

Optimum Quasi-Orthogonal Space Time Turbo Coded MIMO-OFDM System over Frequency Selective Fading Channels

Gajanan R. Gaurshetti, Prof. Sanjay V. Khobragade

Abstract— The research over Multi-Input Multi-Output (MIMO) with Orthogonal Frequency Division Multiplexing (OFDM) has recently been the focused for improvement to make an efficient communication system. By using this technology we can improve bandwidth efficiency and bit error rates. Space-time coding can achieve transmit diversity without sacrificing bandwidth. A class of space-time block codes namely quasi-orthogonal space-time block codes can achieve the full rate. In this paper, we propose an approach which incorporates the turbo code and Quasi-Orthogonal space-time coding approaches. The proposed Quasi-Orthogonal space-time turbo code (QO-ST-TC) and low complexity ML decoding scheme significantly improves the performance. The simulation results show that bit error rate (BER) of 10^{-2} is achieved in QO-ST-TC at a signal-to-noise ratio (SNR) of approximately 20 dB as compared to conventional STBC.

Index Terms— Bit Error rate, Diversity, MIMO-OFDM, ML decoding, Q-OSTBC, Simulink, Turbo Equalization, Wireless Metropolitan Area Network (WMAN).

1 INTRODUCTION

One of the fastest growing areas in consumer electronics is multimedia application based on wireless communication for Metropolitan Area Network (MAN) [1]. A rapidly increase in demand of high data rates to support new features, advanced functionality and better services for multimedia need continuously evolution in wireless MAN [3]. On account of its potential in supporting high data rate transmission over frequency selective fading channels and the simplicity it offers in channel equalization, Orthogonal Frequency Division Multiplexing (OFDM) has become an attractive technique for wideband communications [2]. With the introduction of multiple antennas in the realization of Multiple-Input Multiple Output (MIMO) OFDM, the transmission capacity is largely expanded as the number of spatial communication channels is multiplied. The MIMO (Multiple Input, Multiple Output) system is one of several forms of smart antenna technology for wireless communications in which multiple antennas are used at the both side of transceiver. MIMO system is used to increase link capacity by sending different data stream over different transmit antenna or to improve the link reliability by sending the same data stream over different antenna using Space Time Block Code (STBC) [4] with help of STBC in MIMO-OFDM we can achieve high data rate and full transmit

antenna diversity because of their simple decoding algorithm. Without channel state information (CSI) at the transmitter side, the STBCs can effectively combat channel fading in the wireless communication systems.

Orthogonal Space-Time Block Codes (OSTB) for two transmit antennas provides full rate and for more than two transmit antennas the OSTBC can provide a rate of at most $\frac{3}{4}$. To achieve rate one transmission Quasi-Orthogonal Space-Time Block Codes (QOSTBC) structures were first introduced [5]-[6]. Later on rate one can be achieved with complex constellations by this code using three time slots [7]. Quasi-Orthogonal Space-Time Block Codes (QOSTBC) does not have fully diversity but it can be achieved through constellation rotation [8]-[9]. Use of turbo code increases the system performance [10]. In this paper, we propose an approach for high data rate wireless MAN communication systems. Our approach incorporates the turbo and Quasi-Orthogonal Space-Time Block Codes approaches. The proposed QO-ST-TC can achieve high coding and diversity gains. By simulation results, it is observed that this approach improves the BER.

This paper is organized as follows. In Section II, we present the MIMO-OFDM system model. The Quasi-Orthogonal Space-Time Block Codes and ML decoding is described in Section III. Simulation results are provided in Section IV. Finally, conclusions are given in Section V.

2 SYSTEM MODEL

A system model of MIMO-OFDM used for simulation is shown in Fig.1. The MIMO-OFDM system is consisting of N_m

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$X N_n$ where N_n is no. of transmit antennas and N_m is no. of receive antennas. In this paper we used MIMO-OFDM of 4X1.

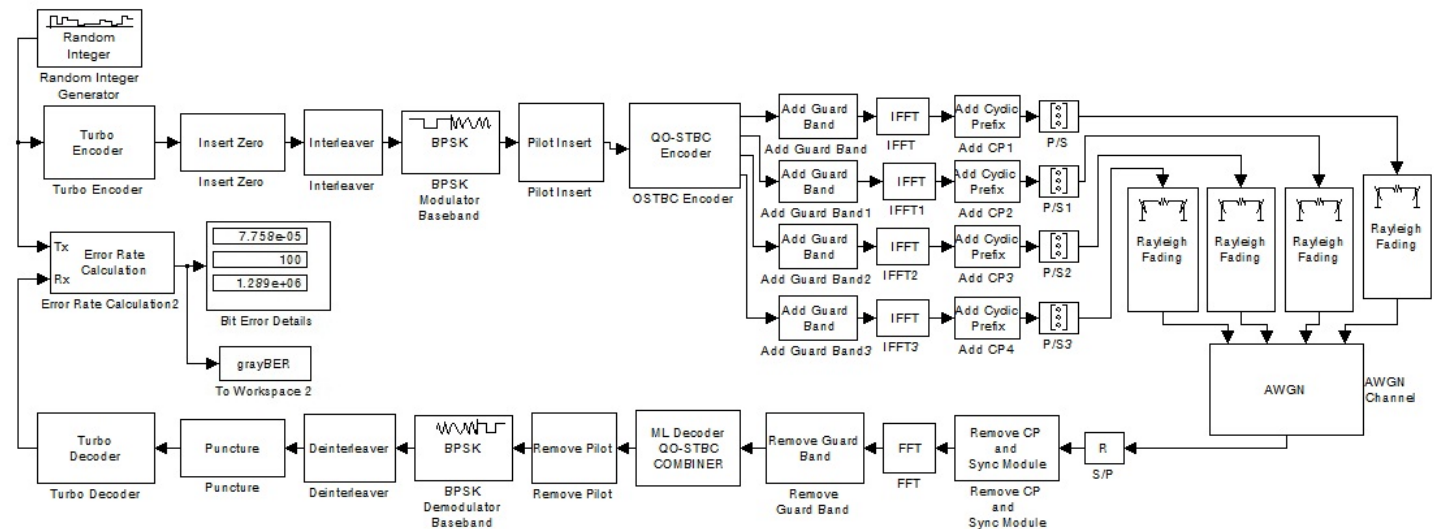


Fig.1. MIMO-OFDM System Model

There are different blocks are used in given system description of each block is given bellow.

2.1 Random Integer Generator

The Random Integer Generator block generates uniformly distributed random integers in the range $[0, M-1]$, where M is the M -ary number.

2.2 Turbo Encoder

The Turbo Encoder block encodes a binary input signal using a parallel concatenated coding scheme. This coding scheme employs two identical convolutional encoders and one internal interleaver. Each constituent encoder is independently terminated by tail bits. The output of the Turbo Encoder block consists of the systematic and parity bits streams of the first encoder, and only the parity bit streams of the second encoder. It accepts an L -by-1 column vector input signal and outputs an M -by-1 column vector signal. For a given trellis, M and L are related by:

$$M = L \cdot (2n - 1) + 2 \cdot \text{numTails} \quad (1)$$

Where L = encoder input length, M = encoder output length, $n = \log_2(\text{trellis.NumOutputSymbols})$, for a rate $1/2$ trellis, $n = 2$, $\text{numTails} = \log_2(\text{trellis.numStates}) * n$.

2.3 Interleaver

The Interleaver block rearranges the elements of its input vec-

TABLE 1
INTERLEAVER PARAMETERS

Sub-Channels	16	8	4	2	1
mod					

BPSK	192	96	48	24	12
QPSK	384	192	96	48	24
16-QAM	768	384	192	96	48
64-QAM	1152	576	288	144	72

tor without repeating or omitting any elements. Number of coded bits per sub channel (Ncbps) for interleaver are mentioned in Table 1 for Number of coded bits per subcarrier (N_{cbps}) = 1.

$$S = \begin{bmatrix} X_1 & X_2 & X_3 & X_4 \\ -X_2^* & X_1^* & -X_4^* & X_3^* \\ -X_3^* & -X_4^* & X_1^* & X_2^* \\ X_4 & -X_3 & -X_2 & X_1 \end{bmatrix} \quad (2)$$

2.4 QO-STBC Encoder

QO-STBC is an Quasi-Orthogonal Space-Time Block Code scheme can be applied to the system with four transmit antennas and its space-time encoding can be described as follow,

Where X_1, X_2, X_3 and X_4 are generated from the circular QPSK or rectangular QAM constellations to be transmitted and $*$ denotes a conjugate operation. Rows indicate the time domain and columns represent the space domain.

2.5 Pilot and Guard Band Insert

Pilot and Guard Band are used for channel estimation at receiver side.

2.6 IFFT

The IFFT block computes the inverse fast Fourier transform (IFFT) of each row of a sample-based 1-by- P input vector, or across the first dimension (P) of an N -D input array. IFFT size is 256.

2.7 Add Cyclic Prefix

In MIMO-OFDM cyclic prefix is used to remove inter symbol interference. The cyclic prefix is nothing but tail symbols of

message frame and it prepended to that message frame. Here length of CP is one fourth of the FFT/IFFT size and it is 256/4 i.e. 64.

2.8 Rayleigh Fading Channel

Rayleigh Fading channel represents wireless fading channel. We have considered 5 multipath and their delay between different multipath in microsecond and power gain of each multipath is (0, 0.3, 0.15, 0.31, 0.37) and (0, -1.5, -1.4, -3.6, -0.6) respectively. Rayleigh channel coefficient between transmitter N_m and receiver N_n is given by

$$h_{n,m}(t) = \sum_{L_{nm}=1}^{M_{nm}} [\alpha_{L_{nm}} \cdot \delta_{L_{nm}}(t - \tau_{L_{nm}})] N_{nm} \quad (3)$$

Where M_{nm} is the number of multipath between N_m transmitter and N_n receiver $\alpha_{L_{nm}}$, $\delta_{L_{nm}}$ are the gain and delay of the path L_{nm} respectively.

3 PROPOSED SYSTEM MODEL

A convolutional code (CC) is described by three parameters n , k and K and it is denoted as CC ($n;k;K$). At each instant, a CC ($n;k;K$) encoder accepts k input bits and outputs n coded bits. The constraint length of the code is K and the number of encoder states is equal to 2^{K-1} . The channel code rate is given by

$$R = k/n \quad (4)$$

However, different code rates can be obtained by suitable puncturing. We denote a turbo convolutional code as TC ($n;k;K$), where n is number of output coded bits, k is the number of input bits and K is the constraint length. The output code-word of turbo encoder is fed to the different constellations.

3.1 Constellation Rotation

It is not possible to achieve code rate 1 for the complex orthogonal codes, to achieve this we use Constellation Rotation. This is done by rotating the symbols during the constellation mapping. This provides full diversity with code rate 1 and gives good performance.

The optimal angle of rotation is determined such that the coding gain is maximized while the code is full-diversity. Thus the optimal angle of rotation for MPSK constellation is π/M (for M even) and $\pi/2M$ (for M odd) and for QAM is $\pi/4$. The optimal angle of rotation for four transmit antennas is listed in Table 2. After the constellation rotation process these symbols are given to QO-STBC block.

TABLE 2
OPTIMAL ANGLE OF ROTATION

Modulation	Angle of rotation
BPSK	$\pi/2$
QPSK	$\pi/4$
16-QAM	$\pi/4$
64-QAM	$\pi/4$

3.2 Quasi-Orthogonal Space-Time Block Code

The full-rate full-diversity space-time block code using orthogonal designs is Alamouti schemes and it is given by equation (5). We can design full rate code for four transmit antennas using this STBC code and pair of symbols as

$$S(X_1, X_2) = \begin{bmatrix} X_1 & X_2 \\ -X_2^* & X_1^* \end{bmatrix} \quad (5)$$

using this STBC code and pair of symbols as

$$S = \begin{bmatrix} S(X_1, X_2) & S(X_3, X_4) \\ -S^*(X_3, X_4) & S^*(X_1, X_2) \end{bmatrix} \quad (6)$$

On simplifying and considering rotated constellation symbols we

$$S = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 \\ -S_2^* & S_1^* & -S_4^* & S_3^* \\ -S_3^* & -S_4^* & S_1^* & S_2^* \\ S_4 & -S_3 & -S_2 & S_1 \end{bmatrix} \quad (7)$$

get

$$Y_t(t) = \sum_{m=1}^{N_m} [h_{nm}(t, \tau) * S_n(t) + N_{nm}(t)] \quad (8)$$

And output of transmitter at time t is given by

Where N_{nm} is the AWGN signal noise with zero-mean.

3.3 ML Decoding

Assuming perfect channel knowledge at the receiver, it computes the following decision metric

$$\sum_{n=1}^N \sum_{t=1}^T |Y_{t,n} - \sum_{m=1}^M h_{nm} S'_{tm}|^2 \quad (9)$$

Where S'_{tm} is the complex space-time block coded transmission matrix with time t and the transmitting antenna m for all possible $X \in S$ that minimize the sum in maximum-likelihood decoding scheme. Using the orthogonality, the maximum-likelihood decision metric (9) can be calculated as the sum of two terms $f_{14}(X_1, X_4) + f_{23}(X_2, X_3)$ where f_{14} is independent of X_2, X_3 and f_{23} is independent of X_1, X_4 . Thus, the minimization of (9) is equivalent to minimizing these two terms independently, i.e. decoder first finds the pair (S_1, S_4) that minimizes $f_{14}(X_1, X_4)$ among all possible pair of (X_1, X_4) . Then, the decoder selects the pair (S_2, S_3) which minimizes $f_{23}(X_2, X_3)$. This reduces the complexity of decoding without sacrificing the performance.

The manipulation of equation (9) for $f_{14}(X_1, X_4)$ and $f_{23}(X_2, X_3)$ is given as

$$f_{14}(X_1, X_4) = \sum_{n=1}^N [(\sum_{m=1}^4 |h_{nm}|^2)(|X_1|^2 + |X_4|^2) + 2 \operatorname{Re}\{(-h_{1,n}Y_{1,n}^* - h_{2,n}Y_{2,n}^* - h_{3,n}Y_{3,n}^* - h_{4,n}Y_{4,n}^*)X_1 + (-h_{4,n}Y_{1,n}^* - h_{3,n}Y_{2,n}^* - h_{2,n}Y_{3,n}^* - h_{1,n}Y_{4,n}^*)X_4 + (h_{1,n}h_{4,n}^* - h_{2,n}h_{3,n}^* - h_{2,n}h_{3,n}^* + h_{1,n}h_{4,n}^*)X_1X_4^*\}] \quad (10)$$

$$f_{23}(X_2, X_3) = \sum_{n=1}^N [(\sum_{m=1}^4 |h_{nm}|^2)(|X_2|^2 + |X_3|^2) + 2 \operatorname{Re}\{(-h_{2,n}Y_{1,n}^* + h_{1,n}Y_{2,n}^* - h_{4,n}Y_{3,n}^* + h_{3,n}Y_{4,n}^*)X_2 + (-h_{3,n}Y_{1,n}^* - h_{4,n}Y_{2,n}^* + h_{1,n}Y_{3,n}^* + h_{2,n}Y_{4,n}^*)X_3 + (h_{2,n}h_{3,n}^* - h_{1,n}h_{4,n}^* - h_{1,n}h_{4,n}^* + h_{2,n}h_{3,n}^*)X_2X_3^*\}] \quad (11)$$

Where Re is the real part of h .

4 SIMULATION RESULT

In this section we have presented the analysis and comparison of the BER performance of the proposed schemes. We have implemented the proposed system in Simulink software with the simulation parameters mentioned in Table 3.

TABLE 3
SIMULATION PARAMETERS

Parameters	Values
Sample Time	8.334e-08
No. of Sub-channels	16
No. of Sub-carriers	256
Channel Coding /Decoding	Turbo/Log-MAP
Modulation	QPSK, 16QAM and 64QAM
IFFT/FFT SIZE	256
Ts	7.20e-05

The simulation result of the proposed system with different modulation techniques like BPSK, QPSK, 16-QAM AND 64 QAM is plotted on graph which is function of BER vs. SNR (E_b/N_0). The result shown in Fig. 2 implies improvement in BER.

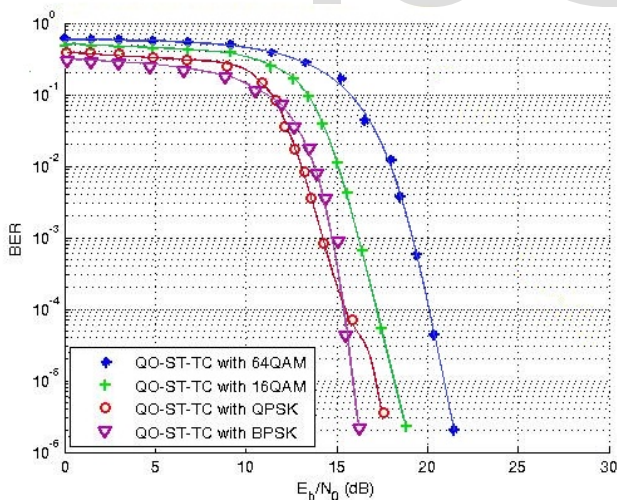


Fig. 2. BER result of proposed system

We have compared BER performance of the proposed system with conventional Quasi Orthogonal Space Time block coded system and it is observed that BER performance of the proposed system is very good. The improvement in BER is about 10^{-2} at SNR of approximately 20dB and gives a gain of 3dB as shown in Fig. 3.

5 CONCLUSION

In this paper, we have proposed a new approach for high data rate WMAN communication system. In this approach we incorporate the turbo coding and Quasi-Orthogonal space-time block code with simple ML decoding. This system gives us full diversity as well as full code rate and reduces the decoding complexity. System performance shows significant improvement in the Bit Error Rate.

As a future extension, the system design can take advantage of special multiplexing by using Space-Frequency coding.

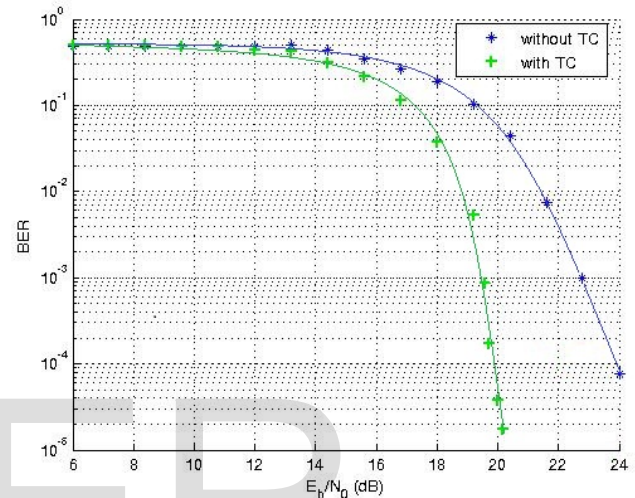


Fig. 3. BER performance comparison between the proposed system and conventional QO-STBC

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