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Performance Analysis of Quasi-Cyclic Low Density Parity Check Codes

[1]Nalini Prasad Tirumani , [2]Patchigolla Subbarao
Department of E.C.E, S.R.K.R Engineering College, Bhimavaram, Andhra Pradesh, India.
[1]naliniprasadt@gmail.com, [2]patsrao@gmail.com

Abstract: Low-Density Parity-Check codes are the class of linear block codes, which perform the near Shannon limit performance on data transmission. Here, Quasi Cyclic codes are circulant permutation matrices, for the efficient encoding purpose. In this paper, QC-LDPC Codes have significant performance improvement due to the effective iterative Min-Sum decoding algorithm in terms of Bit Error Rate (BER) versus E_b/N_o with low and high code rates compared to other existing codes. Soft decision decoding and increased number of iterations of QC-LDPC codes has better performance.

Index Terms: LDPC codes, Quasi-Cyclic codes, QC-LDPC codes, Min-Sum Decoding Algorithm.

I. INTRODUCTION

In order to have reliable communication, over noisy channels, error correcting codes are used. Error correcting codes [1] insert redundancy into the transmitted data stream and receiver possibly correct errors that occur during transmission. There are several types of codes exist. Every code has some special application. Researchers are searching for the best code for wireless communication application. In this paper propose a particular type of error correcting code called LDPC. LDPC Codes originally introduced by Gallager [2] in 1960's. However , it was impossible to implement the code in hardware at that time. Three decades later LDPC Codes rediscovered by Mackay and Neal [3] due to its excellent properties of the code and its current feasibility. LDPC Codes have proven to have very good performance over noisy channels. The main reason is that the error performance is very close to Shannon limit [3], [4]. The main advantage of the LDPC codes is this its performance is very close to turbo codes, however, LDPC codes allow parallel decoding architectures, thus achieving higher throughput as compared to turbo codes. Error correcting capability of turbo codes can be suppressed by LDPC codes; at the same time, the hardware complexity of LDPC codes tends to be significantly smaller than that corresponding to turbo codes. LDPC Codes further classified into two types LDPC Block codes (LDPC-BCs) and LDPC Convolutional Codes(LDPC-CCs).

LDPC codes [5] are explained by their parity check matrix and the way this is connected. LDPC codes are classified into two types, namely regular and irregular codes. In regular LDPC number of ones in row and column weights is equal. Whereas in irregular type number of ones in row and column weights are not same. The more important approach that proposed in this paper is to design circulant LDPC codes with permutation blocks [6]. Due to the block circulant structure of the parity check matrix encoding done very efficiently. These structures allow for small storage requirement, as well as for performing encoding and via fast and simple circuits. Such high-speed architectures are of crucial importance in communications.

The code generated by an intersection of quasi-circulant (Quasi-Cyclic) [6], [7], [8] codes. A quasi-circulant code of is a code with a property that any cyclic shift of a codeward in some positions represents another code word. Additionally, the Min-Sum decoding algorithm [9], [10] employed for soft-decision decoding of these requires a number of binary logic operations at least one order of magnitude smaller than that corresponding to hard-decision decoding of turbo codes.

The rest of the paper is as follows. Section II describes the overview of LDPC codes & Quasi-cyclic codes. The next section III proposed QC-LDPC coding and decoding techniques. In section IV various performance results and appropriate comparisons, while conclusion in section V.

II. OVERVIEW OF LDPC CODES & QUASI-CYCLI CODES

In this section a brief overview of LDPC blocks codes. These codes will be used as a reference for the purpose of proposed QC-LDPC codes.

A. LDPC block codes

Low-Density Parity Check Codes (LDPC) codes, are the class of linear block codes. The name Low Density comes from characteristics of their parity check matrix contains only a few number of 1's in comparison to 0's. Basically, LDPC codes represented by two ways, one is matrix representation and second possibility is graphical (Tanner Graph) representation. In matrix representation, there are two numbers describing the parity check matrix with dimension n x m. w_r for the number of 1's in each row and w_c for the column. A matrix to be called low-density there is two conditions w_r<<min (m, n) and w_c<<min (m, n) must be satisfied [5]. Graphical representation of parity check codes by the tanner graph. Tanner graph not only representing the complete code but also help to describe the decoding algorithm. There are two types nodes in Tanner graph are called variable nodes (v-nodes) and check nodes (c-nodes).The bellow shows the matrix representation and corresponding graphical representation of the Low-Density Parity Check Code

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

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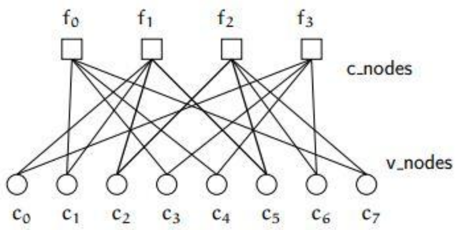

Figure (1): A parity check matrix (H) and its corresponding tanner graph representation

Codeword (c) of n bits is produced by the original uncoded word (u) of k bits. The codeword c is valid if the subsequent parity check equation satisfies the bellow condition:

$$H * c^T = 0 \tag{2}$$

The resultant code rate k/n defines the size of the parity check matrix, which is specified as (n-k) x n.

The near Shannon performance of LDPC block codes is obtained only at large block size (in the order of greater than 1000 bits).

B. Quasi-cyclic LDPC codes

A circulant is a square matrix for which every row is the cyclic-shift of the row above it and the first row is the cyclic shift of the last row. For such a circulant, each column is the downward cyclic shift of the column on its left, and the first column is the first column is the cyclic shift of the last column. The set of columns (reading from the top down) is the same as the set of rows (reading from right to left). The row and column weights of the circulant are the same, say w. The null space of the circulant gives a cyclic code. Given circulants, it is possible to decompose it into an array of circulants of the same size then null space of this array gives a quasi-cyclic code.

III. Proposed QC-LDPC coding technique

A. Encoding procedure of QC-LDPC code

The class of QC-LDPC codes is characterized by the parity-check matrix which contains small square blocks [7], [8], which are the zero matrix or circulant permutation matrices. Let P be the q x q permutation matrix given by Eq. (3).

$$P = \begin{bmatrix} 0 & 1 & 0 & & & & & 0 \\ 0 & 0 & 1 & . & . & . & . & 0 \\ . & . & . & & & & & . \\ . & . & . & & & & & . \\ 0 & 0 & 0 & . & . & . & . & 1 \\ 1 & 0 & 0 & & & & & 0 \end{bmatrix} \tag{3}$$

Where P^i is the circulant permutation matrix which shifts the identity matrix I to the right by times for any integer i, ($0 \leq i \leq q$) and P^∞ denotes the zero matrix, and the resulting parity check matrix H of size (j. q) x (k .q) is illustrated bellow Eq. (4).

$$H = \begin{bmatrix} P^{a_{11}} & P^{a_{12}} & . & . & . & . & P^{a_{1(k-1)}} & P^{a_{1k}} \\ P^{a_{21}} & P^{a_{22}} & . & . & . & . & P^{a_{2(k-1)}} & P^{a_{2k}} \\ . & . & & & & & . & . \\ . & . & & & & & . & . \\ . & . & & & & & . & . \\ P^{a_{j1}} & P^{a_{j2}} & . & . & . & . & P^{a_{j(k-1)}} & P^{a_{jk}} \end{bmatrix} \tag{4}$$

Where $a_{ij} \in \{0, 1, \ldots, q, \infty\}$. The code C with parity check matrix H is quasi-cyclic in the c= (c_0, c1,…., c_{n-1}) ϵ C.

Now C will be referred to as a QC-LDPC code. The parameters j, k are related to the code rate. When H has full rank, then its overall code rate (R) is given by :

$$R = \frac{qk - qj}{qk} = \frac{k - j}{k} = 1 - \frac{j}{k} \tag{5}$$

To set q special care should be taken the prime number and the equation $q \geq k \geq j$ is not valid, otherwise, the coding system would be inadequate.

If the locations of 1's in the first row of the i^{th} row block $H_i = [\, P^{a_{i1}} \ldots\ldots P^{a_{in}} \,]$ are fixed, then the locations of the H_i are uniquely determined. Therefore, the required memory for storing the parity check matrix of the QC-LDPC code can be reduced by factor 1/q, as compared to with randomly constructed LDPC codes.

When H has no blocks corresponding to the zero matrixes, it is a regular LDPC code with column weight j and row weight k. in this case, its code rate is larger than 1-j/k shown in Eq.(5), where there exist at least j-1 linearly dependent rows.

For efficient encoding proposed a modified array code with the following parity check matrix shown in Eq. (6).

$$H(q,j,k) = \begin{bmatrix} I & I & I & .... & I & .... & I \\ 0 & I & P & .... & P^{(j-2)} & .... & P^{(k-2)} \\ 0 & 0 & I & .... & P^{2(j-3)} & .... & P^{2(k-3)} \\ . & . & . & & & & . \\ . & . & . & & & .... & . \\ 0 & 0 & 0 & .... & I & . \ .... & P^{(j-1)(k-j)} \end{bmatrix} \tag{6}$$

Above matrix is an irregular QC-LDPC code, where q is prime and $q \geq k \geq j$. H(q, j, k) has a full rank matrix and it is an upper triangular matrix with non-zero diagonal elements. Due to the upper triangular form of H(q, j, k), it can be efficiently encoded. It is easily checked that there are no cycles in the corresponding Tanner graph.

B. Decoding procedure (Min-Sum Decoding)

Most practical LDPC decoders use soft-decisions. There are two ways to deliver messages in LDPC decoding, one is to use probabilities, and the other is to use log-likelihood ratios (LLRs). In general, LLRs favored since that allows us to replace expensive multiplication operations with inexpensive addition operations. An Iterative algorithm is used for the decoding of QC-LDPC [11] instead of the trellis. The general iterative algorithm, the so-called min-sum algorithm (MSA) or sum-product algorithm (SPA) .This algorithm is better to grasp via

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the code's tanner graph. According to this algorithm, each variable node sends a message to the check node with which it is connected, during each iteration round. This message is an estimation of the exact value of the corresponding code word bit this node represents. LDPC decoding consists of three general steps, initialization, check node update and variable (bit) node update. At the beginning of the decoding process [11], the variable node receives the LLR's. Variable nodes pass these values to check nodes.

First iteration:

i) Check to Variable Pass: For an n^{th} variable node it is connected to, a check node finds the minimum of absolute values, of other nodes except n^{th} node, and send that value with a sign , to satisfy the modulo 2 sum.

ii) Variable node to Check Pass: A variable node sums up all the information it has received at the end of the last iteration, except the message that came from m^{th} check node; and send it to m^{th} check node.

Above process is repeated until the bits are corrected or the stopping the after a subsequent number of iteration rounds reached. On examining the algorithm reveals that check node update can be done in parallel since the rows are uncorrelated with each other and the bit node update on each column can be processed.

IV. Performance Evaluation Results

In this paper, a study is carried out in terms of achievable BER under QC- LDPC scheme with low code rates as well as high code rates. QC-LDPC codes are employed, in order to reduce encoding and decoding complexity [11]. The corresponding evaluation results show that QC-LDPC codes better perform the currently used consultative committee for space data systems.

BER performance evaluation results are illustrated by the means of computer simulation. It is assumed Binary Phase Shift Keying (BPSK) modulation and the AWGN Channel. The simulations were run with a block size of 10000 bits. The number of iteration rounds was set to 30 iterations and 50 iterations, code rates are set to 1/2, 2/3, 2/5.

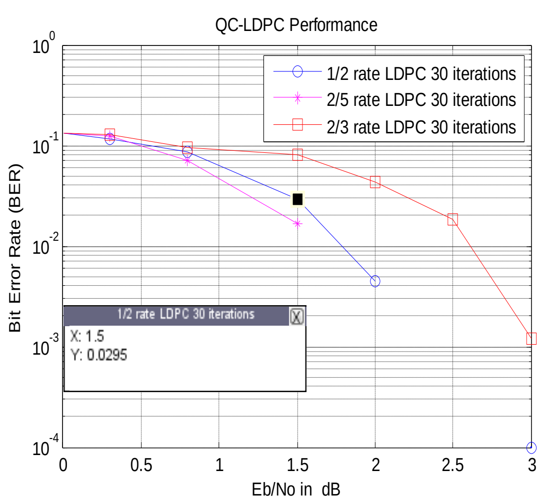

Figure (2): Bit Error rate versus E_b/N_o for QC-LDPC code of code rates 1/2, 2/5 and 2/3 with 30 iterations.

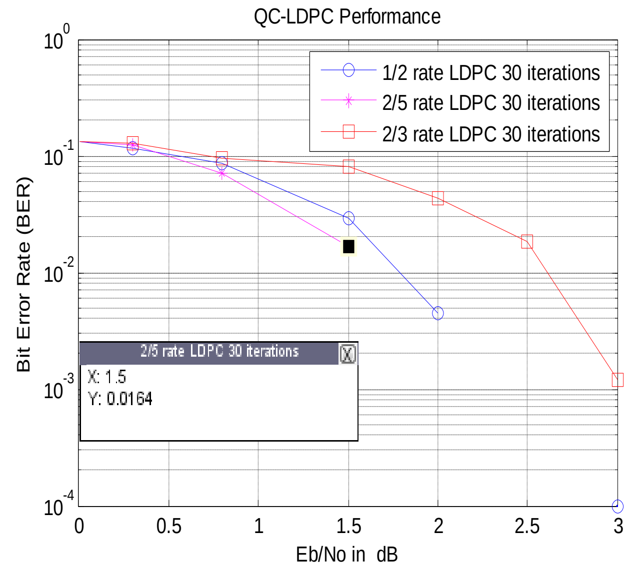

Figure (3): Bit Error rate versus E_b/N_o for QC-LDPC code of code rates, 1/2, 2/5 and 2/3 with 30 iterations.

In figure 2 & figure 3, the BER performance is showed when QC-LDPC codes of 1/2, 2/3 and 2/5 code Rates are used. It is observed that the three code rates follow the same trend entire E_b/N_o range. In figure 2 & figure 3 compare the code rates of 1/2 and 2/5 at particular E_b/N_o value 1.5 dB. There is a decrease of BER of QC-LDPC for 2/5 code rate compared to 1/2 and 2/3 code rates.

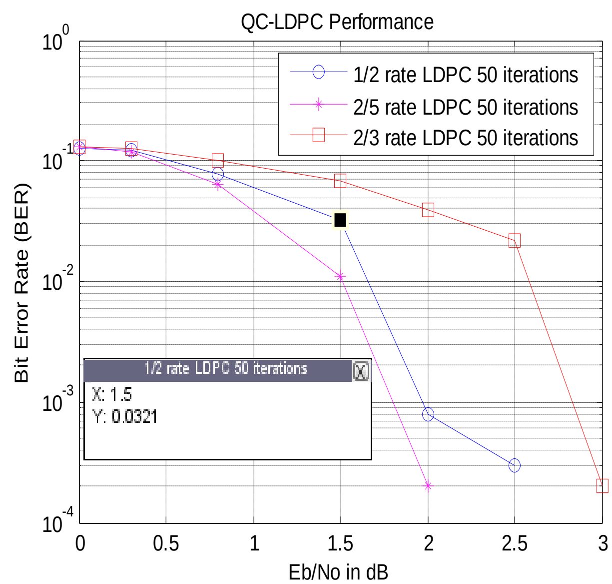

Figure (4): Bit Error rate versus E_b/N_o for QC-LDPC code of code rates 1/2, 2/5 and 2/3 with 50 iterations.

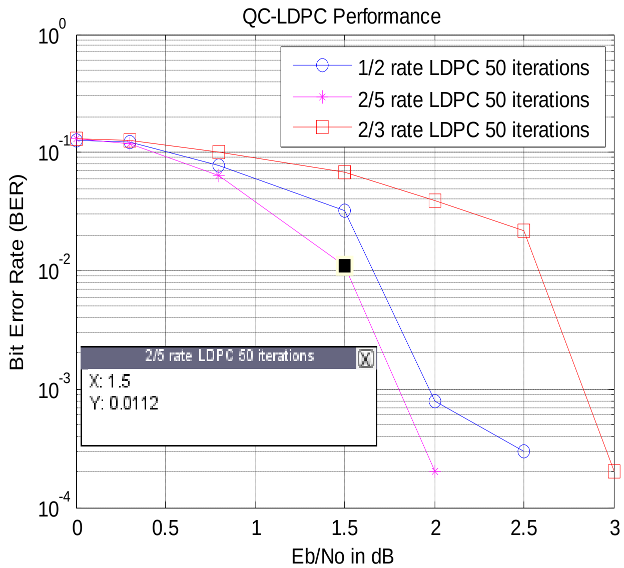

Figure (5): Bit Error rate versus E_b/N_o for QC-LDPC code of code rates, 2/5 and 2/3 with 50 iterations.

In figure 4 and Figure 5, the performance showed when QC-LDPC codes of 1/2, 2/3 and 2/5 code rates and a number of iterations rounds set to 50. It is obvious that a small number of iterations rounds means that the system unable to correct all the errors occurring during the signal's transmission, whereas a larger number of iteration rounds leads to better system's performance. It is also observed that from this graph is that LDPC codes performance is significant especially for lower E_b/N_o values, this is the main aspect of the LDPC code compared to other existing codes. Both high and low code rates have been examined that deep fall in the BER plot occurs for lower E_b/N_o rates in figure 4 and figure 5.The fact that for higher code rates, the bits redundancy is decreased at the expense of the signal's quality, compared to the fewer coded bits the protection offered to the original data bits is of inferior quality.

The main important thing to observe that when examining the plots is that QC-LDPC codes better performance for all code rates when a large number of iteration rounds are set.

V. Conclusion

In this paper, proposes a Quasi-Cyclic Low-Density Parity-Check code for reducing encoding and decoding complexity. Encoding complexity is reduced by means of circulant permutation (Quasi-Cyclic) matrices, and decoding complexity reduced by using iterative Min-Sum decoding algorithm. Also, in this paper a thorough study of a low and high code rates is examined and obtained the Bit Error Rate (BER) versus Bit Energy to the Noise Spectral Density ratio (E_b/N_o) is reported, when a small and large number of iteration rounds was set.

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