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LDPC Coding for Performance Enhancement of MC-CDMA System

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ABSTRACT

A turbo block code (TBC) technique for improving the performance of a multi-carrier code division multiple access (MC-CDMA) system in terms of bit error rate (BER) is proposed in this paper. The objective of this work is to develop a coding scheme that generates low BER code-words. By implementing a time domain TBC, designed using powerful low density parity check (LDPC) code, the BER performance of MC-CDMA system is improved and the same is proved through simulation. Two types of LDPC codes, viz. random LDPC codes and quasi cyclic (QC) LDPC codes are analyzed. These codes also have error correction capability along with high performance efficiency in terms of BER. In addition a decoding algorithm with moderate decoding complexity and with feasible soft output generation is also proposed for each LDPC code.

Key words: Belief-propagation algorithm, LDPC codes, MC-CDMA, Random LDPC codes, QC-LDPC codes, Sum-product algorithm.

1. INTRODUCTION

MC-CDMA system is a combination of code division multiple access (CDMA) and orthogonal frequency division multiple access (OFDM). Consequently MC-CDMA has the advantages of both CDMA and OFDM. The CDMA part increases spectrum utilization and the OFDM part reduces multipath fading and Inter Symbol Interference (ISI). Thus MC-CDMA is an efficient technique that reduces problems like, spectral limitation and distortion due to multipath channels. So it is considered as a strong contender [1] for future mobile communication to obtain high data rates at downlink.

Although MC-CDMA is having many advantages; it also has some disadvantages like multiple access interference (MAI) and high peak to average power ratio (PAPR) [1]. These problems can be effectively reduced by an efficient design of forward error coding (FEC) scheme with high coding gain. Turbo Block Codes (TBC) has proved to be an attractive scheme that provides high coding gain at a moderate decoding complexity. Turbo block codes helps in achieving good BER performance with a low PAPR. It uses iterative decoding algorithms for decoding and the decoder used is a soft decision decoder. Thus it provides a better decoding scheme with lower complexity and higher efficiency for improving the performance of MC-CDMA system in terms of BER.

Several techniques were proposed to reduce BER in MC-CDMA systems. Techniques like PTS [2], spreading code sharing M'ary PSK multi-carrier CDMA (SCS-MPSK-MCCDMA) system [3], a modified PTS scheme for uplink communications [4], optimum fixed subcarrier scrambling [5], cyclic shifted scramble code (CSSC) [6] are based on OFDM properties. These techniques use additional randomizing codes/sequences for reducing PAPR with additional computation at the IFFT modulator. This increases the system complexity, which leads to the development of more efficient MC-CDMA system exploiting the spreading codes, viz. spreading code redistribution [7], modified VCS [8], Spreading code reallocation (SCR) [9] etc. with reduced PAPR. The spreading codes are re-allocated or phase-shifted to obtain low PAPR in the foresaid techniques. Another technique reduces PAPR with an aid of peak reduction signals, which "borrow" the spreading codes of idle users [10]. Also, nonlinear companding [11] is a technique that transforms the amplitude or power of the original signals into uniform distribution to reduce PAPR.

Coding techniques offers excellent performance on PAPR reduction owing to fact of increased coding gain [12]. By using efficient coding techniques, PAPR can be reduced and consequently system performance can be enhanced in terms of BER. Performance enhancement technique for MC-CDMA system through LDPC coding is proposed in this work.

The paper is organized as follows: Section 2 describes the signals generated by the proposed system. The details of LDPC coding are explained in Section 3. The simulation results are presented in Section 4, and the conclusion is arrived at Section 5.

2. SYSTEM MODEL

The basic MC-CDMA signal [13] is generated by a serial concatenation of classical DS-CDMA and OFDM. Processing and spreading occurs in the frequency domain, rather than temporal domain in MC-CDMA system. Different users transmit over the same set of subcarriers but with a spreading code which maintains the orthogonality. The resulting signal has an orthogonal code structure in the frequency domain.

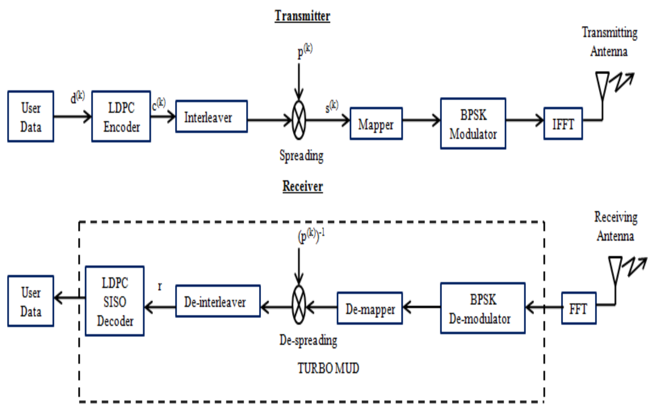

Figure 1: MC-CDMA system using LDPC code

2.1 MC-CDMA System

MC-CDMA system with K active users is considered and figure 1 shows such a system for k^{th} active user. Let $d^{(k)}$ be one complex-valued data symbol assigned to k^{th} user. At the transmitter side, the complex-valued data symbol $d^{(k)}$ is multiplied with the user specific spreading code of length $L=PG$ (where PG is the processing gain) to spread the symbol.

The spreading code for k^{th} user, $c^{(k)}$ is given by,

$$p^{(k)} = (p_0^{(k)}, p_1^{(k)}, \ldots, p_{L-1}^{(k)})^T. \qquad (1)$$

The chip rate $(1/T_c)$ of the serial spreading code $p^{(k)}$ before serial-to-parallel conversion is,

$$\frac{1}{T_c} = \frac{1}{T_d} \qquad (2)$$

and is L times higher than the data symbol rate $1/T_d$.

The complex-valued sequence obtained after spreading is given in vector notations by,

$$s^{(k)} = c^{(k)} p^{(k)} = (S_0^{(k)}, S_1^{(k)}, \ldots, S_{L-1}^{(k)})^T. \qquad (3)$$

A multi-carrier spread spectrum signal is obtained after modulating the components; $S_l^{(k)}$, $l= 0,\ldots,L-1$, in parallel on to L sub-carriers. With multi-carrier spread spectrum systems, each data symbol is spread over L sub-carriers. In cases where the N number of sub-carriers of one OFDM symbol is equal to the spreading code length L, the OFDM symbol duration with a multi-carrier spread spectrum including a guard interval results in

$$T_s' = T_g + LT_c. \qquad (4)$$

In this case one data symbol per user is transmitted for one OFDM symbol.

2.2 MC-CDMA Downlink Signal

The message signal is first encoded using LDPC encoder, the encoded signal is then spreaded and OFDM operation is performed to get the downlink signal. The superposition of the K sequences $s^{(k)}$ results in the sequence,

$$s=PC=\sum_{k=0}^{K-1} s^{(k)} = (S_0, S_1, \ldots, S_{L-1})^T, \qquad (5)$$

where C is the vector with LDPC encoded code words,

$$C=(C^{(0)}, C^{(1)}, \ldots, C^{(K-1)})^T \qquad (6)$$

and P is the spreading matrix,

$$P = (p^{(0)}, p^{(1)}, \ldots, p^{(K-1)}). \qquad (7)$$

MC-CDMA downlink signal is obtained after processing the sequence s in the OFDM block. By assuming that the guard time is long enough to absorb all echoes, the received vector of the transmitted sequence s after inverse OFDM and frequency de-interleaving is given by,

$$r=Ts + n=(R_0, R_1, \ldots, R_{L-1})^T, \qquad (8)$$

where T is the $L \times L$ channel matrix and n is the noise vector of length L. The vector r is fed to the data detector in order to get a soft estimate of the transmitted data. For the description of the multi-user detection techniques, an equivalent notation for the received vector r is introduced,

$$r=AC + n=(R_0, R_1, \ldots, R_{L-1})^T. \qquad (9)$$

The system matrix A for the downlink is defined as,

$$A = TP. \qquad (10)$$

2.3 MC-CDMA Uplink Signal

The received vector on the receiver side after inverse OFDM and frequency de-interleaving is given by,

$$r= \sum_{k=0}^{K-1} T^{(k)} s^{(k)} + n = (R_0, R_1, \ldots, R_{L-1})^T, \qquad (11)$$

where $T^{(k)}$ contains the coefficients of the sub-channels assigned to user k. The uplink is assumed to be synchronous in order to achieve the high spectral efficiency of OFDM. The vector r is fed to the data detector in order to get a soft estimate of the transmitted data. The system matrix, A comprises K user specific vectors.

$$A=(a^{(0)},a^{(1)},\ldots,a^{(K-1)}), \quad (12)$$

where $a^{(k)}$ is given by,

$$\begin{aligned} a^{(k)} &= T^{(k)}p^{(k)} \\ &= (T_{0,0}^{(k)}p_0^{(k)}, T_{1,1}^{(k)}p_1^{(k)}, \ldots, T_{L-1,L-1}^{(k)}p_{L-1}^{(k)})^T. \end{aligned} \quad (13)$$

3. LOW DENSITY PARITY CHECK CODE

A LDPC code is a class of linear block codes [14] which can be defined in terms of a sparse parity check matrix, H. For an $m \times n$ parity check matrix H, m rows specify the number of parity message bits, and n represents the length of a codeword. H is also characterized by W_r and W_c, which represent the number of 1's in the rows and columns, respectively.

3.1 Construction of LDPC codes

The parameters such as row and column weights, rate, girth and code length are considered in the construction process of LDPC code. The main objectives in code construction are good decoding performance and low implementation complexity. This is mostly achieved by having a code with regularly arranged row-column connections. But putting these kinds of constraints will limit decoding performance. So the main challenge in code construction is to obtain codes with required length and rates that have good decoding performance.

Two methods are used for LDPC code construction in this work; viz. random construction and quasi-cyclic construction.

3.2 Encoding LDPC Code

The encoding efficiency has quadratic complexity with respect to block length of the code, since it requires multiplication by the generator matrix which is not sparse. This complexity is in contrast to the turbo code case, which has linear encode complexity.

Steps involved in encoding a message u are as detailed,

i. Let u be the message block to be encoded and H be the parity check matrix of order $(m \times n)$.

ii. H should be in the form of an augmented matrix given by

$$H=[I|B], \quad (14)$$

where I is an identity matrix of order $(m \times m)$ and B is a matrix of order $(m \times (n-m))$called parity.

iii. Original message u should be encoded to get the code word C (such that $C.H^T=0$),

$$C = [c \mid s], \quad (15)$$

where c denotes check bits and s denotes the message bits.

iv. To find c;
A code word, C is said to be valid, if it satisfy the condition,

$$C \,.\, H^T = 0 \quad (16)$$

From (14), (15) and (16); we have,

$$Ic + Bs = 0 \quad (17)$$

Therefore,

$$c = I^{-1}Bs \quad (18)$$

3.3 Random LDPC Code

The random constructions connect rows and columns of LDPC code matrix without any structured or predefined connection pattern. Constructions could be made in tanner graph by connecting check nodes to variable nodes with edges or by replacing 0's in check matrix with 1's. Randomly adding edges to the Tanner graph or adding 1's to parity check matrix will not produce desired rate and may have cycles of four. The resulting code will be then optimized by either post processing or by putting constraints on random choices. Post processing exchanges or deletes some connections in order to get a desired girth and rate. Random construction with constraints adds a connection in the code if it does not violate the desired girth or row column weights. Random codes have good performance especially at long code lengths.

Sum-product algorithm is used for decoding random LDPC codes in this work. In sum-product decoding algorithm the values of the messages sent to each node are probabilistic denoted by log likelihood ratio. What we receive are positive and negative values of a sequence. The signs of these values show the value of the bit supposed to be sent by the sender and the confidence in this decision is represented by a real value. For a positive sign it will send a 0 and for a negative sign it will represent a 1. Sum-product decoding algorithm use soft information and the nature of the channel to obtain the information about the transmitted signal.

3.4 Quasi-Cyclic LDPC Code

There are several methods for constructing QC-LDPC codes. A QC-LDPC code can be formed by a concatenation of circularly shifted sub-matrices with or without zero sub-matrices. The code structure depends on the arrangement of sub-matrices and their shift values. Random shifting of identity matrices may result in codes with cycles of length four that will reduce the code performance. The codes have a general structure as

$$H = [M_1, M_2, \ldots, M_l] \quad (19)$$

where M_i is a circulant matrix, l is the number of sub-matrices and H is the parity-check matrix. Some construction methods like finite geometry, combinational designs, algebraic difference sets and search algorithm impose constraints to avoid cycles.

The decoding algorithm used in this work for QC-LDPC code is belief-propagation algorithm. In this algorithm it is assumed that the variable nodes (x) and check nodes (z) form a 'belief network' or a 'Bayesian network'. The algorithm consists of two alternating phases in which for each non-zero entry of H, the two quantities q_{ij} and r_{ij} are iteratively updated. q^z_{ij} approximates the probability that j^{th} bit of x, i.e. $x(j)$ is z given all the checks of bit j other than i. r^z_{ij} approximates the probability that i^{th} check node is satisfied when j^{th} bit of x, i.e. $x(j)$ is z and all the other message bits j' associated with i have a separable distribution given by the appropriate $q_{ij'}$. i.e., we assume that the other bits j' are independently 1 with probability $q^1_{ij'}$ and use it to calculate r^z_{ij} .

$$L(m) \equiv\equiv \{l : A_{ml} = 1\}$$
$$M(l) \equiv\equiv \{m : A_{ml} = 1\}$$

where $L(m)$, $M(l)$ are two quantities defined to represent the set of bits l which participate in check m and the set of checks in which l participates respectively.

4. SIMULATION RESULTS

The simulation results and comparisons of the proposed system were executed and analyzed using MATLAB version 7.12.0. BER performance of random LDPC codes over AWGN channel and Rayleigh fading channel and quasi-circular LDPC codes over AWGN channel for different values of iterations were evaluated.

The code rate used is 1/2 for both random LDPC codes and quasi-circular LDPC codes; performance of both LDPC codes is evaluated for different iterations. As the number of iterations increases performance also improved, since the error count decreases in steps with each iteration. In Rayleigh fading channel the performance varies as non-clear line of sight is considered, where as in AWGN channel variations are negligible.

Figure 2 portrays the performance comparison of random LDPC codes for various values of iterations over AWGN channel. The figure lists BER values of the system for varying SNR values. It is observed that as the number of iterations increases the BER performance also increases; also the BER value decreases with increase in SNR value. The dimension of the parity check matrix used here is 2048 x 4096 with a code a rate of 1/2.

Performance comparison of random LDPC codes for various values of iterations over Rayleigh channel is revealed in Figure 3. In Rayleigh fading channel the performance varies each time for same input parameters. It is observed that as the number of iterations increases the BER performance also increases. Dimension of the parity check matrix and code rate used here is the same used for random LDPC over AWGN channel. The performance of the system is degraded the when channel used is Rayleigh fading channel, as the channel introduce fading and more noise when compared to AWGN channel.

The comparison of performance of QC-LDPC codes for various values of iterations is illustrated Figure 4. Similar to random LDPC codes, it is observed that as the number of iterations increases the BER performance also increases; also the BER value decreases with increase in SNR value. The dimension of the parity check matrix used is 635 x 1270 with a code a rate of 1/2.

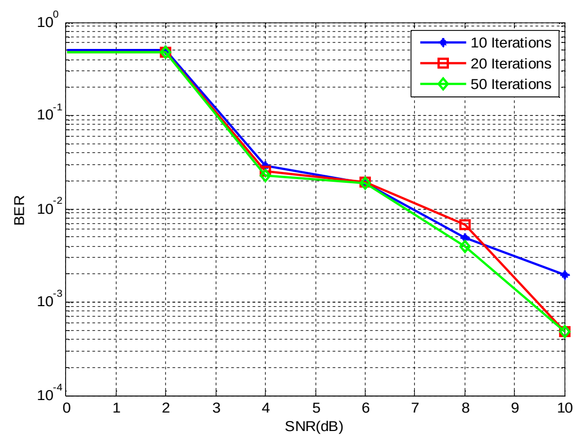

Figure 2: BER performance graphs of Random LDPC codes over AWGN channel

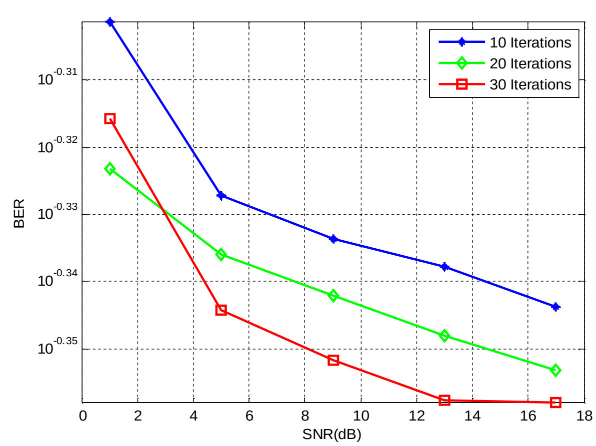

Figure 3: BER performance graphs of Random LDPC codes over Rayleigh fading channel

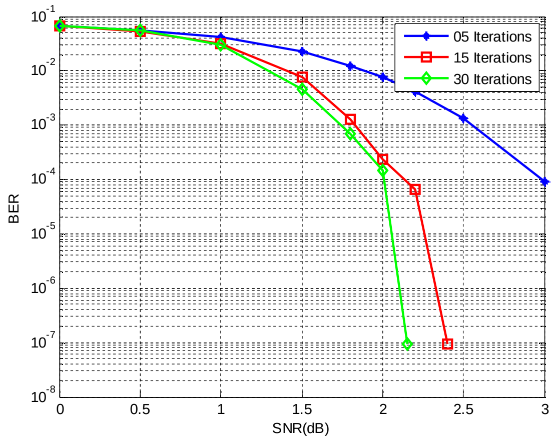

Figure 4: BER performance graphs of QC-LDPC codes over AWGN channel

5. CONCLUSION

LDPC coding is proposed for MC-CDMA system for improving the system performance in terms of BER in this work. It enhances the BER performance with a quadratic encoding complexity and linear decoding complexity with respect to block length of the code. The simulation results and comparisons of the proposed system were executed and analyzed using MATLAB. BER performance of random LDPC codes over AWGN channel and Rayleigh fading channel and quasi-circular LDPC codes over AWGN channel for different values of iterations are also analyzed at a code rate of 1/2. It was observed that the BER performance of the system increases with the number of iteration at the cost of latency.

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