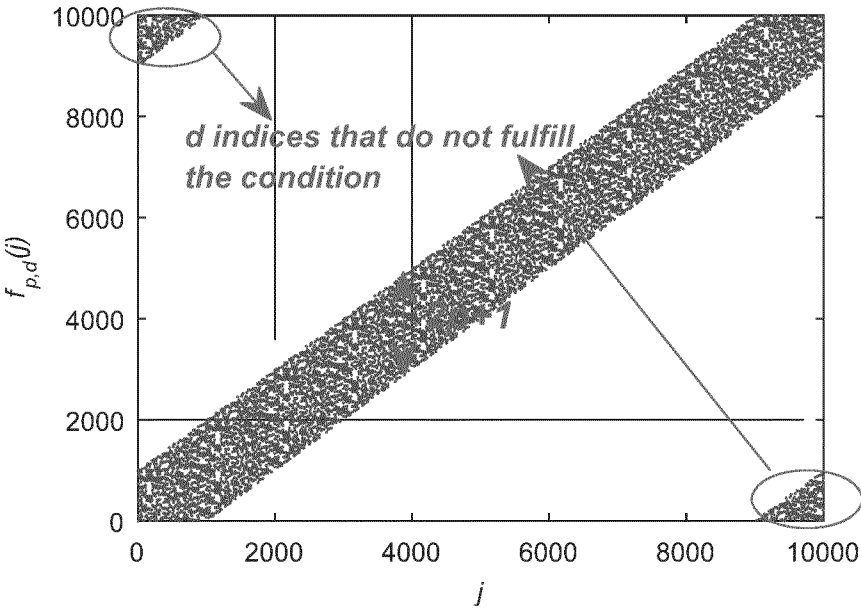


Fig. 7

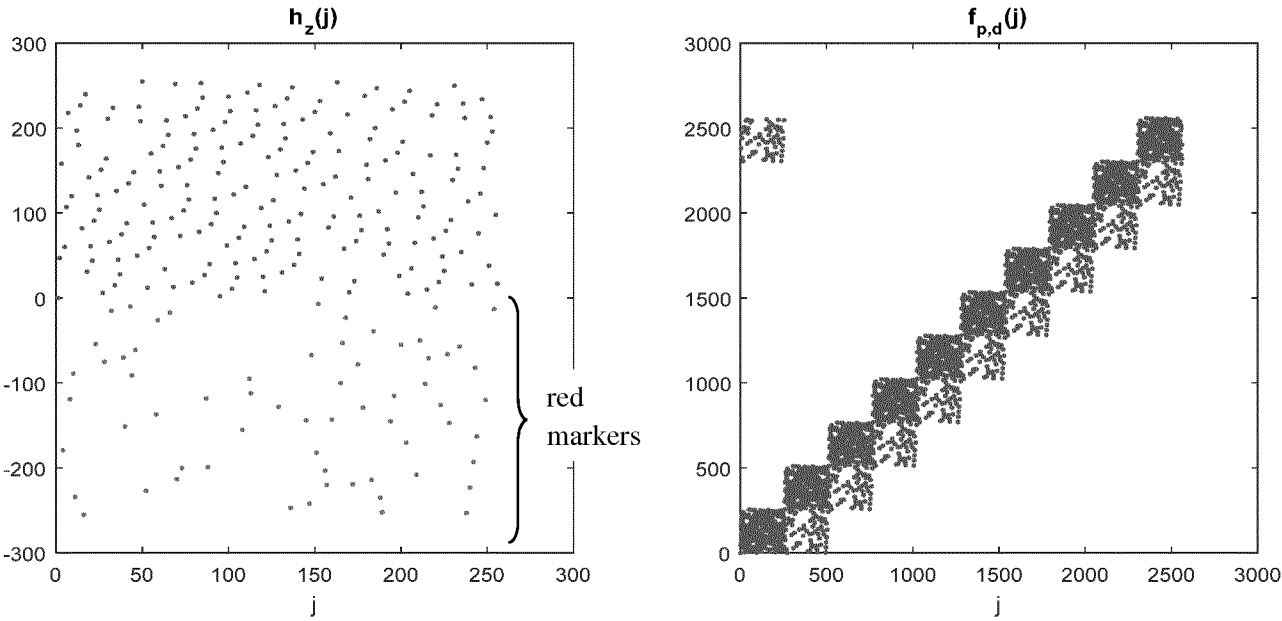


Fig. 8

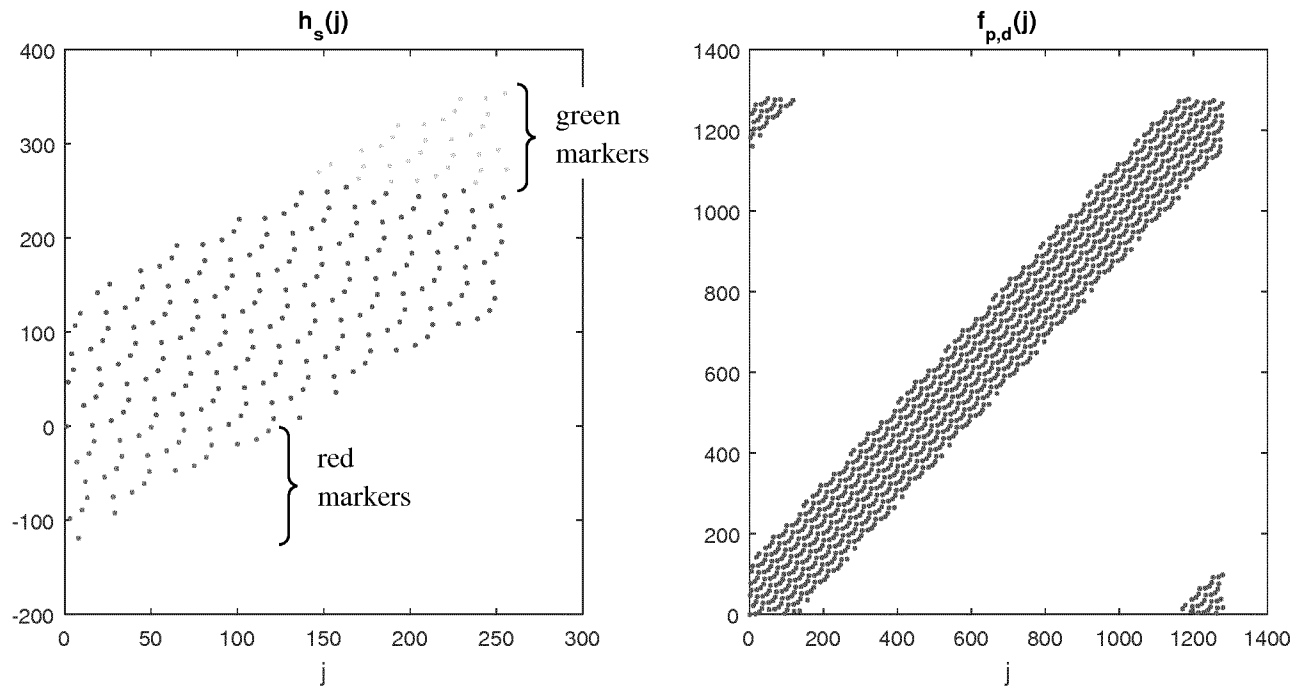


Fig. 9

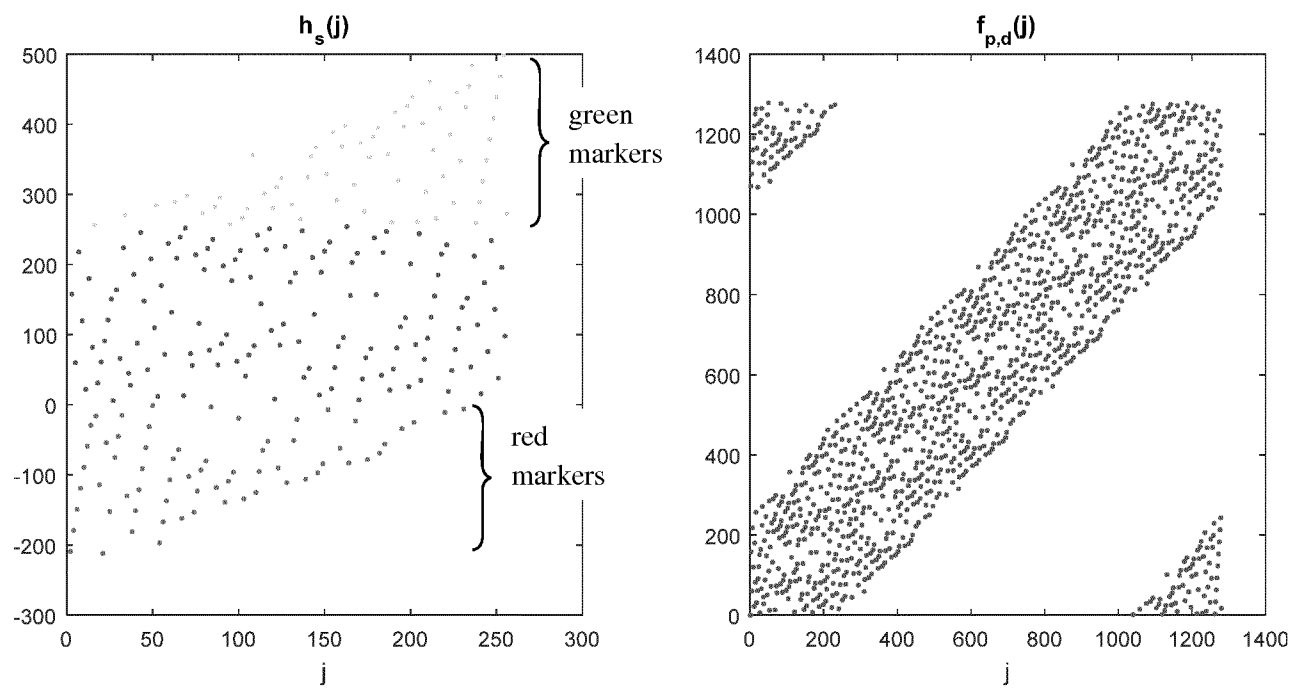


Fig. 10

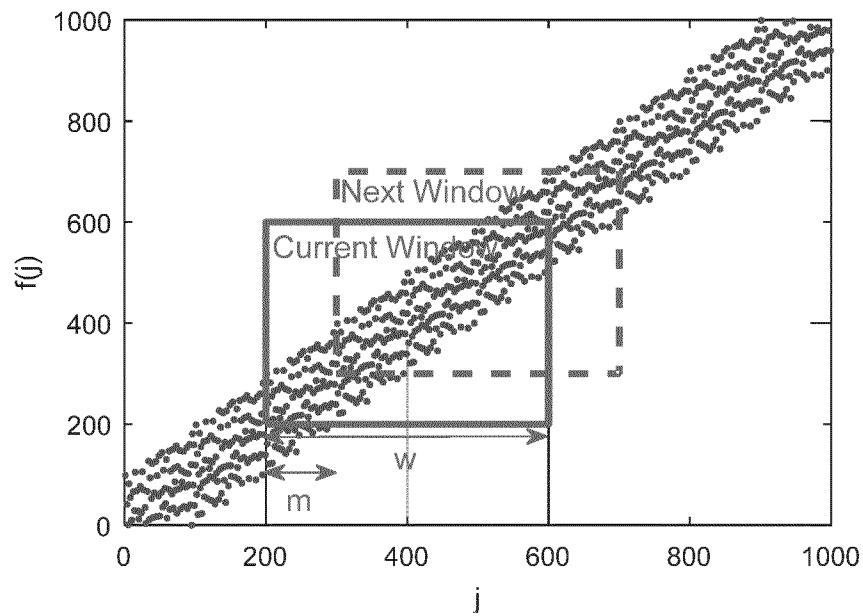


Fig. 11

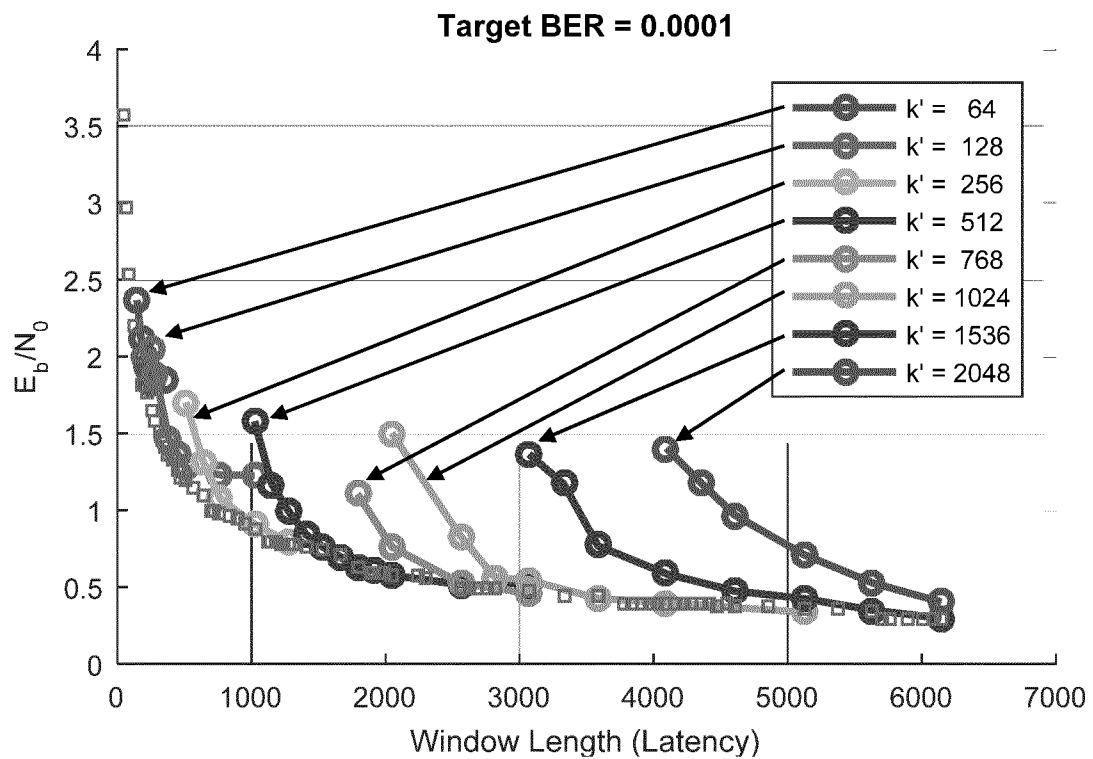


Fig. 12

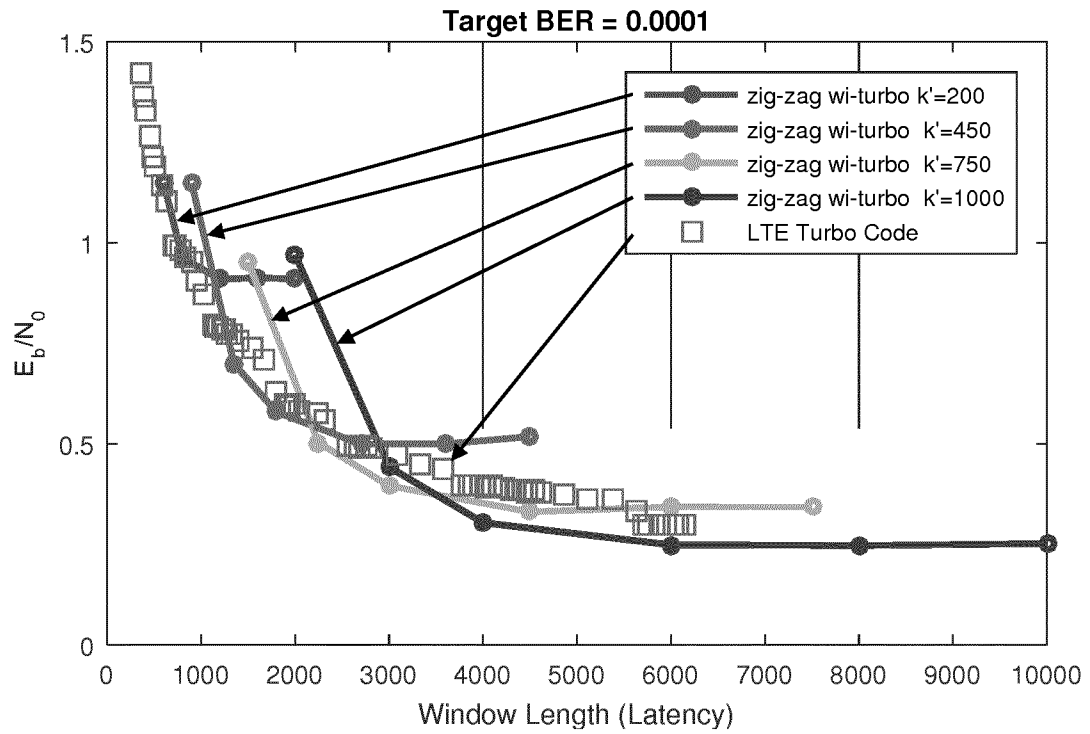


Fig. 13

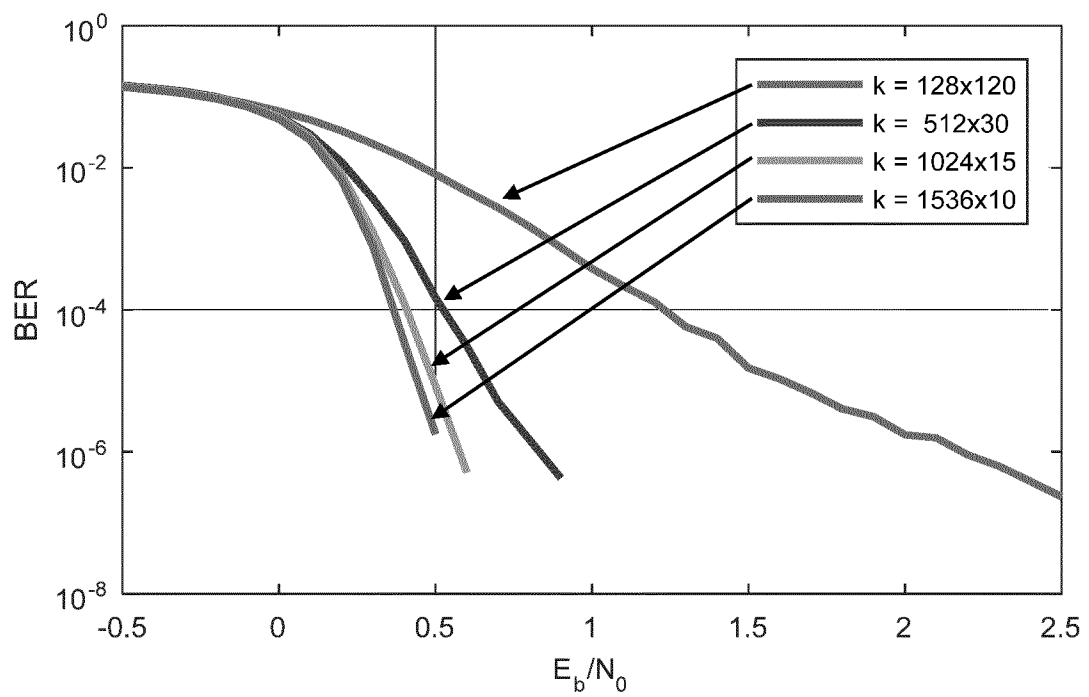


Fig. 14

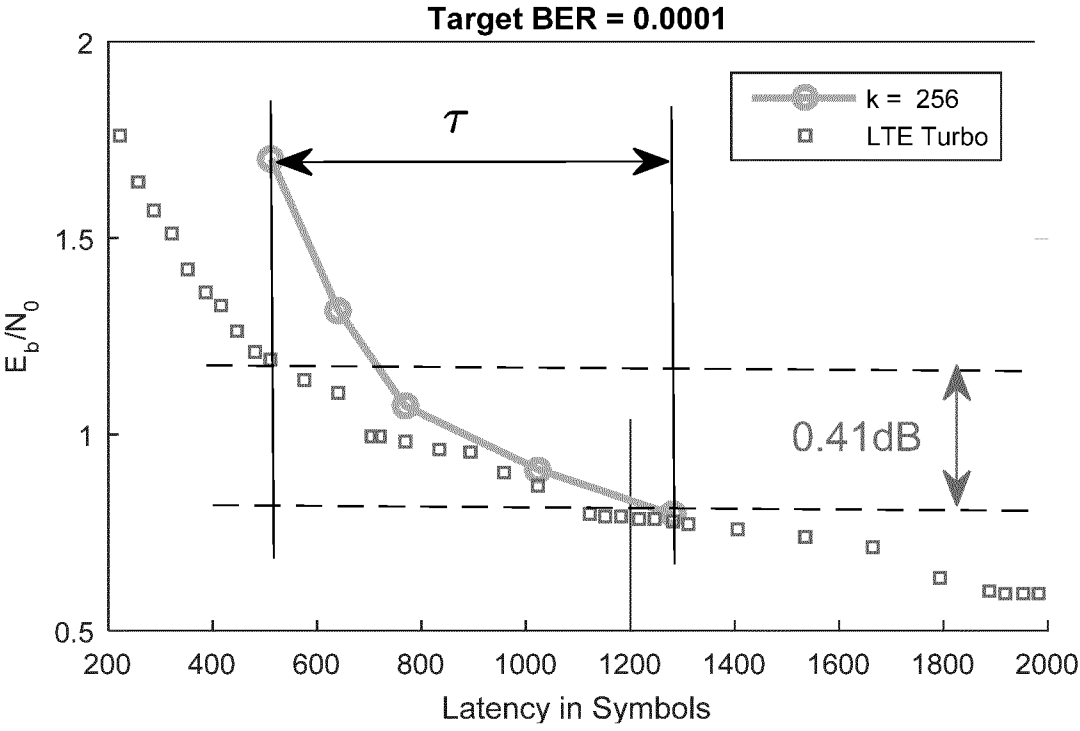
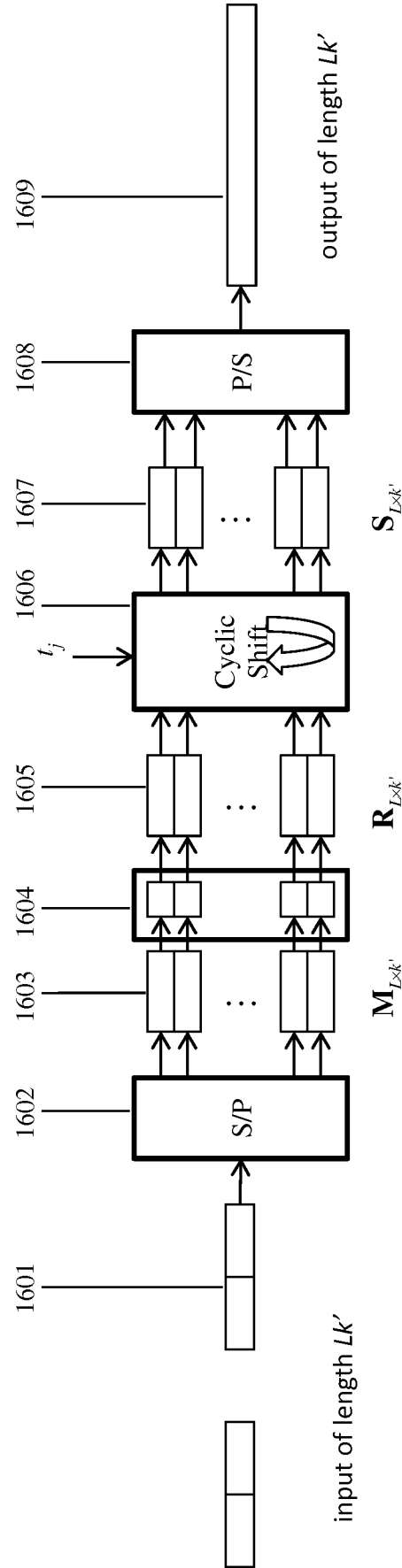


Fig. 15



1600

Fig. 16

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/050570

A. CLASSIFICATION OF SUBJECT MATTER

INV. H03M13/27 H03M13/29 H03M13/39
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)

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, COMPENDEX, INSPEC, 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 Y A	US 2003/041293 A1 (ZHENG YAN-XIU [TW] ET AL) 27 February 2003 (2003-02-27) abstract paragraph [0041] - paragraph [0046] paragraph [0048] - paragraph [0049] figures 1,3-6,7 ----- -/--	1-7, 10-13,23 9 8,14,15



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

5 October 2016

Date of mailing of the international search report

20/10/2016

Name and mailing address of the ISA/

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Authorized officer

Burkert, Frank

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/050570

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YAN-XIU ZHENG ET AL: "A new interleaver design and its application to turbo codes", PROC. IEEE 56TH. VEHICULAR TECHNOLOGY CONFERENCE 2002, VANCOUVER, CANADA, SEPT. 24 - 28, 2002; [IEEE VEHICULAR TECHNOLOGY CONFERENCE], NEW YORK, NY : IEEE, US, vol. 3, 24 September 2002 (2002-09-24), pages 1437-1441, XP010608666, DOI: 10.1109/VETECF.2002.1040453 ISBN: 978-0-7803-7467-6	1-5,15, 23
A	page 1437, right-hand column - page 1438, right-hand column page 1440 figures 2,3	6-14
Y	----- EROZ M ET AL: "On the design of prunable interleavers for turbo codes", PROC. IEEE 49TH VEHICULAR TECHNOLOGY CONFERENCE 1999, HOUSTON, TX, USA, 16-20 MAY 1999, PISCATAWAY, NJ, USA,IEEE, US, vol. 2, 16 May 1999 (1999-05-16), pages 1669-1673, XP010342111, DOI: 10.1109/VETEC.1999.780687 ISBN: 978-0-7803-5565-1 abstract page 1670, left-hand column	9
A	----- US 6 437 714 B1 (KIM JAE-YOEL [KR] ET AL) 20 August 2002 (2002-08-20) abstract column 6, line 10 - line 33 column 7, lines 35,36 column 9, line 10 - line 14 figure 3	8,9,14
A	----- US 2003/014715 A1 (LOBINGER ANDREAS [DE] ET AL) 16 January 2003 (2003-01-16) paragraphs [0023], [0024], [0043], [0045] figure 1	8,9,14
X	----- DINOI L ET AL: "Variable-size interleaver design for parallel turbo decoder architectures", PROC. 2004 GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM '04), IEEE DALLAS, TX, USA 29 NOV.-3 DEC., 2004, PISCATAWAY, NJ, USA,IEEE, PISCATAWAY, NJ, USA, vol. 5, 29 November 2004 (2004-11-29), pages 3108-3112, XP010758294, DOI: 10.1109/GLOCOM.2004.1378924 ISBN: 978-0-7803-8794-2 page 3108, right-hand column ----- -/--	16

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/050570

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 453 441 B1 (DAOUDI MOHAMED [FR] ET AL) 17 September 2002 (2002-09-17) column 5, line 6 - line 28 figure 1	16
X	----- QI F ET AL: "A novel interleaver design method for turbo codes", PROC. WIRELESS COMMUNICATIONS AND NETWORKING CONFERENCE 1999 (WCNC 1999), NEW ORLEANS, LA, USA 21-24 SEPT. 1999, PISCATAWAY, NJ, USA, IEEE, US, 21 September 1999 (1999-09-21), pages 476-479, XP010353796, DOI: 10.1109/WCNC.1999.797871 ISBN: 978-0-7803-5668-9	17-19
Y	page 476, right-hand column page 478	20,21
Y	----- ERICSSON: "Quadratic Permutation Polynomial Interleaver Designs for LTE Turbo Coding", 3GPP DRAFT; R1-070462, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Sorrento, Italy; 20070110, 10 January 2007 (2007-01-10), XP050104493, [retrieved on 2007-01-10] page 1	20,21
X	----- GONZALEZ-PEREZ LUIS F ET AL: "Parallel and configurable turbo decoder implementation for 3GPP-LTE", PROC. 2013 INTERNATIONAL CONFERENCE ON RECONFIGURABLE COMPUTING AND FPGAS (RECONFIG), IEEE, 9 December 2013 (2013-12-09), pages 1-6, XP032562610, DOI: 10.1109/RECONFIG.2013.6732316 [retrieved on 2014-02-04] page 3, right-hand column - page 4, right-hand column figures 1,2,3b ----- -/--	22

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/050570

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YANG SUN ET AL: "Configurable and scalable high throughput turbo decoder architecture for multiple 4G wireless standards", PROC. INTERNATIONAL CONFERENCE ON APPLICATION-SPECIFIC SYSTEMS, ARCHITECTURES AND PROCESSORS 2008 (ASAP 2008), IEEE, PISCATAWAY, NJ, USA, 2 July 2008 (2008-07-02), pages 209-214, XP031292402, ISBN: 978-1-4244-1897-8 page 210, right-hand column - page 212, right-hand column figures 1,4,6 -----	22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2016/050570

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. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
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. ☒ 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.
- ☒ 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: 1-15, 23

The first group of alleged inventions comprises claims 1-15 and 23. Owing to lack of novelty of the subject-matter of the first 7 claims, the first invention (having regard to the prior art) within said first group is defined by the subject-matter of claim 8. Claim 8 defines a turbo encoder comprising an interleaver, wherein the interleaving function of said interleaver comprises mapping an input sequence of k indexed input symbols to an output sequence of k indexed output symbols, wherein for a subset of all k input indices, comprising the input indices $b, \dots, k-b-1$, b being a non-negative integer smaller than $k/2$, a distance between the input index and the output index defined by the interleaving function is smaller than or equal to a threshold p , p being a positive integer smaller than k . The encoder further comprises an identification unit to determine the input indices that do not satisfy the aforementioned constraint and a computing unit adapted to insert known bits at the identified positions.

2. claim: 16

The subject-matter of claim 16 concerns a method for obtaining an interleaving function, in which two constraints are considered that have to be met by said interleaving function, viz. a minimum spread and a maximum allowable distance between input and output indices.

3. claims: 17-21

The subject-matter of these claims concern a method for obtaining an interleaving function (claim 17), an interleaving method using an interleaving function (claims 18, 20, 21) and an interleaving device comprising means for performing interleaving according to an interleaving function (claims 19-21), wherein the interleaving function is for interleaving a sequence of $L \cdot k'$ bits and is based on a base interleaver of size k' and a helper function, which provides an integer for all indices k' .

4. claim: 22

Claim 22 is directed to a channel encoder for encoding an input sequence into an encoded sequence, the channel encoder comprising at least one interleaver and at least two constituent encoders, wherein the interleaver is defined such that the encoded sequence is adapted to be decoded by a channel decoder in the form of a sliding window decoder.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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