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Analysis of LDPC Codes under Wi-Max IEEE 802.16e

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Abstract:- The LDPC codes have been shown to be by-far the best coding scheme capable for transmitting message over noisy channel. The main aim of this paper is to study the behaviour of LDPC codes on under IEEE 802.16e guidelines. The rate- ½ LDPC codes have been implemented on AWGN channel and the result shows that they can be used on such channels with low BER performance. The BER can be further minimized by increasing the block length.

Keywords:- LDPC- Low density parity check, BER- bit error rate, PAPR- Peak power peak ratio, Wi-Max OFDM IEEE 802.16e, Encoding, Decoding.

I. INTRODUCTION

LOW-DENSITY parity check (LDPC) codes were originally invented and investigated by Gallager [1]. The crucial innovation was Gallager's introduction of iterative decoding algorithms (or message-passing decoders) which he showed to be capable of achieving a significant fraction of channel capacity at low complexity. Except for the papers by Zyablov and Pinsker [2], Margulis [3], and Tanner [4], the field then lay dormant for the next 30 years. Interest in LDPC codes was rekindled in the wake of the discovery of turbo codes and LDPC codes were independently rediscovered by both MacKay and Neal [5] and Wiberg [6]. The past few years have brought many new developments in this area. It was demonstrated in [7] that LDPC codes can come extremely close to Shannon capacity on many channels.

In many ways, LDPC codes can be considered serious competitors to turbo codes. In particular, LDPC codes exhibit asymptotically better performance than turbo codes (as demonstrated in [7]) and they admit a wide range of trade-offs between performance and decoding complexity. One major criticism concerning LDPC codes has been their high *encoding* complexity. Whereas, Turbo codes can be encoded in linear time, a straightforward encoder implementation for an LDPC code has complexity quadratic in the block length. Several authors have addressed this issue.

1) It was suggested in [8] and to use cascaded rather than bi-partite graphs. By choosing the number of stages and the relative size of each stage carefully one can construct codes which are enclosable and decodable in linear time.
2) In [9], it was suggested to force the parity-check matrix to have (almost) lower triangular form, i.e. the ensemble of codes is restricted not only by the degree
constraints but also by the constraint that the Parity-check matrix has lower triangular shape.
3) In [10], the authors suggested to force the parity-check matrix to have almost upper triangular form with as small gap as possible. This method resulted in almost linear encoding complexity in block length.
4) In [11], the authors have proposed an algorithm to extend the parity-check matrix of an IRA (Irregular repeat accumulate) code, by using the extended Vander monde Matrix.

The main aim of this paper is to study the behaviour of the LDPC codes in the IEEE 802.16e standard. The paper is divided in five sections as follows: In section II, we have described about the LDPC codes and IEEE standard 802.11e, and the method of achieving the model parity-check matrix, $\mathbf{h}_{\mathbf{bm}}$. Furthermore, we will describe about the encoding of LDPC codes, in Section III. In Section IV, we have described the message passing decoding algorithms, with main focus on the log-domain decoding algorithm. Finally, Section V comprises of the conclusions.

II. LDPC

Low-Density Parity-check codes (LDPC) codes were first invented by Gallager [1], in his Ph.D. thesis. The ensemble (and each code in it) of LDPC codes is described by a sparse parity check matrix **H** of size *m-by-n*, where *n* is the length of the code and *m* is the number of parity check bits in the code. There are $k=n-m$ number of systematic bits.

The sparse Parity-Check Matrix **H**, is defines as:

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{P}_{0,0} & \cdots & \boldsymbol{P}_{0,n_b-1} \\ \boldsymbol{P}_{0,1} & \cdots & \boldsymbol{P}_{1,n_b-1} \\ \cdots & \cdots & \cdots \\ \boldsymbol{P}_{m_b-1,0} & \cdots & \boldsymbol{P}_{m_b-1,n_b-1} \end{bmatrix}$$

Where $\mathbf{P_{i,j}}$ is a [z×z] permutation matrices or a [z×z] zero matrices. The parity-check matrix **H**, is expanded from a binary base matrix $\mathbf{H_b}$ of size m_b×n_b, where n=z .n_b and m=z .n_b, where z ≥1. The base matrix is expanded, and this is done by replacing each 1 in the base matrix by [z×z] permutation matrix, and each 0 is replaced with a [z ×z] zero matrix. The base matrix size n_b=24.

The base matrix $\mathbf{H_b}$ is partitioned in two sections:

$$H_b = \left[(H_{b1})_{m_b x k_b} \vdots (H_{b2})_{m_b x m_b} \right]$$

Where $\mathbf{H_{b1}}$ are systematic bits and $\mathbf{H_{b2}}$ are the parity-check bits. The section $\mathbf{H_{b2}}$ is further divided into two parts, where vector $\mathbf{h_b}$ are the odd weight and $\mathbf{H'_{b2}}$ is a dual-diagonal structure given by:

$$H'_{b2}(i,j) = \begin{cases} 1 & if\ i = j\ or\ i = j+1 \\ 0 & elsewhere \end{cases}$$

The vector h_b is such that: $h_b(0) = 1 = h_b(m_b - 1)$ and $h_b(j) = 1\ for\ 0 < j < m_b - 1$. The base matrix structure is such that it avoids having multiple -1 weight columns in the expanded matrix **H**.
In particular, all the non-zero values are circularly right shifted by a particular shift value in the sub-matrix. In $\mathbf{H'_{b2}}$ matrix each 1is assigned shift size of 0, and is replaced by a z×z identity matrix while expanding it to H. Equal shift sizes are assigned to two 1s which are placed at the top and bottom of the $\mathbf{h_b}$ and the middle 1 is assigned by a unpaired shift size.
The permutations are circularly right shifted, and the permutation matrices contains the [z×z] identity matrix and circularly right shifted version. Since, each permutation matrix is specified by a single circular right shift, the binary base matrix information and permutation matrix may be combined into a single compact model matrix, $\mathbf{H_{bm}}$. The model matrix $\mathbf{H_{bm}}$ is of equal size as the base matrix, contains each binary entry (i,j) of the base matrix is replaced and the model matrix $\mathbf{H_{bm}}$ is formed. The base matrix $\mathbf{H_b}$ is transformed to the model matrix $\mathbf{H_{bm}}$ by replacing the values as follows:

I. Each 0 in the base matrix is replaced by a blank or negative value (e.g., by -1) to denote a *zXz* all-zero matrix.
II. Each 1 is replaced by a circular right shift size $P(i,j) \geq 0$. Then the model matrix $\mathbf{H_{bm}}$ can be expanded directly to **H** of any desired code-length.

A base model matrix is defined for the largest code length (*n=2304*) of each code rate. The set of shifts *{p(i,j)}* in the base model matrix are used to determine the shift sizes of all other code lengths of the same code rate. Each base model matrix has $n_b=24$ columns, and the expansion factor $Z_f=n/24$, for code length *n*. The shift sizes *{p(i,j)}* for different code rates are determined as follows:

a) For code rates ½, ¾ A and B, 2/3 B and 5/6 code, the shift sizes *{p(f,i,j)}* for an expansion factor Z_f are derived from *{p(i,j)}* by scaling it proportionally, as follows:

$$p(f,i,j) = \begin{cases} p(i,i), & p(i,j) \leq 0 \\ \left\lfloor \dfrac{p(i,j).Z_f}{Z_0} \right\rfloor, & p(i,j) > 0 \end{cases}$$

Where, z_0 is the expansion factor for highest code length (n=2304), and is equal to 96, and $\lfloor x \rfloor$ denotes the greatest integer function.

b) For code rate 2/3 A code:

$$p(f,i,j) = \begin{cases} p(i,j), & p(i,j) \leq 0 \\ mod\left(p(i,j).Z_f\right), & p(i,j) > 0 \end{cases}$$

The model matrix for rate-1/2 code is given in table II.1. [For model matrices of other code rates, see 11].

III. ENCODING PROCEDURE

As discussed earlier, the direct encoding procedure of LDPC code is of quadratic complexity in block length. Different approaches are suggested by various authors to decrease the same. Here we will describe some of these encoding schemes.
Encoding is the process of determining the parity sequence, given the data sequence. This can be done by various methods. The easiest method is by using the generator matrix **G**, but, encoding with help of **G** is very

complex. So, various methods have been proposed to reduce the complexity of such codes. All these methods rely on utilization of the sparseness of the parity-check matrix which defines the particular LDPC code.

Upper Triangulation

In this method, proposed by Richardson and Urbanke [10], the parity-check matrix is forced to take an upper triangular form. The parity check matrix is pre-processed to take the form

$$H = \begin{bmatrix} A & B & T \\ C & D & E \end{bmatrix}$$

Where, *A* is *(m-z) X kα, B* is *(m-z) X z, T* is *(m-z) X (m-z), C* is *z X k, D* is *z X z,* and finally *E* is *z X (m-z).* $\begin{pmatrix} B \\ D \end{pmatrix}$ and **D** corresponds to the expanded $\mathbf{h_b}$ and $\mathbf{h_b}(m_b\text{-}1)$, respectively.

The code vector v can be written as:

-1	94	73	-1	-1	-1	-1	-1	55	83	-1	-1	7	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	27	-1	-1	-1	22	79	9	-1	-1	-1	12	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	24	22	81	-1	33	-1	-1	-1	0	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
61	-1	47	-1	-1	-1	-1	-1	65	25	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
-1	-1	39	-1	-1	-1	84	-1	-1	41	72	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	46	40	-1	82	-1	-1	-1	79	0	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
-1	-1	95	53	-1	-1	-1	-1	-1	14	18	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
-1	11	73	-1	-1	-1	2	-1	-1	47	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1
12	-1	-1	-1	83	24	-1	43	-1	-1	-1	51	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
-1	-1	-1	-1	-1	94	-1	59	-1	-1	70	72	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
-1	-1	7	65	-1	-1	-1	-1	39	49	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
43	-1	-1	-1	-1	66	-1	41	-1	-1	-1	26	7	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

$$v = [u, p1, p2]$$

Where *u* is the message vector and *p1* and *p2* combined denotes the parity part. ***P1*** has length ***z,*** and ***p2*** has length *(m-z)*. For a code vector *v* to be a proper code vector, the following conditions should be satisfied: $H.v^T = 0$

The above equation can be solved to get the following result

$$Au^T + Bp_1^T + Tp_2^T = 0$$

On further manipulations, we get the form $(ET^{-1}A + C)u^T + (ET^{-1}B + D)p_1^T = 0$

On solving the above equations, we get the value of $\boldsymbol{p_1}$ and $\boldsymbol{p_2}$**.** The above encoding scheme can be summarized as:

1) Compute Au^T and Cu^T
2) Compute $T^{-1}Au^T$
3) Compute $-E[T^{-1}Au^T]$
4) Compute $p_1^T = -\varphi^{-1}[-ET^{-1}Au^T + Cu^T]$
5) Compute Bp_1^T
6) Compute $p_2^T = -T^{-1}[Au^T + Bp_1^T]$

Where, $\varphi = -ET^{-1}B + D$

The authors have also presented some greedy algorithms for conversion of the parity-check matrix to the desired form. They have shown that, if encoding is done by this method, the complexity is greatly reduced, without any significant loss in the performance.

IV. RESULT

Figure 1 shows the result obtained for an Additive White Gaussian channel with QPSK modulation of signal amplitude ± 1.

The results obtained show that the performance of LDPC codes increases with an increase in the corresponding block length.

The results shown here are for block lengths upto 2304 (as restricted by the IEEE). As have been shown in [13], these codes can achieve a BER performance as low as 10^{-2} for block lengths greater than or equal to 10^{0}.

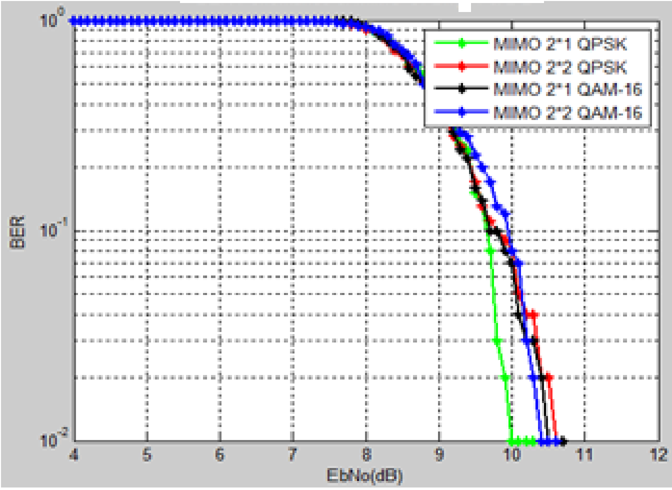

Figure 1: Simulation Result of QPSK and QAM-16 Modulation in BER Performance of WiMAX IEEE 802.16 Systems

V. CONCLUSION

Designing a channel code is always a tradeoff between peak power peak ratio (PAPR) and bit error rate (BER). WiMAX-OFDM in the 3.5 GHz band is of practical interest due to the potential for large-scale WiMAX deployment in the recent example. Communication system can operate with a lower transmit power, transmit over longer distances, tolerate more interference, use smaller antennas and transmit at a higher data rate. These properties make the code energy efficient. Hence, new codes were sought that would allow for easier decoding and encoding. The task of the decoder and encoder easier is using a code with mostly high-weight code words. Error detection and correction techniques are essential for reliable communication over a noisy channel.

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