Image coding using Cellular Automata based LDPC codes

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Summary
Image transmission in wireless channel includes the Low Density Parity Check(LDPC) Codes as the Channel coder for better error performance in the AWGN Channel. The LDPC Codes are included in image transmission due to their low latency and highly parallelizable with capacity approaching near to Shannon's Limit. Parity Check Matrix (PCM) in the LDPC Codes need to be more sparse to reduce the computational complexity in encoding and decoding algorithms. Cellular Automata (CA) is a computational method for implementing the complex computational blocks into power efficient simple structures. Parity Check matrix in the LDPC codes are structured by the non-uniform Cellular Automata rules. In this paper the LDPC codes with the Cellular Automata based Hierarchical Diagonal Parity Check Matrix (HDPCM) structured PCM has been used as the Channel coder in the Image transmission. Performance analysis on the channel in different noise variance has been done for the Binary image in the AWGN channel. The proposed CA based LDPC Codes with CA based HDPCM outperforms the Lower Diagonal Parity Check Matrix and Double Diagonal Parity Check Matrix.
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Key words:
LDPC Codes, Cellular Automata, FFT-SPA decoding algorithm, Generation Matrix, Image transmission.

1. Introduction

Low density parity check codes(LDPC) are class of linear block codes, presented by Gallager [1] in 1962 and rediscovered in 1995 to form the Shannon's capacity approaching codes[2]. The design, construction, efficient decoding, performance analysis, and applications of these codes become the centre of interest of almost all digital communication and storage systems. The drawback of turbo codes is high latency rates and high decoding complexity [3]. LDPC codes finds application in the major fields such as underwater communication, deep space communication, wireless sensor networks, biometric cryptosystem, patterned media storage, mobile communication, image authentication, image compression and in various other wireless standards [4]. In image transmission, LDPC codes are used as the channel coder as it has the advantages such as highly parallelizable hardware implementation, low-latency in decoding, capacity approaching and high throughput [5]. Parity check matrix in the LDPC codes is sparse with few non-zero numbers and each row in the parity check matrix denotes the parity check constraints. The sparse matrix reduces the computational complexity of the decoding algorithm of the LDPC Codes. Various decoding algorithm are studied in the literature to further reduce the computational complexity of the LDPC codes [6]. Further, Parity Check Matrix are constructed by different methods to reduce the computational complexity and memory required for storing the PCM is reduced by structuring the matrix such as Quasi-cyclic method [7] in which the parity check matrix is obtained by the circular permutation. By increasing the order of the Galosis field the bit error rate of the decoding performance has been improved [8]. Parity Check Matrix has been structured into LDM (Lower Diagonal Parity Check Matrix) and DDM(Double Diagonal Parity Check Matrix) to reduce the computational strength with better error performance[9].Cellular automata are the computational method used to implement the complex computational structures into simple, regular and modular structures[10]. Cellular automata are used in the applications such as compression, encryption, error correction and testing of circuits in which highly intensive computational algorithm is replaced with simpler implementation of a CA to achieve low power consumption. As the decoding complexity of the LDPC codes depends on the sparsity of the Parity Check Matrix, the cellular automata based Parity Check Matrix is obtained by cellular automata rules. Hierarchical Diagonal Parity Check Matrix (HDPCM) is structured using cellular automata rules and applied in the FFT-SPA decoding algorithm to reduce the computational complexity. The proposed design of CA based HDPCM structured LDPC decoder is for the binary image, the performance analysis has been done for varying SNR values and Noise variance values. This paper includes the concept behind CA for computation, CA in image coding and the image decoding with CA based structured LDPC decoder.

2. Cellular automata

Cellular automata consist of infinite number of cells with finite states arranged in a regular lattice with a rule associated with it. Cellular automata depending on the

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neighborhood cells consideration are classified as zero dimensional, one dimensional and two dimensional.

Cellular automaton is defined as a set of {G, Z, N, f}.[11]

Where G is a metric field on which a cellular automaton operates;

Z is a set of states for each cell;

N are neighborhood cells that affect the status of the selected cell;

f is a cellular automaton rule.

In zero dimensional cellular automata the value of the cell x at time t+1 is given by the value of x in t and the rule associated with it. The infinite number of values is governed to finite values to cell by considering two values to the cell either 0 or 1 by modulo operating the rule $(x_i(t+1) = x_i(t)\%2)$. In one dimensional CA[10] the number of neighborhood cell depends on the radius value r, where r is the distance between the current cell and the neighborhood cells. For a cell $x_i(t+1)$ with r=1 the value depends on $x_{i-1}(t)$, $x_i(t)$, $x_{i+1}(t)$ neighborhood cells, where $x_{i-1}(t)$ corresponds to the cell to the left of the current cell and $x_{i+1}(t)$ corresponds to the cell to the right of the current cell. The value of the current cell depends on neighborhood cells previous values results in 8(i.e.23) possible neighborhood combinations and 256 (i.e.28) rules.

$x_{i-1}(t)$	$x_i(t)$	$x_{i+1}(t)$

Rule 90: A simple linear CA rule generates sparse matrix by the exclusive-or of its two neighbors [12].

$$x_i(t+1) = x_{i-1}(t) \oplus x_{i+1}(t)$$

Rule 240: Shift-right operations are performed [10].

$$x_i(t+1) = x_{i-1}(t)$$

Two Dimensional Cellular Automata consist of the cells arranged in two dimensional arrays with eight neighborhood cells. The possible combination is 512 (i.e.2^8) and hence 2^{512} rules. If same rule is used by all the cells then it is uniform cellular automata rules. If the cells are updated by different CA rules then it is called non-uniform cellular automata rules.

2.1 Cellular Automata based Parity Check Matrix

The sparsity can be increased by structuring the PCM such that it consists of only few non-zero numbers. The cellular automata rules for random number generation with more sparsity is analyzed and the non-uniform set of CA rules gives better randomness compared to the uniform CA rule. The HDPCM is given by

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

Parity Check Matrix in the LDPC Codes are generated using the cellular automata rules. CA rule 90 and rule 240 are used to obtain the sparse PCM with the HDPCM structure.

3. Image Transmission System

In wireless image transmission system, the image is compressed by the JPEG source code, followed by the separation of the header and marker for RS encoding [13]. The RS encoded output is given as input to the LDPC Encoder. The LDPC encoder adds the redundancy bits to the input bit streams for better error performance in the receiver. The encoded bit stream is fed to the BPSK modulator and transmitted through AWGN Channel.

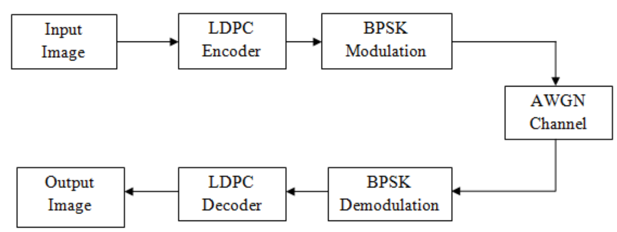

Fig. 1 LDPC in Image coding system.

LDPC decoder is applied to the received signal subsequent to demodulation to retrieve the bit stream by the decoding algorithm implemented in the LDPC decoder. Further the original image is obtained after RS decoding and JPEG decoding. In the block diagram figure.1 the input image is the binary image and the code length of the decoder is 648 (WLAN).

3.1 LDPC Encoder

The major task of LDPC encoder is to generate the code word with the sparse parity check matrix. The Generation matrix G is constructed from the parity check matrix and is less sparse than the Parity Check Matrix. To increase the sparsity there are various methods and algorithms are studied. The sparsity is increased by the Gaussian Elimination method to reduce the encoding complexity

[14]. The encoded codeword is derived from normal multiplication of the code word (c) and generator matrix G. The redundancy bits are added in channel coding to reduce the error in transmission. In this paper the binary image is given as input to the LDPC encoder.

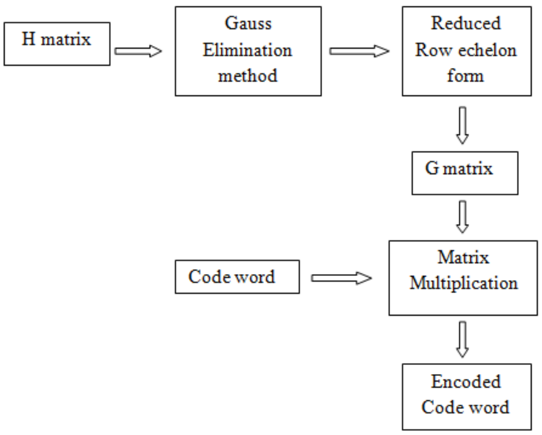

Fig. 2 LDPC Encoder flow diagram.

3.2 LDPC Decoder

LDPC Codes are decoded by the SPA(Sum Product Algorithm) decoding algorithm. The SPA provides better performance with increased computational complexity as it includes multiplication in both check node and variable node processing. The decoding complexity is decreased by transforming the SPA to the Fourier domain as the FFT-SPA decoding algorithm reduces the computational complexity from O(q2) to O(q) and also provides better error performance [15]. Later on various modified decoding algorithms are added to reduce the computational complexity with the decrease in the error performance.

The FFT-SPA decoding algorithm has been implemented with the CA based structured HDPCM to reduce the computational complexity in the check nodes and variable node processing.

4. Performance analysis

The analysis of the decoder has been done for the code rate of ½ with code length of 648 and BPSK modulation in the AWGN channel without CA method. Qualitative analysis of the image transformation has been done for various SNR values in the AWGN channel and is shown in fig.3. With the inclusion of the CA based methods, the qualitative analysis has been done and it is shown in fig.4.

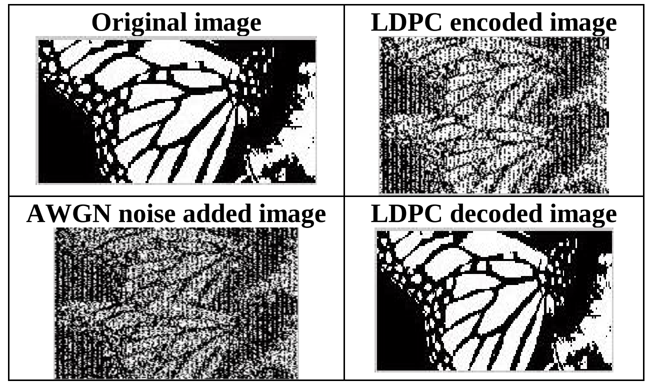

Fig. 3 Qualitative analysis of AWGN channel (without CA)

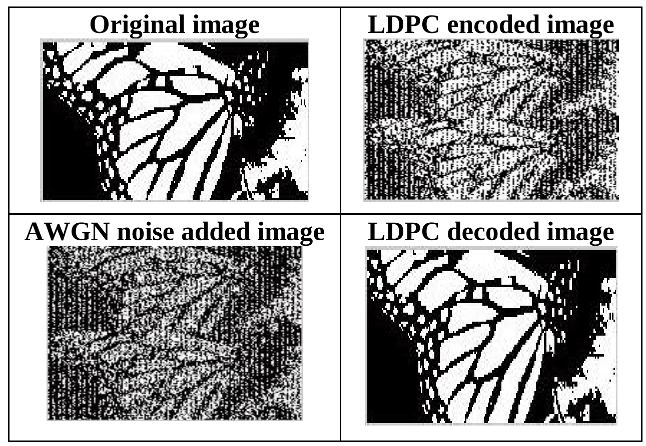

Fig. 4 Qualitative analysis of AWGN channel (with CA)

Quantitative measure of the image transmission in the AWGN channel has been analyzed for various noise variance. The PSNR values for various SNR and noise variance are tabulated in table 1. Noise Variance for AWGN channel is given by,

$$\sigma = \frac{1}{\sqrt{2}} * \frac{1}{10^{\frac{SNR}{20}}} \quad (1)$$

The encoded image and the decoded image by the LDPC codes are analyzed for the different SNR values and the performance is better in terms of the PSNR value. The structured CA based HDPCM reduces the computational complexity of the decoding algorithm due to the sparsity compared to DDM(Double Diagonal PCM) and LDM(Lower diagonal PCM).

Table 1: PSNR analysis for AWGN channel (without and with CA)

SNR (dB)	*Noise variance*	*PSNR (without CA)*	**PSNR (with CA)**
1	0.6301	32.446	33.34

2	0.5616	33.286	34.65
3	0.5005	34.235	35.59
4	0.4461	36.526	36.21
5	0.3763	37.654	37.26

The analysis of the decoder has also been extended using jitter noise with the same specifications. The following fig 5 and 6 shows the qualitative analysis of the image transformation has been done for various SNR values, using jitter noise, without and with the inclusion of CA technique respectively.

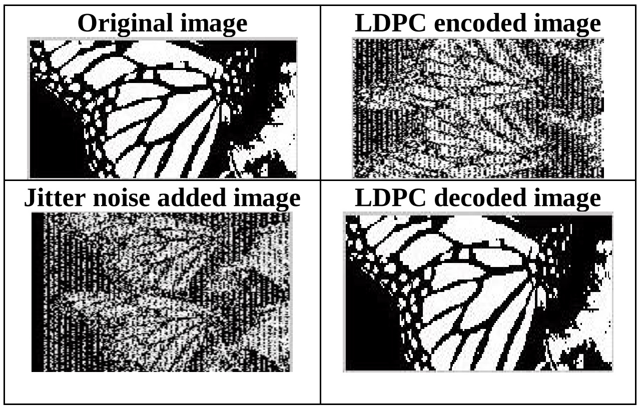

Fig. 5 Qualitative analysis of Jitter noise (without CA)

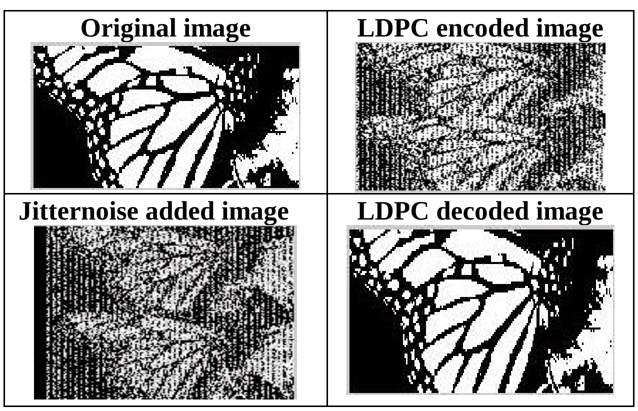

Fig. 6 Qualitative analysis of Jitter noise (with CA)

Of the same kind, the quantitative measures of the proposed technique for jitter noise have been carried out with the PSNR analysis. The table 2 tabulates the PSNR values for the various noise variances taken into considerations.

Table 2: PSNR analysis for Jitter noisel (without and with CA)

SNR (dB)	*Noise variance*	*PSNR (without CA)*	**PSNR (with CA)**
1	0.6301	33.56	34.521
2	0.5616	34.92	35.256
3	0.5005	36.31	35.965
4	0.4461	36.92	37.561
5	0.3763	37.86	38.824

Comparative qualitative and quantitative performance analysis for images coding, CA based approach shows the better improvements in both the ways.

5. Conclusion

Image transmission includes the LDPC Codes as the channel coding method to improve the error performance and latency. The sparsity in the Parity Check Matrix is improved to reduce the encoding and decoding algorithms computational complexity. Cellular Automata based HDPCM structured LDPC codes are included to improve the error performance and the computational complexity is reduced in the LDPC Codes due to the sparse HDPCM with code length 648. Performance analysis of the image with the CA based structured LDPC codes validates a better performance compared to other PCM in LDPC Codes.

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