Performance of LDPC Codes in OFDM System with QAM Modulation

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Abstract

OFDM with Quadrature AM (QAM) technique can be employed for high-speed optical applications. Since the order of modulation increases, the bit error rate (BER) increases. Forward Error correction (FEC) coding like LDPC coding is usually accustomed to improve BER performance. LDPC provides large minimum distance plus the power use of the LDPC code increases significantly using the code length. This paper offers a overview of block coding along with the design of encoder and decoder. Finally using LDPC and convolution coding in OFDM system in order to their performance in AWGN channel for BER. A long irregular code is simulated on the AWGN channel demonstrating the belief that LDPC coded OFDM provides very lower bit error rate or a larger gain in transmitter power and so making the hyperlink more power efficient. Through simulation, what’s so great about applying this long irregular LDPC coded OFDM link in Optical wireless communication (OWC).

Keywords—Bit error rate (BER), Orthogonal frequency division multiplexing (OFDM), Low density parity check codes (LDPC), Additive white Gaussian noise (AWGN)

Introduction

OFDM offers an effective and low complexity means for eliminating inter-symbol interference for transmission over frequency selective fading channels. It mitigates the severe multipath propagation effect that produces massive data errors and loss in signal inside the microwave and UHF spectrum. In OFDM the subcarrier frequencies are chosen in this particular manner that the signals are mathematically orthogonal more than one OFDM symbol period [1]. During the past decades, channel coding has been used extensively in most digital transmission systems, from those requiring only error detection, to people needing quite high coding gains, like deep space links.

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In past, optical communication systems have ignored channel coding, until it became clear that could be a powerful, yet inexpensive, tool to incorporate margins against line impairments such as amplified spontaneous emission (ASE) noise, channel cross talk, nonlinear pulse distortion, and fibre aging-induced losses [2].

Nowadays, channel coding can be a standard practice in numerous optical communication links. Turbo codes were proposed in my ballet shoes in 1993 by Berrou et alii. [3] that showed astonishing performance: a rate-1/2 turbo code in addition to a binary PSK (BPSK) modulation in the AWGN channel showed coding gains very close (0.5 dB) for the Shannon capacity limits the massive interest raised by turbo codes led researchers inside the field to resurrect and enhance the LDPC codes [4]. Turbo and LDPC codes have revolutionized coding theory and their used in optical communication, is under heavy investigation and discussion. The 2nd perhaps the paper discusses theoretically the full block diagram of OFDM system. Third part gives an overview of error control coding and linear block code. In fourth section a short introduction of LDPC codes are shown. Fifth and sixth sections are simulation result and conclusion respectively.

**OFDM System**

The fundamental principle of OFDM is to split an increased rate data stream right into a volume of lower rate streams which have been transmitted simultaneously spanning a variety of orthogonal sub-carriers. Orthogonality is achieved with the fact that carriers are put exactly on the nulls within the modulation spectra of one another. Here, the rise of symbol duration for that lower rate parallel sub carriers reduces the relative quantity of dispersion with time a result of multi-path delay spread.

Here, Inter symbol interference (ISI) is eliminated almost completely by introducing a guard in time every OFDM symbol. Inside guard time, the OFDM symbol is cyclically extended in order to avoid inter carrier interference. [5] In line with Srabani Mohapatra Figure-1, shows a block diagram associated with an OFDM system, in which the upper path is the transmitted chain plus the lower part corresponds for the receiver chain. Here, first the person information bit sequence is mapped to symbols of either 16-QAM or QPSK. Then the symbol sequence is transformed into parallel format. Then, the IFFT modulator modulates a block of input modulated values onto several sub carriers. Following this the OFDM modulated symbol is again changed into the serial format. Then guard serious amounts of cyclic prefix are inserted between OFDM symbols, to ensure ISI and ICI may be eliminated. Resulting sequence is then changed into an analog signal using DAC and handed down the RF modulation stage. The resulting RF modulated signal will be transmitted to the receiver while using the transmit antennas Here; antenna array is used to accomplish directional beam-forming, allowing spectrum reuse by providing spatial diversity [6].
In the receiver reverse operation is carried out, first RF demodulation is completed. Then, the signal is digitized utilizing an ADC. Then, timing and frequency synchronization are performed. Then, the guard time is slowly removed from each OFDM symbol and also the sequence is transformed into parallel format. At the receiver, the carriers are demodulated by an FFT, which perform a reverse operation of an IFFT. The output will be serialized and symbol de-mapping is performed to obtain back an individual bit sequence. Here, Some time to frequency synchronization are necessary because without correct frequency the orthogonality won’t exist among the carriers that leads to a surge in BER. Without correct timing synchronization. It is not possible to spot start of frames. [6]

**Role of coding**

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Consider a binary symmetric channel .Where '0' will become '0' with probability '1-P' and '1' will become '1' with '1-P' probability. So, error probability is 'P'. The implied assumption is “each bit is independent of whatever happens to other bits” .The ideal value for ‘P’ is ‘0’. So, the optimization in the transmitter side requires a lot of power in transmitter to drive ‘P’ ideally to '0'. So, the drawback here is, the signal needs more power than the theoretical case to reduce ‘P’. So, the efficient solution is to use error control codes which reduces ‘P’ in an indirect way. The kind of SNR we need in a noisy channel, to make this
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P close to zero, depends on the transmitting constellation. The Block diagram of a Digital communication system with error control coding is given in Figure.2. Values of parameters in the block are:

1. Message ∈ \{0, 1\}^k
2. Encoder is a one-to-one mapping function
3. Codeword ∈ \{0, 1\}^n
4. Set of all messages = \{0, 1\}^k
5. Set of all Codewords 1 NOT EQUALS TO \{0, 1\}^n (since encoder is one-to-one mapping)
6. Set of all Codewords C \{0, 1\}^n
7. Received word ∈ \{0, 1\}^n

- All received test is possible based on channel modelling. Meaning if one vector is it being sent, all vectors in O, I n can be received with possible probability. So, the many possibilities with non-zero probabilities will be in the receiver side.
- The decoder won't do the inverse operation of encoder, since message to codeword mapping is one-to-one and codeword to received word mapping is a-to-many.
- So, the aim in designing a decoder would be to minimize the big mistake making of decoder.
- Which means the intention of decoder design should be to minimize \(Pr(\text{decoded message} \neq \text{transmitted message})\)
- So, Receiver/decoder follows many-to-one mapping [7][8][9].

![Figure 2: Block Diagram of Digital Communication systems](image)

**Design considerations of encoder and decoder**

There is 2^k codeword to be selected from 2^n possibilities.

- When there are many possibilities of designing an encoder and we are picking one, then your design problem becomes non-trivial.
- So, collection of encoder means selection of map from message to codeword, that is arbitrary.
- Since only codeword is transmitted, therefore choice of list of code words is important than the mapping from message to codeword.
- Our aim is usually to design an encoder that can minimize the probability of error.
- For great coding select the report on code words first after which design an encoder with the selected directory code words lastly design a decoder for the chosen set of code words.
- Hence, forever encoder and decoder design, the possibility of error need to be very less and also the design penalties are; Complexity, Delay and Rate (k/n). The complexity adjusted tremendous since now i am sending more no of bits with coding, rather than single bit such as uncoded scheme for BSC.
• Here the delay is a vital factor since before decoding one bit; were waiting for every one of the n bits.
• So, regardless of whether we have been transmitting at a very good rate, then also delay will create problem. Changing enough time constants we are able to handle delay. It isn't an impossible issue it will be handled.
• From communication stand , previously i am using channel once to attempt to communicate one bit, the good news is in Figure-II the channel is employed n times to try and communicate k bits. So, the rate (k/n) is a vital penalty. So, Rate is just the no. of bits sent in one channel use.
• Now, using coding the gain factor in the system will include chance of error and transmit power.
• With coding the possibility of error lowers faster compared to the case of without coding.
• With coding you will find there's grow in transmitter power at same error rate. Using coding we are able to decrease the transmit power and thus the price tag on transmitter will take down therefore it helps make the link power efficient. [7][8][9]

**Overview of linear block code**

Any linear block code is represented as (n, k) where Linear block codes have the property of linearity, i.e. the sum of any two code words is also a codeword, and they are applied to the source bits in blocks, hence the name linear block codes. 'n' is the length of the codeword, in symbols and 'k' is the number of source symbols that will be used for encoding. The information sequence is divided into message blocks of k-information bits.

**LDPC code**

Low-density parity-check (LDPC) codes can be a class of linear block codes. The name originates from the sign of their parity-check matrix which contains not many 1’s with regards to the quantity of 0’s. Their main advantage is they offer a performance which is very close to the proportions for several different channels and linear time complex algorithms for decoding. Furthermore are they fitted to implementations that will make heavy utilization of parallelism? These were first introduced by Gallager in her PhD thesis in 1960. But because of the computational effort in implementing coder and encoder for such codes and also the introduction of Reed-Solomon codes, we were holding mostly ignored until about decade ago [10].

**Representations of LDPC Codes**

Basically there are two different the possibility to represent LDPC codes. As with any linear block codes can be described via matrices. The next possibility can be a graphical representation.
Matrix Representation

Let’s look at an example for a low-density parity-check matrix first. The matrix defined below is a parity check matrix with dimension n x m for a (8, 4) code. Two numbers describing this matrix are wr for the number of 1’s in each row and wc for the columns. For a matrix to be called low-density the two conditions wc<<n and wr<<m must be satisfied. In order to do this, the parity check matrix should usually be very large, so the example matrix can’t be really called low density. [10]

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

(1)

Graphical Representation

Tanner introduced an effective graphical representation for LDPC codes. Not only provide these graphs a complete representation of the code, they also help to describe the decoding algorithm. Tanner graphs are bipartite graphs. That means that the nodes of the graph are separated into two distinctive sets and edges are only connecting nodes of two different types. The two types of nodes in a Tanner graph are called variable nodes and check nodes. [10]

Gallager’s construction of LDPC (regular) codes:

Let, n be the transmitted block-length of an information sequence of length k. m is the number of parity check equations. Construct a m x n matrix with Wc 1’s per column and Wr 1’s per row [4]. Divide a m x n matrix into Wc m/Wc.n sub-matrices, each containing a single 1 in each column.

Figure 3 (b): Tanner graphs corresponding to the parity check matrix in equation (1)
The first of these sub-matrices contains all 1 "s in descending order. The other sub-matrices are merely column permutations of the first sub-matrix. One example are shown in fig.4 (a). [9]

![Figure 4 (a) parity check matrix of a regular (12, 3, 6) LDPC code](image)

**Irregular LDPC codes:**

For an irregular low-density parity-check code, the degrees of each set of nodes are chosen according to some distribution. In the construction of irregular LDPC code, the first step involves selecting a profile that describes the desired number of columns of each weight and the desired number of rows of each weight. Second step includes a construction method, i.e. algorithm for putting edges between the vertices in a way that satisfies the constraints. The edges are placed "completely at random" subject to the profile constraints. It is shown in fig.4 (b).

**LDPC Encoding**

Low-density parity-check (LDPC) codes have been adopted by high-speed communication systems to their near Shannon limit error-correcting capability. In order to achieve the desired bit error rate (BER), longer LDPC codes with higher code rate are preferred in practice. As in the case of block codes, we define a generator matrix \( G \) and parity check matrix \( H \). In order to achieve a systematic LDPC code \( G \) must be in the following form:

\[
G = [I_k P]
\]

Where \( I_k \) is an identity matrix and \( P \) defines the parity bits.

to solve for the \( G \) matrix. The \( H \) matrix is often in an arbitrary format, it must be converted into echelon canonical form here In some cases, a code may be specified by only the \( H \) matrix and it becomes necessary

\[
H = [-P^T I_{n-k}]
\]

Where \( I_{n-k} \) is an identity matrix and defines the parity Bits [7]. Typically, encoding consists of using the \( G \) matrix to compute the parity bits and decoding consists of using the \( H \) matrix and soft-decision decoding. This conversion can be accomplished with the assistance of a computer program. Afterwards, the \( G \) matrix can be observed by inspection. In the encoding stage, the main task is identifying the fixed bits position. As we know, in the systematic LDPC codes, the value of the transmission codeword is the same.
with the value of the $H$ matrix's message word. So we can fix some codeword bits in the encoder's codeword. [9]

![Graphical structure](image)

$$\lambda (x) = \frac{1}{4}x + \frac{7}{12}x^2 + \frac{1}{12}x^3 + \frac{1}{12}x^4$$

$$\rho (x) = \frac{1}{3}x^4 + \frac{1}{3}x^5 + \frac{1}{3}x^6$$

**Figure 4(b): Based on graphical structure where $\lambda(x)$ and $\rho(x)$ are column and row distributions**

**Decoding process in LDPC code**

Hard decision decoding involves Bit-flipping algorithm as well as the soft decision decoding involves Sum-product and Min sum algorithms [11, 12]. Here bit flipping algorithm is discussed below: The list of bits contained in a parity-check equation creates a parity check set.

Odd-even check set tree is usually a representation of redundancy check kick in a tree structure. An arbitrary bit $d$ is represented by the node on the lower tree. Each line rising because of this node represents one of many parity-check sets containing $d$.

Another nodes bit through these parity-check sets are represented from the nodes on the first tier in the tree. The lines rising from tier 1 to tier 2 of the tree represent the other parity-check sets containing the bits on tier 1. The nodes on tier 2 represent the opposite bits in those odd-even check sets.

**Simulation Results**

Here the simulation is implemented using MATLAB coding. The LDPC code is surely an irregular LDPC code with parity check matrix (32400, 64800). Parity-check matrix of the LDPC code is stored as being a sparse logical matrix. The system was simulated for OFDM with 8, 16, 32 and 64QAM. Columns 32401 to 64800 really are a lower triangular matrix. The elements on its principal diagonal along with the sub diagonal immediately listed here are $1$'s. The LDPC decoder is of hard decision type along with the decoder is bit flip type. The info is binary anyway. The Figure 5 shows the BER plot for these 4 cases. We've seen that there's a cut in BER with coding with less transmitted power, making the web link power efficient in Table 1.
Figure 5 BER of LDPC coded OFDM for 8, 16, 32 and 64 QAM

Table I

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>BER ROWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNR (dB)</td>
<td>8 QAM</td>
</tr>
<tr>
<td>0</td>
<td>0.0016</td>
</tr>
<tr>
<td>2</td>
<td>0.0011</td>
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<tr>
<td>4</td>
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<td>10</td>
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</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
</tbody>
</table>

Conclusion

In this paper there is comparison of different BER ratio on different order QAM in LDPC coded OFDM system. By using LDPC technique, the BER is reduced significantly. As the order of modulation increases BER also increases. In the future LDPC codes can apply on higher order of modulation to reduce BER and PAPR.

References


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