LDPC CODED MULTIUSER MC-CDMA PERFORMANCE OVERMULTIPATH RAYLEIGH FADING CHANNEL

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ABSTRACT
This work presents the simulation of a Low density Parity Check (LDPC) coding scheme with multiuser Multi-Carrier Code Division Multiple Access (MC-CDMA) system over Additive White Gaussian Noise (AWGN) channel and multipath fading channels. The decoding technique used in the simulation was iterative decoding since it gives maximum efficiency with ten iterations. Modulation schemes that used are Phase Shift Keying (BPSK, QPSK and 16 PSK), along with the Orthogonal Frequency Division Multiplexing (OFDM). A 12 pilot carrier were used in the estimator to compensate channel effect. The channel model used is Long Term Evolution (LTE) channel with Technical Specification TS 25.101v2.10 and 5 MHz bandwidth including the channels of indoor to outdoor/ pedestrian channel and Vehicular channel.

KEY WORDS
MC-CDMA, OFDM, LDPC, SUM-PRODUCT DECODING ALGORITHM, CONVOLUTIONAL CODING.
INTRODUCTION

Recent studies by researchers have combined the principles of CDMA with Orthogonal frequency Division Multiplexing (OFDM) which allows one to use the available spectrum in an efficient way to retain the many advantages of CDMA system if the number of spacing between subcarriers is chosen appropriately, it is unlikely that all the subcarriers will be in deep fade and thus provides frequency diversity [Laith 2007]. This combination of OFDM and CDMA is an alternative for 4G systems, which has the property of variable data rates as well as provides reliable communication systems.

Since 1993, MC-CDMA rapidly has became a topic of research. Wireless mobile communication systems present several design challenges resulting from the mobility of users throughout the system and the time-varying channel (Multi-path fading). There has been an increasing demand for efficient and reliable digital communication systems. To tackle these problems effectively, an efficient design of forward error coding (FEC) scheme is required for providing high coding gain.

Low-Density Parity-Check (LDPC) codes with iterative decoding algorithm were proposed by Gallager in 1962 [Gallager 1962, MacKay 1997]. These codes have been almost forgotten for about thirty years, in spite of their excellent properties. However, LDPC codes are now recognized as good error correcting codes achieving near Shannon limit performance [Gallager 1963].

MC-CDMA SYSTEM DESCRIPTION

A complete block diagram of an LDPC coded multiuser MC-CDMA system is shown in Fig. 1. The data coming from each user is first encoded with the LDPC coding technique. A single data symbol is replicated into $N$ parallel copies. Each branch of the parallel stream is multiplied by one chip of a spreading code of length $N$. The resulting chips are then fed to a bank of orthogonal subcarriers. As is commonly done in MC-CDMA, it is assumed that the spreading sequence length $N$ equals the number of subcarriers. Each user has its own spreading code $C_i$. Pilot carriers with double energy are inserted at equal distances within the data. Carrier modulation is efficiently implemented using the inverse fast Fourier transform (IFFT) [Aqiel 2011, Husam 2010, Nathan 1993].

After parallel-to-serial (P/S) conversion, a cyclic prefix (CP) is appended to the resulting signal to minimize the effects of the channel dispersion. It is assumed that the CP length exceeds the maximum channel delay spread and therefore, there is no interference among successively transmitted symbols (i.e. there is no interblock interference).

At the receiver side, opposite operation to that done at the transmitter is done. These operations are the OFDM demodulation, dispreading, MPSK demodulation, demapping and the LDPC decoding. For more details about the MC-CDMA system refer to references Husam 2009 and Aqiel 2011 published by the author. Finally decoding the data stream from every user individually using the iterative decoding algorithms for the LDPC coding scheme.

LDPC CODING

LDPC codes are linear block codes specified by a very sparse (containing mostly 0’s and only a small number of 1’s) random parity-check matrix, but are not systematic. The parity-check matrix of an LDPC is an $M \times N$ matrix $A$, where $M$ is the number of parity bits, and $N$ is the transmitted block length ($N = K + M$, with $K$ as the source block length). The matrix $A$ is specified by a fixed column weight $j$ and a fixed row weight $k = jN/M$ (in the MacKay’s and Neal’s codes $k$ is as uniform as possible [MacKay 1999]), and code rate $R = K/N$. It has been reported that when the block length is relatively large, irregular LDPC codes with nonuniform column weight outperform turbo codes with almost the same block length and code rate [Richardson 2000]. LDPC codes can be decoded using probability propagation algorithm known as the sum-product or belief propagation algorithm [Kschischang 2001], which is represented by a factor graph that contains two types of nodes: the “bit nodes” corresponding to a column of the parity-check matrix, which also corresponds to a bit in
codeword and the “check nodes” corresponding to a row of the parity-check matrix, which represents a parity-check equation.

**SUM-PRODUCT DECODING ALGORITHM**

The decoding problem is to find the most probable vector \( x \) such that \( A x \mod 2 = 0 \), with the likelihood of \( x \) given by \( x^\top \prod_n f_n \), where \( f_n^0 = 1 - f_n \) and \( f_n^1 = 1/(1 + \exp(-2y_n / \sigma^2)) \) for AWGN channel or \( f_n^1 = (y_n / \sigma^2) \exp[-y_n^2 / 2\sigma^2] \) for Rayleigh channel, and \( y_n \), \( \sigma^2 \) represent the received bit and noise variance, respectively. We denote the set of bits, \( n \), that participate in check \( m \) as \( N(m) \equiv \{n : A_{mn} = 1\} \), where \( A_{mn} \) represents the element of the \( m \)th row and \( n \)th column in the parity-check matrix. Similarly, we define the set of checks \( m \) in which bit \( n \) participates as \( M(n) \equiv \{m : A_{mn} = 1\} \). We denote a set \( N(m) \) with bit \( n \) excluded as \( N(m) \setminus n \).

The algorithm has two alternating parts, in which quantities \( q_{mn} \) and \( r_{mn} \) associated with each non-zero element in the matrix \( A \) are iteratively update. The quantity \( x_{mn}^0 \) is meant to be the probability that bit \( n \) of \( x \) is 0, given the information obtained via checks other than check \( m \). The quantity \( r_{mn}^0 \) is meant to be the probability of check \( m \) being satisfied if bit \( n \) of \( x \) is considered fixed at 0 and the other bits have a separable distribution given by the probabilities \( \{q_{mn} : n \in N(m) \setminus n\} \). The a posteriori probabilities for a bit are calculated by gathering all the extrinsic information from the check nodes that connect to it, which can be obtained by the following iterative sum-product procedure [Luis 2006].

Step 1: Initialization The variables \( q_{mn}^0 \) and \( q_{mn}^1 \), which are the probabilities sent from the \( n \)th bit node to the \( m \)th check node along a connecting edge of a factor graph, are initialized to the values \( f_n^0 \) and \( f_n^1 \), respectively.

Step 2: Horizontal Step (bit node to check node) We define \( \Delta q_{mn} = q_{mn}^0 - q_{mn}^1 \) and compute eq.(1) and eq. (2) for each \( m \) and \( n \):

\[
q_{mn}^0 = \prod_{n' \in N(m) \setminus n} q_{mn'}^0
\]

\[
r_{mn}^0 = \{1 + (-1)^0 A_{mn}\}/2
\]

Where, \( r_{mn}^0 \) represents the probability information sent from the \( m \)th check node to the \( n \)th bit node.

Step 3: Vertical Step (check node to bit node) For each \( n \), \( m \) and \( x = 0,1 \) we update eq.(3):

\[
q_{mn}^0 = \alpha_{mn} f_n^0 \prod_{m' \in M(n) \setminus m} r_{m'n}^0
\]

Where, \( \alpha_{mn} \) is a normalization factor chosen such that \( q_{mn}^0 + q_{mn}^1 = 1 \). We can also update the a posteriori probabilities \( q_n^0 \) and \( q_n^1 \), given by eq.(4):

\[
q_n^0 = \alpha_n f_n^0 \prod_{m' \in M(n) \setminus m} r_{m'n}^0
\]

Where, \( \alpha_n \) is a normalization factor chosen such that \( q_n^0 + q_n^1 = 1 \).

Step 4: Check stop criterion soft decision is made on the \( q_n^1 \). The resulting decoded vector \( \hat{x} \) is checked against the parity-check matrix \( A \). If \( A\hat{x} = 0 \), the decoder stops and outputs \( \hat{x} \). Otherwise, it repeats the procedure from the Step 2. The sum-product algorithm sets a maximum number of iterations: if the number of iterations reaches that maximum, the decoder stops and outputs \( \hat{x} \) as the results of the decoding.

**SIMULATION RESULTS**

The proposed system is illustrated in Fig. 1. A 20 Mbps was transmitted over the system. Since the channel for the 4th generation is not developed yet, therefore, the LTE channel specifications were used in the simulation process. These channels are Additive White Gaussian Noise AWGN, Vehicular channel. The modulation schemes are the MPSK with \( M=2,4 \) and 16. The simulation was done using the MATLAB R2010apackage. A flow
The increase of the number of iteration improves the performance of the system.

Table 2 summarizes the obtained results as a comparison for AWGN channel and Multipath fading channel for modulation techniques of bpsk, 4psk and 16psk with uncoded, convolution coded (CE) and LDPC coded data.

It can be noticed that there is an improvement in the results of the use of the LDPC coding technique over others in many dB's of SNR.

Table 2: A comparison for SNR in dB for Uncoded, CE and LDPC for bpsk, 4psk and 16psk for BER of $10^{-4}$.

<table>
<thead>
<tr>
<th>M-psk</th>
<th>SNR/dB for AWGN channel</th>
<th>SNR/dB for indoor to outdoor//pedestrian channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncoded</td>
<td>CE</td>
</tr>
<tr>
<td>2psk</td>
<td>5</td>
<td>3.8</td>
</tr>
<tr>
<td>4psk</td>
<td>9</td>
<td>4.1</td>
</tr>
<tr>
<td>16psk</td>
<td>22</td>
<td>12.4</td>
</tr>
</tbody>
</table>

CONCLUSION:

From the results, it can be noticed that the LDPC gives a better BER for both the AWGN channel and Rayleigh channel for low SNR and increases for higher values of SNR.

For AWGN channel with LDPC coded data, the BER is around $10^{-4}$ for about 1 dB better than convolution coding and 2 dB better than uncoded system for BPSK and 6 dB gain over uncoded for QPSK. The gain increases as the order of modulation increases showing superiority for higher data rates. For low SNR the results contain a little difference from both uncoded data and convolution coded data.

For Rayleigh channel, at a BER of $10^{-4}$, the performance of the LDPC coded MC-CDMA system is better than that with convolutional coding one by about 2 and 3 dB for BPSK and 4PSK modulation schemes respectively. It’s better by 4.5 dB than convolutional coding for 16PSK. The number of iterations was set to 10 which represents a low computational.
complexity comparable to convolutional decoder. For better performance and higher computational complexity, the number of iterations can be increased to 100 as shown in Fig. 8.

REFERENCES


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Figure 1 Block Diagram of the LDPC Coded MC-CDMA System.
Figure 2 LDPC coded MC-CDMA performance for AWGN channel with BPSK modulation.

Figure 3 LDPC coded MC-CDMA performance for AWGN channel with QPSK modulation.

Figure 4 LDPC coded MC-CDMA performance for AWGN channel with 16PSK modulation.

Figure 5 LDPC coded MC-CDMA performance for Rayleigh Fading channel with BPSK modulation.

Figure 6 LDPC coded MC-CDMA performance for Rayleigh Fading channel with 4PSK modulation.

Figure 7 LDPC coded MC-CDMA performance for Rayleigh Fading channel with 16PSK modulation.
Figure 8 LDPC coded MC-CDMA performance for Rayleigh Fading channel with 16PSK modulation with different number of iterations for decoding process.

Figure 9 Flow chart describe the simulation of the proposed system.