A Short Length Low Complexity Low Delay Recursive LDPC Code

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Abstract: - Due to their low delay and complexity, short length codes are attractive for use in wireless communication systems. Also, achieving low complexity, high performance and low decoding latencies, is the key requirements of low-density parity-check (LDPC) code because these provide more reliable code for many applications. In this paper, a novel method was proposed to construct a short length code based on the convolutional encoder and LDPC decoder. In this code, delay and computational complexity of encoding and decoding were significantly reduced compared to other LDPC codes when they were simulated at the same length and code rate. The main contribution of this work was to design a code with low time delay and low computation complexity while having an improved bit error rate (BER) performance. Complexity and latency were reduced by using a convolutional technique for the encoding and by providing an improved parity-check matrix for the decoding. The codes were simulated over additive white Gaussian noise (AWGN) channel using different modulation schemes. Theoretical analysis denoted that the encoder and decoder may offer advantages in terms of latency and complexity, while simulation results have showed that the proposed code achieved an improvement over other LDPC codes that have the same length and code rates.

Key-Words: - LDPC codes, Low-density parity-check matrix (H), Convolutional encoder, Decoding complexity, Latency, BER performance.

1. Introduction

Low-density parity-check (LDPC) codes were investigated by Gallager [1]. With soft decoding algorithms on Tanner Graph, these codes can achieve outstanding capacity and approach Shannon limit over noisy channels at moderate decoding complexity [2]. The structure of the code is given by a parity-check matrix H, and different codes have different parity-check matrices [3]. LDPC codes are block codes and the biggest difference between them and classical block codes is how they are decoded. Due to high error correction performance, LDPC codes have become serious competitors to turbo codes [4], and they share the main concept of message passing algorithm as the turbo code. However, it is shown that the LDPC codes beat turbo codes in terms of bit error rate (BER) performance for the higher code rates [5,6]. Recently, many researchers have focused on performance analysis of recursive LDPC code. Based on the structure of the H matrix, a recursive can be designed using a set of shift-register where the encoder requires only a number of memory units. The recursive encoding significantly reduces the encoding time and the complexity compared to the encoding of LDPC block codes [7]. It has been shown that the processing time (latency) and decoding complexity increase linearly with increasing code length. This means small length LDPC codes result in low computational complexity and low time delay. So, researchers in LDPC codes look for good code's performance, but they also look for code structures that allow reducing the hardware and software encoding and decoding complexity [8]. In more applications, it is desired to design a code with low complexity and latency where the decoding over the large code length would result in large latency and decoding complexity. In this work, it has been focused on a small code length to construct LDPC codes which can provide these requirements and have improved high BER performance. The convolutional encoder technique and LDPC decoder are utilized in this approach, where the proposed code is based on the convolutional encoder and LDPC decoder. This paper is organized as follows; an overview of LDPC code is described in section II, the convolutional encoder is reviewed in section III, the proposed model is detailed in section IV and simulation results are done in section VI.

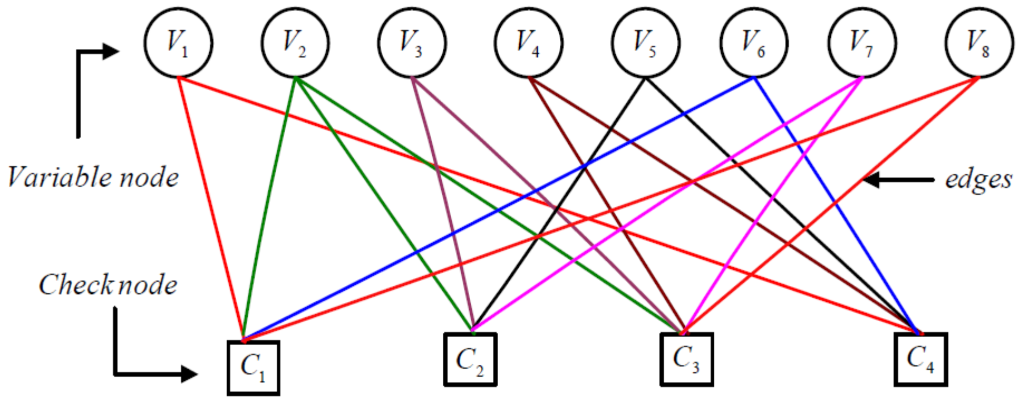

Fig.1. Tanner Graph Representations of LDPC code.

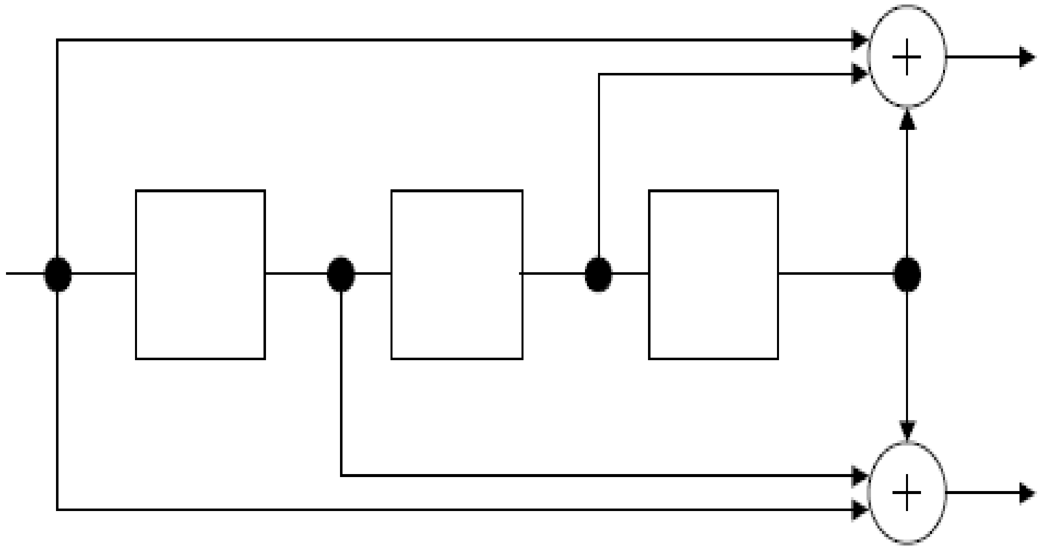

Fig.2. a model of convolutional encoder.

2. LDPC Code

The structure of the code is given by a parity-check matrix (H matrix). The code x is constructed so that

$$Hx^T = 0\ (mod\ 2),\ \forall\ x\ \in c \quad (1)$$

The code may then be written as

$$x^T = [i \mid c] \quad (2)$$

Correspondingly, the parity check matrix may be split into two matrices:

$$H = [A \mid B] \quad (3)$$

Also, equation (1) may be written as

$$Ai + Bi = 0 \quad (4)$$

If the matrix B is non-singular, the code can be found as

$$c = B^{-1}Ai \quad (5)$$

H can be defined with parameters such as row weight (r_w) and column weight (c_w), where m and n represent the number of parity check equations and the code length respectively. The row weight corresponds to the number of non-zero elements in a row, while the column weight corresponds to the number of non-zero elements in a column. If the row weight and column weight are uniform with all the rows and columns, then LDPC codes are called regular LDPC codes. With the non-uniform row and column weights, the codes are called irregular codes [9]. The decoding of LDPC codes can be efficiently performed using Tanner graphs [3]. This graph is constructed from H matrix and contains two sets of nodes, variable nodes and parity nodes, which represent the n bits and parity constraints respectively. The number of edges in Tanner graph is equal to the number of ones in H matrix. Fig.1 shows the Tanner graph for the H matrix given below

$$H = \begin{bmatrix} 1\ 1\ 0\ 0\ 0\ 1\ 0\ 1 \\ 0\ 1\ 1\ 0\ 1\ 0\ 1\ 0 \\ 0\ 1\ 1\ 1\ 0\ 0\ 1\ 1 \\ 1\ 0\ 0\ 1\ 1\ 1\ 0\ 0 \end{bmatrix} \quad (6)$$

The columns are represented as the variable node of set 8 and check node corresponding to the rows as the set of 4. As shown in Fig.1, H has a row weight of 4 and a column weight of 2.

Performance of LDPC codes is most related to the construction of H parameter which can be regular or irregular. The original LDPC codes presented by Gallager are regular and defined by a banded structure in H [10, 11]. There are three significant properties of H matrix: row-column (RC) constraints, girth, and rank. The RC constraints represent the weight of ones in rows and columns, the girth is the length of shortest cycles of Tanner graphs and the rank is the maximum number of linearly independent row vectors of the matrix. Increasing girth or column weight increases the minimum distance of the code and results in high BER performance [9]. The effect of girth on the performance of LDPC codes can be reduced by choosing the codes having longer girths. Generally, short length LDPC codes require a longer girth for a good performance [12]. In the receiver, there are many algorithms known to recover information [12], such as; 1) sum-product algorithm (SPA), 2) min-sum algorithm, 3) min-max algorithm, 4) message-passing algorithm and 5) bit-flipping decoding algorithm. The SPA is based on belief propagation and has the best decoding performance but with high computational complexity. In this paper, all simulation results are obtained using the sum-product algorithm.

3. An overview of the convolutional encoder

In this code, the bits come in serial form instead of a block form. Convolutional codes are commonly specified by three parameters (n, k, and K) where these parameters correspond to the number of output bits, the number of input bits and the length constraint respectively. These codes can be recursive or non-recursive, systematic or non-systematic. If input data appear in the code, the convolutional code is said to be systematic code. Convolutional encoder consists of an M-stage shift register and multiplexers. Fig.2 shows an example for (2,1,4) convolutional encoder with a code rate R= 1/2. The block diagram shows a model of a non-recursive, systematic convolutional encoder.

The impulse response streams $g_1(n)$ and $g_2(n)$ for the input $x(n) = (1\ 0\ 0\ 0 \ldots)$ for the encoder shown in Fig.2 can be introduced as follows:

$$g_1(n) = x(n) + x(n-2) + x(n-3) \quad (7)$$

$$g_2(n) = x(n) + x(n-1) + x(n-3) \quad (8)$$

Impulse responses can be written in a sequence form as $g_1 = [1011]$ and $g_2 = [1101]$, or in an octal form as $g_1 = 13$ and $g_2 = 15$. In addition, they can be defined in a polynomial form as

$$g_1(D) = 1 + D^2 + D^3 \quad (9)$$

$$g_2(D) = 1 + D + D^3 \quad (10)$$

where D is an operator related to the Z-transform. The linear combination of the two sequences can be described as

$$G_i = [g_1(D)\ g_2(D)] \qquad 0 \le i \le r \quad (11)$$

The generator matrix of the convolutional encoder can be described in a matrix form as

$$\mathrm{G} = \begin{bmatrix} G_0 & G_1 & G_2 \ldots & G_r & 0 & 0 & \\ & G_0 & G_1 & G_2 \ldots & G_r & 0 & \\ & & G_0 & G_1 & G_2 \ldots & G_r & \ldots \\ & & \vdots & & & & \end{bmatrix} \quad (12)$$

Then, the transform of the encoder output can be expressed as

$$Y(D) = X(D)\ G(D) \quad (13)$$

where $X(D)$ is the input sequence and

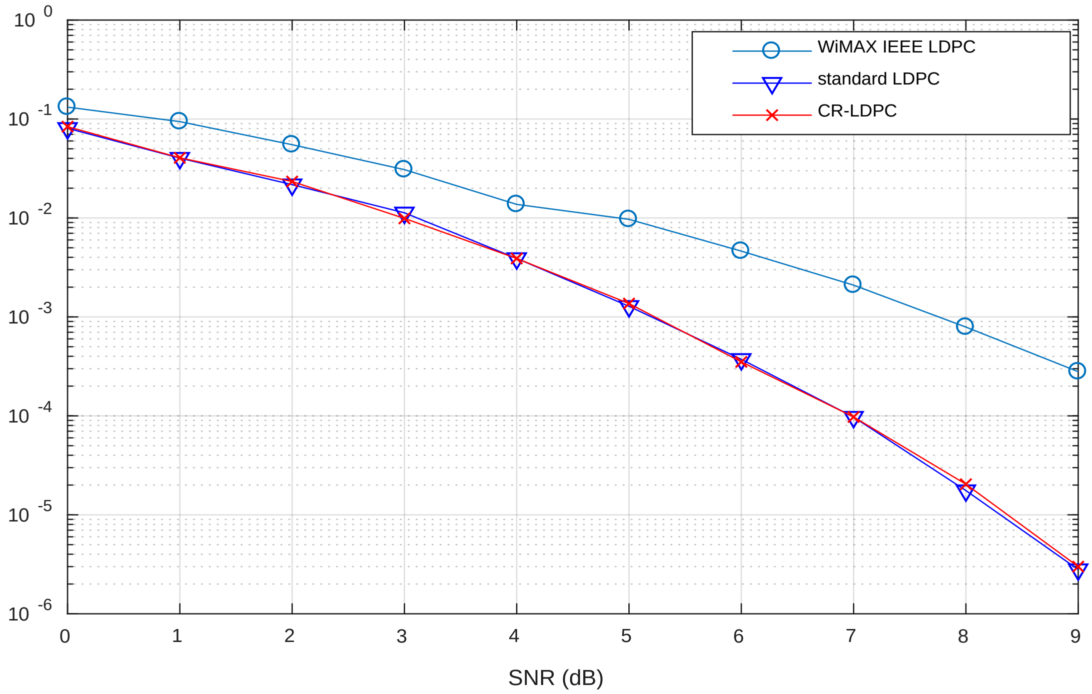

Fig.6 Performance of CR-LDPC, LDPC standard, and WiMAX LDPC codes, R=1/2, QPSK

$$Y(D) = [Y_1(D)\ Y_2(D)] \quad (14)$$

For $g_1 = [1011]$ and $g_2 = [1101]$, the generator matrix is

$$G = \begin{bmatrix} 11 & 01 & 10 & 11 & 00 & 00 & 00 & \\ 00 & 11 & 01 & 10 & 11 & 00 & 00 & \\ 00 & 00 & 11 & 01 & 10 & 11 & 00 & \cdots \\ 00 & 00 & 00 & 11 & 01 & 10 & 11 & \\ & & & \vdots & & & & \end{bmatrix} \quad (15)$$

If data sequence $u = [u_0\ u_1 \ldots\ u_m]$, then block code can be found as

$$c = u\,G \quad (16)$$

To confirm a better degree distribution of ones and girth, and then provides improved BER performance, the length of the generator r must be selected so that it is no less than k/2, as will be shown in the next sections.

4. System Model

In communication systems, low BER of LDPC code is a necessary but not a sufficient requirement. The latency (time required for encoding and decoding) and complexity of the encoder and decoder also needed to be considered. Recently, a lot of research has been done to present a high BER performance LDPC code with low latency and complexity. In [13-16], the researchers propose several methods to reduce the decoding complexity by updating the individual decoder algorithm or by reducing the total global wire-length. While achieving short length LDPC codes with low delay and complexity remains a challenge. In general, complexity and delay are directly related to the following issues; the number of operations required in each node, the average number of iterations, and the number of active nodes in each iteration [17]. The model proposed attempts to reduce delay and complexity of the encoder by replacing the LDPC block encoding with only a set of the shift register, and reduce delay and complexity of the decoder by constructing a novel parity-check matrix which has an improved construction that can decode the information with low delay and complexity as well as with optimum BER performance. The code generated based on convolutional encoding and recursive parity-check matrix, thus named CR-LDPC code. The two following sections show how encoder and decoder are constructed.

4.1 Encoder Construction

Here, an attempt has been made to construct a recursive and systematic encoder. The recursive encoding means that the encoder repeats the encoding procedure after a specific length of information. The code is systematic in that, the data bits are part of the code and the parity-check matrix is a repeat-accumulate matrix similar to the matrix of standard WiMAX code [17]. These considerations simplify the hardware implementation and allow the code to be easily encoded and decoded. In the convolutional encoder, the code is generated using a set of shift registers which are implemented according to the generator sequence. Generator sequence is a key parameter of the proposed code since it specifies the configuration of the encoder and the decoder. The block diagram depicted in Fig.3 shows the simplest way to generate CR-LDPC code. Firstly, the information is encoded into two pairs of the parity bit, and secondly, the information is added at the end of the code by the multiplexer. The memory unit is only used to illustrate that the information is separated from the parity bits and the code generated is similar to the WiMAX LDPC code.

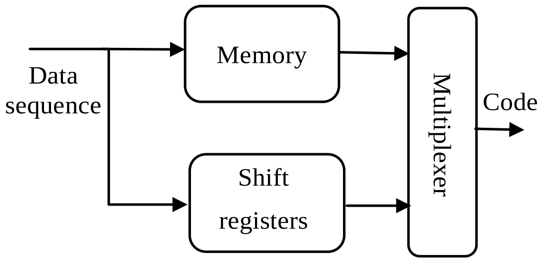

Fig.3 the block diagram of CR-LDPC

In addition to data bits, a sequence of zero bits of length Li is added at the end of the information and provided as input to the shift registers. This addition shifts data sequence by Li times and increases the parity sequence from k to k+Li, where k is the size of information bits. The most important benefit of adding zero bits is that it allows for providing a code with variable lengths and multi-rates. As a result, parity bits are produced separately from information using a convolutional encoder, and then the information is added at the end of parity bits to perform the CR-LDPC code. Fig.2 shows a convolutional encoder of (2,1,4); however, CR-LDPC encoder requires a convolutional encoder of one input and one output, such encoder has a rate of one and can be defined by a single generator polynomial. The generator matrix for the proposed encoder can be obtained as follows.

Consider an encoder with a generator polynomial of $g = [g_1\ g_2\ \ldots g_r]$. The generator matrix of convolutional encoder can be found using equation (12)

$$G_c = \begin{bmatrix} g_0 & g_1 & g_2 \cdots & g_r & 0 & 0 & \\ 0 & g_0 & g_1 & g_2 \cdots & g_r & 0 & \cdots \\ 0 & 0 & g_0 & g_1 & g_2 \cdots & g_r & \\ & & \vdots & & & & \end{bmatrix} \quad (17)$$

For inputs of k data bits and Li zero bits, the equivalent generator matrix is

$$G_e = \begin{bmatrix} 1 & 0 & 0 & g_0 & g_1 & g_2 \cdots & g_r & 0 & 0 & \\ 0 & 1 & 0 & 0 & g_0 & g_1 & g_2 \cdots & g_r & 0 & \cdots \\ 0 & 0 & 1 & 0 & 0 & g_0 & g_1 & g_2 \cdots & g_r & \\ & & & & \vdots & & & & & \end{bmatrix} \quad (18)$$

This equation can be written as

$$G_e = M[\mathrm{Li} + \mathrm{k}, 2(\mathrm{Li} + \mathrm{k})] \quad (19)$$

The information is not sent with code, then the actual generator matrix of the CR - LDPC encoder can be expressed as

$G_a = M[\mathrm{Li} + \mathrm{k}, \mathrm{Li} + 2\mathrm{k}]$ (20)

In LDPC block code, two encoding methods are known for encoding process [12]: 1) preprocessing method which has a computational complexity of $O(n^2)$ and 2) efficient encoding method which has a computational complexity of $O(n)$. However, by CR-LDPC code, only a set of shift registers is used and no multiplication or addition operations are required in the encoder. Clearly, the generated code is identical to that code generated by LDPC block code. To ensure that the most elements of the last rows are not equal to zero, r is selected so that r > k/2, this increases the edges of Tanner graph and then improves the code performance.

4.2 Decoder Construction

In the receiver, LDPC decoder is employed to decode the information from the received code. The H matrix is the most important parameter in LDPC decoder where constructing an efficient H matrix is the key to designing a good LDPC decoder. The H matrix is constructed using the generator matrix which is extracted from the impulse response of convolutional encoder. Generator matrix is constructed so that it leads to produce an efficient H matrix for the decoder. Using encoder parameters, H matrix can be obtained as follows.

The equivalent generator matrix which is represented by equation (19) can be written as

$G_e = [\, I \mid P \,]$ (21)

where I is identity matrix correspond to the data bits and P is a matrix that represents parity-check equations.

For $n \geq 2(k + Li)$, specify a matrix such that:

$[\, I \mid P \,] = G_e[k + Li, n]$ (22)

find $H[\mathrm{n} - \mathrm{k} - \mathrm{Li}, \mathrm{n}] = [\, P^T \mid I \,]$ (23)

H matrix is derived from the equivalent generator matrix; however, to correctly decode the received CR-LDPC code, the structure also requires adding a number of zero inputs of size Li to the decoder corresponding to that added through the encoding process. This process improves decoding efficiency and results in a code with variable lengths and multi rates. Clearly, if n = 2k and no zero inputs are considered in the code (Li=0), then the constructed H matrix has a size of (k, 2k) and the code rate exactly is equal to 1/2. The length, rate, as well as the performance of the code, will be changed when the Li is changed. For an efficient H matrix, several factors need to be considered through the construction of impulse response or generator sequence for the convolutional encoder.

1) The degree of the impulse response, r must be larger than k/2 to ensure a good degree distribution of ones in H,
2) To remove girth 4 from Tanner graph, the generator sequence must be prefix-free, that is, this code is free from similar individual codes.
3) The sparsity of H matrix is required for the high algorithmic efficiency. So, efficient encoding can be satisfied if ones are sparse in the generator sequence.

Now, we have selected a simple example to verify the theory and to explain how the code is constructed. A convolutional encoder considered with (n, k, K) = (1, 1, 9) and impulse response of $g = [1\ 1\ 0\ 0\ 0\ 1\ 0\ 0\ 1]$. Suppose Li=0, the convolutional generator matrix can be found using equation (17)

$$M = \begin{bmatrix}
1&1&0&0&0&1&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&1&1&0&0&0&1&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&1&1&0&0&0&1&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&0&1&1&0&0&0&1&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&1&1&0&0&0&1&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0&0&0&0&0\\
0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1
\end{bmatrix} \quad (24)$$

The generator matrix after adding the data sequence can be written as

$$G_e = \begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0&1\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&0\\
0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1\\
0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0&0\\
0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1&1\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix} \quad (25)$$

This encoder can be performed by a simple set of shift registers as in Fig.4.

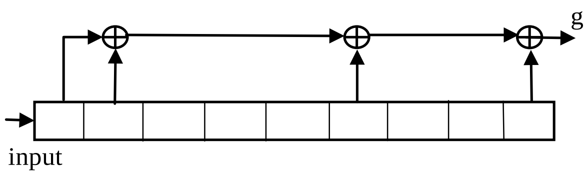

Fig.4. A block diagram for a convolutional encoder of (n, k, K) = (1, 1, 9)

In this example, a data sequence of 12 bits and code rate of 1/2 are considered. The corresponding code length is 24 bits and the size of H matrix is (12, 24). The H matrix can be obtained using equation (23)

$$H = \begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0\\
0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
1&0&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&1&0&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0&0\\
0&0&1&0&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&1&0&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix}$$
(26)

The Tanner graph of H matrix is presented in Fig.5. The rectangles represent check nodes while the circles represent variable nodes. The filled circles correspond to data bits while the empty circles denote the parity bits.

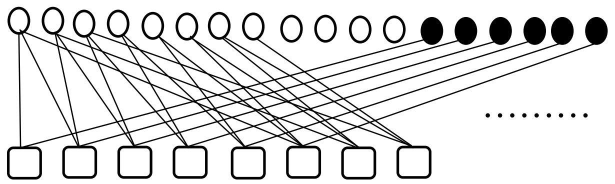

Fig.5. Tanner graph of H matrix

From the H matrix and its Tanner graph, it can be noted that the parity check matrix has a recursive structure, that is, if the code length is increased by the encoder, the decoder requires only a number of edges to be added to the structure in a recursive manner. Such adding is easy to implement since the edge connections of the added nodes are similar to the edge connections that exist in the graph. The characteristics of this structure can be summarized as follows:

1) The code is systematic since the information is part of it.
2) The decoder has a recursive structure so that the parity bits are determined depending on data bits and encoded parity bits. This provides significant advantages in terms of implementation complexity and delay.
3) H is a random and irregular matrix where the edge connection on the variable node connects to a check node one position away. This reduces delay and improves BER performance.
4) Girth 4 is removed from the H matrix and the Tanner graph has a longer girth. This leads to improve BER performance because minimum weight distance increases by increasing the girth, and also reduces delay since it reduces the number of iterations required in the decoding.
5) The convolutional encoder can be constructed so that the generated CR-LDPC codes have a good minimum distance, and also the Tanner graph of these codes contains edge connections of a short cycle.
6) By a process of shifting the information, the proposed structure is capable of providing codes with variable lengths and multi rates.
7) The structure can avoid variable nodes that have a low number of edges in the Tanner graph and can then provide codes with a high BER performance.
8) The process of adding zero bits at the decoder also improves decoding performance and reduces decoding delay because this process increases the signal-to-noise ratio (SNR) of the received code, and also because the added bits represent symbols of a high probability

5. Simulation and results

The BER performance of proposed code is evaluated for the example considered in the paper. Performances of different code rates over additive white Gaussian noise are compared and evaluated. Firstly, a generator sequence of g = 611 and data of k=12 bits are used. The code rate is 1/2 and the Li is set to zero. The proposed code is evaluated and compared with the LDPC block code used in the WiMAX 802.16e standard and with LDPC block codes which use the LDPC block encoding method. All simulation results are obtained using the sum-product decoding algorithm. Fig.6 shows the BER performance of CR-LDPC code using QPSK modulation. It can be seen that the performance of the proposed code is identical to that achieved by the LDPC block encoder (standard encoding method). Also, the curves show that the proposed code achieves performance better than the code that is generated using the parity-check matrix considered in the IEEE 802.16 standard.

If a number of zero inputs of length, Li is used, then the performance of CR-LDPC code will be significantly improved. Fig.7 shows an improvement in CR-LDPC code compared to the standard LDPC code when k=12 bits and Li=4 bits. However, the rate of the code is reduced to 1/3. So, this process can be utilized to provide a code with improved performance and multi-rates. Consider a code with k=12 and Li= 12. This code has a rate of 1/3 and comprises 36 bits, 12 as information bits and 24 as parity-check bits. such codes provide a significant improvement in BER performance as will be shown in the next results.

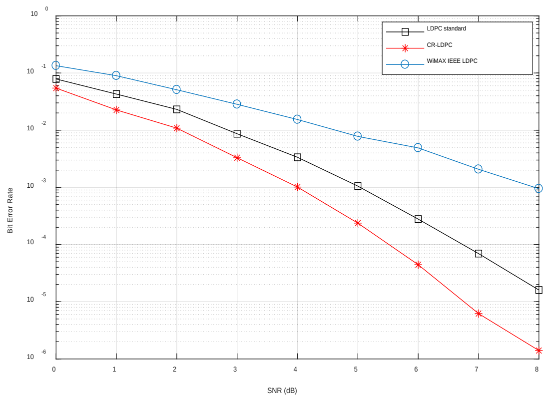

Fig.7 Performance of CR-LDPC, LDPC standard, and WiMAX LDPC codes, Li=4, QPSK

Fig.8 shows results when k=12, Li=12, and all codes having a rate of 1/3. The curves show that the BER performance of CR-LDPC code is better than standard LDPC code and WiMAX LDPC code despite the length of WiMAX LDPC code is 48 bits.

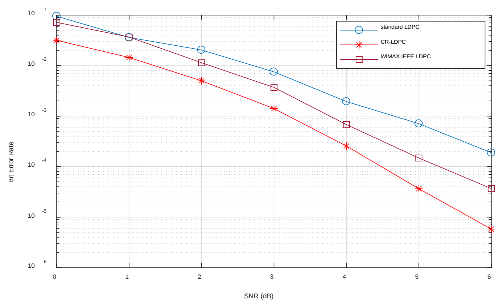

Fig.8 Performance of CR-LDPC, standard LDPC, and WiMAX LDPC codes, R=1/3, QPSK

There are several factors behind this significant improvement in the BER performance: 1) the proposed code has a large minimum distance. 2) the constructed parity-check matrix has good randomness and irregular construction. 3) the Tanner graph is characterized by a large girth. 4) the zero inputs inserted at the decoder significantly increase the SNR of the received code, as they represent a received message with no error probability. 5) By the process of adding zeroes, variable nodes that have a low number of edges are avoided 6) the decoder uses a matrix of size (24 x 48) instead of (24 x 36), this leads to a better decoding performance because the performance of LDPC decoder directly relates to the size of parity-check matrix. The BER performance over 8PSK using same parameters is depicted in Fig.9. As in LDPC block code, the performance of CR-LDPC is improved when code length is increased.

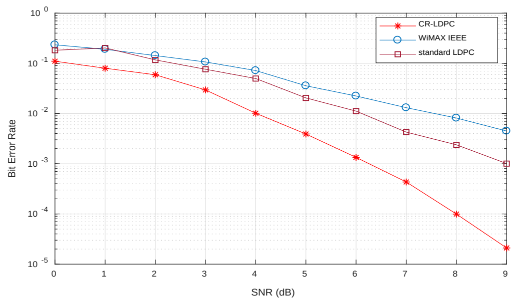

Fig.9 Performance of CR-LDPC, LDPC standard, and WiMAX LDPC codes, R=1/3, 8PSK

Fig.10 shows results when data length and code rate are set to 24 bits and 1/2 respectively. The generator sequence is g = 6111 and Li=0. Again, using Li=4 bits, the performance of the proposed code is significantly increased as shown in Fig.11.

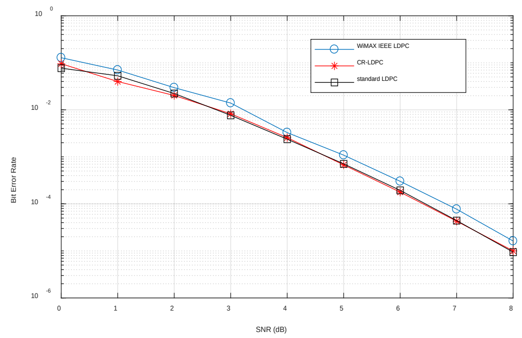

Fig.10 Performance of CR-LDPC, LDPC standard, and WiMAX LDPC codes, R=1/2, QPSK

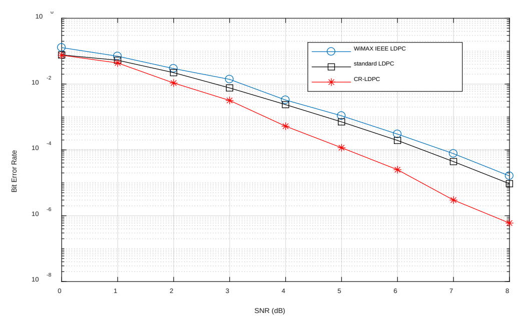

Fig.11 Performance of CR-LDPC, LDPC standard, and WiMAX LDPC codes, Li=4, QPSK

6. Conclusion

In this paper, a novel short length LDPC code is presented, called convolutional recursive LDPC (CR-LDPC) code. This code was based on convolutional encoding and LDPC decoding. The parity-check matrix used in the decoder was derived from the generator matrix of the convolutional encoder. Several constraints were considered through designing the generator matrix at the encoder in order to make the parity-check matrix simple and efficient. It has been analytically demonstrated that the proposed structure can significantly reduce computational complexity and delay of encoding by using a convolutional encoder instead of using LDPC block encoder. While delay and complexity of the decoder were reduced by constructing an improved generator matrix so that the parity-check matrix constructed can achieve these requirements. By comparing results with WiMAX LDPC codes and LDPC codes which based on a block encoding method, simulation results showed that the proposed code achieved a suitable performance at rate 1/2, and a good performance when the code rate changed to 1/3.

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