Abstract—Orthogonal Frequency Division Multiplexing (OFDM) is a suitable candidate for high data rate transmission with Forward Error Correction (FEC) methods over wireless channels. Turbo codes are one of the best error correcting codes. In this paper performance of Turbo coded OFDM (T-COFDM) over uncoded & convolutional coded OFDM (C-COFDM) is compared in terms of Bit Error Rate (BER) versus Eb/No.

Index Terms—OFDM, Turbo Codes, Ber, Eb/No, Convolutional Codes

I. INTRODUCTION

Recently, orthogonal frequency-division multiplexing (OFDM) is becoming more popular in broad-band wireless communication areas [1]. In an OFDM scheme, a large number of orthogonal, overlapping sub-carriers are transmitted in parallel which divide the available transmission bandwidth and data can be recovered at the receiver by exploiting the orthogonality among the sub-carriers. The result of OFDM using a large number of narrowband sub-carriers is that each sub-carrier suffers from flat fading because the sub-carriers are subject to flat fading [1]. The attraction of OFDM is mainly due to how the system handles the multi-path interference at the receiver [2]. Due to these advantages, OFDM has become the physical layer of choice for many wireless and mobile communication standards, such as digital audio and video broadcasting (DAB/DVB), wireless local access networks (WLANs) and wireless metropolitan area networks (WMANs) [2]. Multi-path generates two effects such as frequency selective fading and inter-symbol interference (ISI), using powerful error correcting codes together with time and frequency interleaving yields robustness against frequency selective fading [4].

OFDM is a parallel transmission scheme, where high data rate serial data stream split into a set of low-rate sub streams, each of which is modulated on a separate SC (FDM). Thereby the bandwidth of the SCs become small compared with coherence bandwidth of the channel that is the individual SCs experience flat fading which allows for simple equalization[2]. This implies that symbol period of sub stream is made long compared to delay spread of the time dispersive radio channel.

By selecting special set of (orthogonal) carrier frequencies, high spectral efficiency is obtained because the spectra of SCs overlap. The IFFT & FFT are used in OFDM at transmitter & Receiver respectively as they are computationally efficient. This paper is organized as per following sections.

Section II explains Block diagram of OFDM. Section III illustrates the Turbo Encoder, Interleaver & Turbo Decoder. In section IV Turbo coded OFDM system is elaborated and in section V simulation results analysed.

II. BLOCK DIAGRAM OF OFDM

![Figure 1: Block Diagram Of OFdm Transceiver](image)

III. TURBO CODES

The Forney first proposed the idea of Concatenated coding scheme for achieving large coding gains by combining two or more relatively simple building blocks or component codes. A turbo code can be thought as a refinement of the concatenated encoding structure plus an iterative algorithm for decoding the associated code sequence.[5] Berrou along with two scientists introduced this code in 1993 [3]. For the proper working of turbo codes, soft decision decoding should be preferred over hard decision. Most designs follow the following ideas first the turbo encoders used are normally identical second the code is in systematic form and the interleaver reads the bits in pseudo-random manner. The choice of interleaver is a crucial part in the design of turbo coding [6].

A. Turbo Encoder

The structure of Turbo encoder is made up of RSC
coders and interleaver. The block diagram of encoder is shown in Figure 2. The given encoder has a code rate 1/3. As for single bit input two bits are produced at output of the encoder. The binary input data sequence is represented by $d_k = (d_1, ......., d_N)$. The input sequence is passed into the input of a convolutional encoder ENC1 and a coded bit stream, $x^p_{k+1}$ is generated. The same input sequence $d_k$ is passed through random interleaver to the Second convolutional encoder ENC2 and a second coded bit stream, $x^p_{k+2}$ is generated. The code sequence that is passed to the modulator for transmission is consisting of systematic code bits $x^p_k$ and parity bits from both the first encoder $x^p_{k+1}$ and the second encoder $x^p_{k+2}$.[7]

![Figure 2: Block Diagram Of Turbo Encoder](image)

- **RSC Components Codes:**
Convolusion codes uses feedback hence they are known as recursive and input sequence at the turbo Encoder is faithfully reproduced at the output side so systematic. Thus Encoder 1 and Encoder 2 are recursive systematic convolution codes (RSC). The encoder has two output sequence; One is the data sequence: $x^p_k = \{x^p_1, ......., x^p_N\}$. Other is the parity sequence: $x^p_{k+1} = \{x^p_1, ......., x^p_N\}$.

**B. Interleaver**
In an interleaver the input bits are permuted in a matrix, such that the interleaver output is a pseudo-random string of the input bits. This means that the input and output bits of the interleaver is the same just in a different temporal order. Interleaving plays an important role to avoid the burst error. Without the interleaver it is impossible to derive the message when a burst error corrupts a chunk of letters in the middle of the text [8].

Interleaving the text before sending it through a noisy channel spreads out the burst error and the text is much easier to derive after deinterleaving. In 3GPPs standardization of internal interleaver for turbo coding the permutation matrix is based on the number of bits per block. Functions based on prime numbers and modulus are used to make intra- and inter-row permutation to assure that each input bit is allocated to different indexes in the permutation matrix.

**C. Turbo Decoder**
The Block diagram of Turbo Decoder is shown in figure 3. The decoder also uses the parallel concatenated decoding scheme. The iterative decoding scheme uses the a posteriori probability (APP) decoder as the constituent decoder, an interleaver, and a deinterleaver. Decoder 1 & Decoder 2 use the same trellis structure and decoding algorithm.

![Figure 3: Block Diagram of Turbo Decoder](image)

The iterative decoding proceeds as follows. In the first iteration SISO 1 outputs the extrinsic information $\pi(u; O)$ on the systematic bit & first parity bit. Second bit is not used. After appropriate interleaving, the extrinsic information $\pi(u; O)$ from SISO 1 computed from equation (1) is delivered to SISO 2 as $\pi(u; I)$. Output of SISO 2 is $\pi(u; O)$ & $\pi(c; O)$ among which latter is not used. $\pi(u; O)$ after suitable deinterleaving, is delivered to SISO 1 as (a priori information) $\pi(u; I)$. Then new iteration will begin. After a precise no of iterations or better output is reached, the log likelihood $\pi(u; O)$ at the output of SISO 2 is deinterleaved & delivered to the hard decision devices, which in turn estimates the information bit based only on the sign of the deinterleaved LLR.[9]

**IV. TURBO CODED OFDM SYSTEM**
OFDM is the multi carrier modulation method in which single high data rate is divided in to multiple low rate data stream and modulated using SCs [1]. These SCs are orthogonal to each other. The main advantages of OFDM are its efficient spectral usage by allowing overlapping in the frequency domain and multi-path delay spread tolerance. Other significant advantage is that the modulation and demodulation can be done using IFFT and FFT operations, which are very efficient computationally. OFDM has become a very popular modulation method in high-speed wireless communications. OFDM is a suitable technology for high data rate transmission with FEC methods over wireless channels. The combination of turbo codes with the OFDM transmission is called T-COFDM. It can yield significant improvements in terms of lower energy needed to transmit data. There is a large potential gain in using the iterative property of turbo decoders where soft bit estimates are used together with the known pilot symbols.
V. RESULTS & SIMULATION

Since the main aim of this paper is to simulate the COFDM system by utilizing turbo codes. The block diagram of the entire system is shown in Figure 4. Here Block 1=turbo encoder, Block 2=16 QAM Modulation, Block 3=Serial to parallel converter, Block 4=IIFT, Block 5=Parallel To serial converter, Block 6=AWGN Channel, Block 7=Serial to parallel converter, Block 8=FFT, Block 9=Parallel to serial converter, Block 10=16 QAM demodulation and Block 11=turbo decoder.

In this section MATLAB simulation results are shown. The performance of turbo codes is evaluated in terms of BER. These simulations are conducted in the presence of AWGN channel and the modulation scheme used is 16-Quadrature Amplitude Modulation (QAM). The true APP algorithm is used in decoding. The BER plots for un-coded OFDM, C-COFDM Vs T-COFDM are shown in this section. In figure 5 a comparison is made between coded and un-coded data over AWGN channel. It is clear from the graph that with the use of coding scheme we can achieve better BER at less value of Eb/No as compared with the un-coded data. In the figure shown below T-COFDM provides a gain of approximately 2dB as compared with the C-COFDM & 1.5 dB as compared to uncoded OFDM.

In figure 6 a comparison is made between different types of coding schemes for various constraint lengths. It is showing that turbo codes provide better performance as compared with other techniques mentioned in this paper. It is concluded that turbo codes provide better error performance as compared with other schemes. It is also deduced that the no of iteration plays very important role in turbo decoding and presence of interleaver is much important in order to minimize the burst error.

REFERENCES


Performance Analysis Of Turbo Coded OFDM Over Uncoded & Convolutional Coded OFDM