Performance Improvement of Block Turbo Coded OFDM System Using Channel State Information

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Abstract: In this paper, we present a block turbo coded OFDM system. In case of OFDM system which makes use of block turbo codes or shorted block turbo codes as an error correcting code, we propose a new decoding algorithm which is better using the Channel State Information(CSI) in order to improve error correcting capability

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is a very promising approach to combat the intersymbol interference that occurs in multipath propagation[1]. However, OFDM technology alone cannot ensure reliable transmission due to frequency selectivity on the OFDM subcarriers introduced by the channel multipaths. This results in some of the subcarriers being so severely attenuated that reliable detection is simply not possible. As such, forward error correction code (FEC) has to be applied to introduce redundancies across the subcarriers in the hope that those information bits undergoing deep-fades in the frequency domain can be recovered through the channel decoding process.

In this paper, as a powerful FEC we adopt block turbo code (BTC) due to its powerful error-correction capability based on soft-input-soft-output (SISO) iterative decoding algorithm. In 1994, a near-optimum iterative algorithm for decoding block turbo codes was introduced , which is based on the chase algorithm [2][3]. In case of OFDM system which makes use of block turbo codes or shorted block turbo codes as an error correcting code, we propose a new decoding algorithm which is better using the Channel State Information(CSI) in order to improve error correcting capability. When the iterative decoding of block turbo codes based on the chase algorithm is working, the soft input using CSI which gets into the turbo decoder is presented.

This paper is organized as follows. Section 2 describes the encoding and decoding of block turbo codes. Section 3 describes the block trubo coded OFDM system using CSI. Section 4 presents computer simulations and Section 5 summaries the conclusions of the paper.

2. Encoding and decoding of block turbo codes

2.1 Encoding of block turbo codes

The product code is a simple concept allowing to build very long block codes by using two short block codes. In order to build a long block code P having parameters (n, k, δ) out of two systematic linear block codes E^1 having parameters (n_1, k_1, δ_1) and E^2 having parameters (n_2, k_2, δ_2) where n, k and δ stand for code length, number of information bits and minimum Hamming distance respectively. The product code $P = E^1 \otimes E^2$ is obtained by placing (k_1, k_2) information bits in an array of k_1 rows and k_2 columns, coding the k_1 rows using code E^2 and coding the n_2 columns using code E^1 as illustrated in figure 1. The parameters of the resulting product code P are given by $n = n_1 \times n_2$, $k = k_1 \times k_2$ and $\delta = \delta_1 \times \delta_2$, and the code rate R is given by $R = R_1 \times R_2$ where R_i is the code rate of code E^i.

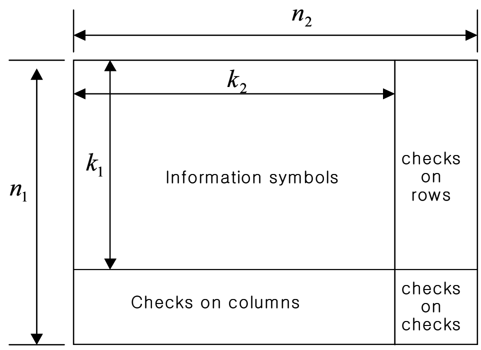

Fig. 1. Construction of product code

In the case of block turbo coded QPSK modulation, each binary element of the product code is used to select a symbol from the in-phase channel (or from the quadrature channel) of the QPSK constellation. For block turbo coded 16-QAM modulation, every two binary elements of the product code is used to select a symbol from the in-phase channel (or from the quadrature channel) of the 16-QAM constellation. For block turbo coded 64-QAM modulation, each symbol from the in-phase (or quadrature) channel is selected by three binary elements. In order to improve the performance of this product code, this code must bo decoded by using soft-input/soft-output decoders to allow an iterative decoding.

2.2 Soft-In Soft-Out(SISO) Decoding of block turbo codes

If we consider the transmission of block turbo coded QPSK, 16-QAM and 64-QAM in a Gaussian channel, the Log Likelihood Ratio (LLR) associated to each binary element corresponding to a row or column of block turbo code will be noted $R=(r_1 \cdots r_i \cdots r_n)$. From the received soft input R, the optimum decoded sequence is given by

$$D=C^i \quad \text{if} \quad |R-C^i|^2 < |R-C^l|^2 \quad \forall l \neq i \qquad (1)$$

where $C^i=(c_1^i,\cdots,c_j^i,\cdots c_n^i)$ is the i^{th} code word of the component code E^i with parameters (n_i, k_i, δ_i). Decision $D=(d_1,\cdots,d_j,\cdots d_n)$ corresponds to the maximum likelihood transmitted sequence conditionally to R and

$$|R-C^i|^2 = \sum_{j=1}^{n}(r_j - c_j^i)^2 \qquad (2)$$

is the squared Euclidean distance between R and C^i. For block codes with a high code rate R, the number of code words 2^k is relatively large and maximum likelihood sequence decoding is too complex for implementation. To reduce the complexity of the soft decoder we used the Chase algorithm which approximates maximum likelihood sequence decoding of block codes with a low computation complexity and a small performance degradation. Instead of reviewing all the code words $l=1,\cdots 2^k$, the Chase algorithm searches for the code words at Hamming distance within a sphere of radius $(\delta-1)$ centered on $Y=(y_1,\cdots,y_j,\cdots y_n)$ where y_j is the sign of r_j. To further reduce the number of reviewed code words, only the most probable code words within the sphere are selected by using channel information R. The SISO decoding steps using Chase algorithm are like this:

1) Search p least reliable positions

The first step of the decoding procedure involves in determining the position of the $p=\lfloor \delta/2 \rfloor$ least reliable elements of Y using the received codeword R. The reliability of y_i is given by $|r_j|$

2) Generating test patterns

Test patterns T^q for $q=0,\cdots,2^p-1$ are generated by defining all the combination of patterns with 0 and 1 in the p least reliable positions.

3) Generating candidate codes

Candidates codes are generated by decoding $Z^q = Y \oplus T^q$ with an algebraic decoder. The algebraic decoder determines code words C^q $q=0,\cdots,2^p-1$

4) Euclidean distance computation and decision code C^d

Euclidean distances between these codes C^q and the soft input R are calculated.

$$|R-C^q|^2 = \sum_{j=1}^{n}(r_j - c_j^q)^2 \qquad (3)$$

Among distances between these codes and the soft input R we have to find the code word at minimum Euclidean distance from R and choose it as the decision code C^d.

5) Choosing competing code C^c

We search for the code word C^c at minimum Euclidean distance such that $c_j^c \neq c_j^d$.

6) Computing the soft decision for each bit d_j (Soft-out calculation)

When the competing codeword C is in test patterns, the soft decision for each bit d_j of the decoded sequence can be computed like this

$$r_j' = \left(\frac{|R-C^c|^2 - |R-C^d|^2}{4}\right)c_j^d \qquad (4)$$

Otherwise we use the relation

$$r_j' = r_j + \beta \times c_j^d \qquad (5)$$

where β is pre-assigned coefficient.

7) Computing the extrinsic information for each bit d_j

$$w_j = r_j' - r_j \qquad (6)$$

2.3 Iterated Decoding of block turbo codes

On receiving the matrix [R] corresponding to a transmitted code word [E] of the product code, the first decoder performs the soft decoding of the rows (or columns) of the matrix, estimates the normalized LLR [R'] and gives as output [W(1)]. Then the next decoder performs the same operations on the columns (or rows) using as input

$$[R(1)] = [R] + \alpha(1)[W(1)] \qquad (7)$$

where the coefficient $\alpha(m)$ is used to reduce the influence of [W(m)] in the first iterations when the BER is relatively high and thus when [W(m)] is not absolutely reliable. The decoding procedure described is then iterated by cascading elementary decoders illustrated in Figure 2.

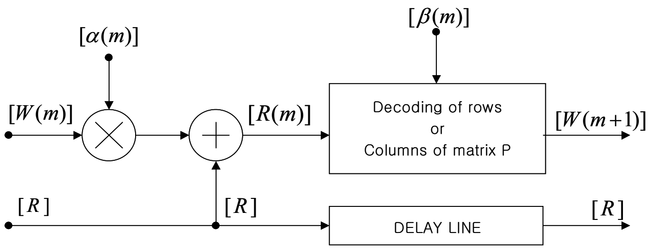

Fig. 2. Block diagram of soft decision decoder

3. Block turbo coded OFDM system using channel state information

The transmitter configuration for the block turbo coded OFDM system is shown in figure 3.

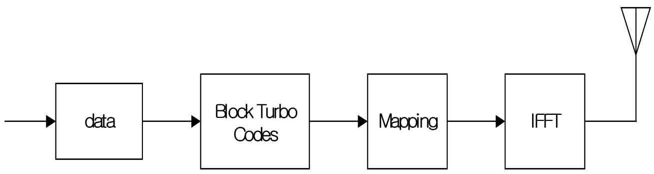

Fig. 3. transmitter configuration for the block turbo coded OFDM system

For block turbo code encoding, a total of $k \times k$ information bits are placed into a $k \times k$ array. Then a single-parity-check code is applied to every row of the array to result in a $k \times n$ matrix and subsequently the same code is applied to every column of the resultant matrix to yield an $n \times n$ matrix. The block turbo coded bits are mapped onto complex numbers representing QPSK, 16-QAM or 64-QAM constellation points. The stream of complex valued sub-carrier modulation symbols at the output of the mapper is divided into groups of 48 complex numbers. Each group is transmitted in an OFDM symbol with 4 pilot carriers added. Thus, each symbol is constituted by a set of 52 carriers. 12 virtual carriers are then padded with zeros to make the number of subcarriers per symbol become a power of 2 and applied to a 64-point IFFT which performs the OFDM modulation. The guard interval is inserted at the transition between successive symbols to absorb the intersymbol interference (ISI) created by multipath in the channel.

Figure 4. shows the receiver configuration for the block turbo coded OFDM system. Under the assumption that the OFDM symbol synchronization was accomplished perfectly, the symbol cyclic prefix or guard interval are then removed and the useful portions of the OFDM data symbols are fed into a 64-point FFT which performs the OFDM demodulation.

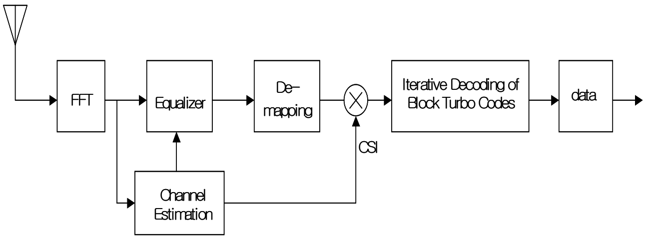

Fig. 4. receiver configuration for the block turbo coded OFDM system

The symbols at the output of the FFT block are used in the channel estimation block. The channel estimation block estimates the channel impulse response by comparing the received training symbols with the known training symbols. The equalization block corrects the channel distortion by dividing the data carriers by the estimated channel response determined in the channel estimation block. The equalized symbols are fed into a soft decision calculation block, which passes the soft input values to the iterative decoding block for block turbo code.

Until now, we have discussed the conventional receiver operations. When the received soft input [R] enters into Soft-In Soft-Out (SISO) decoder for block turbo codes, the first thing that the decoder have to do is to search p least reliable positions which are distorted severely by the channel. Based upon how accurately we find the p least reliable positions, the error correction capability of the block turbo code will be varied. For conventional receiver operation the received symbols went through the equalization block where compensates for the distortion created by multipath in the channel. Due to such compensation being done by equalizer, it might cause the decoder not to find weak points, which can lead to lower the error correction capability of the block turbo code. What happens if we do not use such equalizer. Since we are considering coherent demodulation, we can not think the system without having channel estimation and equalization blocks. As a method of finding the parts distorted by the channel as weak points, we can come up with the scheme applying channel state information(CSI) to the soft input value so that the modified soft input at the input of the iterative decoder can be defined as

$$R' = CSI \cdot R \tag{8}$$

If we replace R in section 2 by R', all equations are held in themselves. Particularly, Eq. (4) can be written like this

$$r_j' = \left(\frac{|CSI \cdot R - C^c|^2 - |CSI \cdot R - C^d|^2}{4} \right) c_j^d \tag{9}$$

4. Simulation Results

In this section, we describe and present simulation results with block turbo coded-QPSK, -16QAM and -64QAM OFDM modulations over Rayleigh fading channel. We used the following values for α and β.

$\alpha(m) = [0.0, 0.2, 0.3, 0.5, 0.7, 0.9, 1.0, 1.0]$

$\beta(m) = [0.2, 0.3, 0.5, 0.7, 0.9, 1.0, 1.0, 1.0]$

and used 16 test patterns based on the 4 least reliable bits (weak points).

Figure 5 shows the simulation results of block turbo code BCH(64,57,4)× BCH(32,26,4) with 64QAM-OFDM modulation. The results show that at a BER of10^{-3} the block turbo decoder using CSI offers an improvement of 4.5[dB] over the block turbo decoder without using CSI after 1 iteration. In addition to that, the block turbo decoder using CSI after one iteration shows a 2.5[dB] performance improvement when compared to the block turbo decoder without using CSI after 4 iterations. That results in reducing the considerable amount of computations.

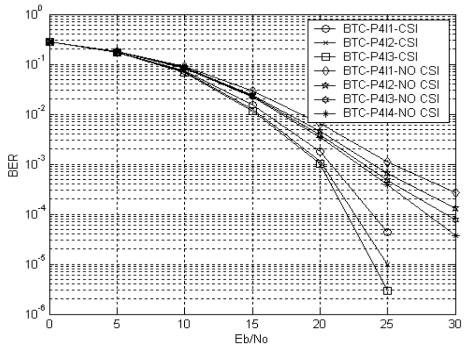

Fig 5. BER performance of block turbo coded 64QAM-OFDM modulation

Figure 6 shows the simulation results of block turbo code BCH(32,26,4)× BCH(32,26,4) with 16QAM-OFDM modulation. The results show that at a BER of10^{-3} the block turbo decoder using CSI offers an improvement of 7[dB] over the block turbo decoder without using CSI after 1 iteration. In addition to that, the block turbo decoder using CSI after one iteration shows a 4.5[dB] performance improvement when compared to the block turbo decoder without using CSI after 4 iterations.

Figure 7 shows the simulation results of block turbo code BCH(32,26,4)× BCH(16,11,4) with QPSK-OFDM modulation. The results show that at a BER of 10^{-3} the block turbo decoder using CSI offers an improvement of 10[dB] over the block turbo decoder without using CSI after 1 iteration. In addition to that, the block turbo decoder using CSI after one iteration shows a 7[dB] performance improvement when compared to the block turbo decoder without using CSI after 4 iterations.

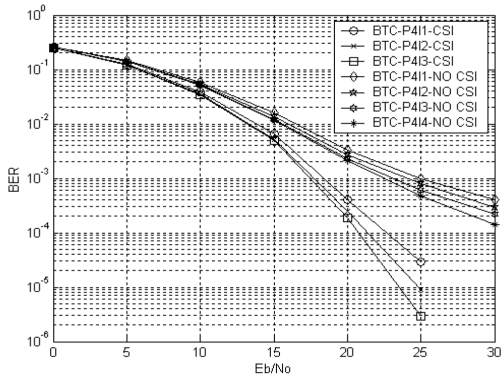

Fig 6. BER performance of block turbo coded 16QAM-OFDM modulation

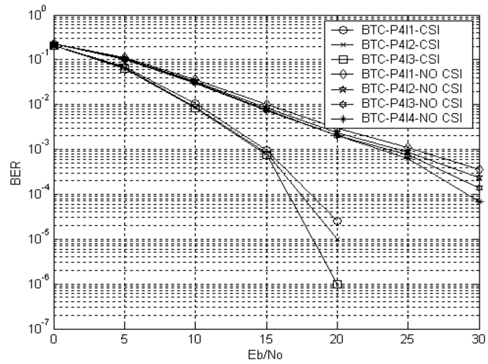

Fig 7. BER performance of block turbo coded QPSK-OFDM modulation

5. Conclusions

In this paper, the new decoding algorithm of block turbo codes and shorted block turbo codes using Channel State Information was proposed in order to improve error correction capacity during decoding procedure in OFDM system. Experimental results showed that in case of only one iteration coding gains can be obtained by applying the channel state information to the conventional decoding algorithm according to the modulation methods. In addition to that, the new decoding algorithm using channel state information at only one iteration shows a performance improvement when compared to the conventional decoding algorithm after four iterations. That leads to reduce the considerable amount of computation.

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