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Enhancing Error Performance in OFDM System

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***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) provides high data rate transmission in the given bandwidth of the channel. The main problem with the OFDM system is that it is prone to the channel-induced noise that corrupts the data during transmission and thus the Bit Error Rate (BER) of the system increases. So Turbo encoder is proposed in this paper which implements channel coding thus adding redundancy in the message bits that helps to improve the BER of the system and ease reliable data transmission. Log-Map decoder is used for the decoding purpose that consists of two elementary decoders where each one calculates the extrinsic value in the log domain and exchanges information with each other that take place to come up with the more accurate detection of the transmitted data. Similarly the delay spread introduced between the signals during transmission and the filtering effect of the transmission system causes the symbols to interfere thus introducing the Inter Symbol Interference (ISI) which degrades the error-performance of the System. To cope with this problem, cyclic prefix is inserted at the start of the transmitted OFDM symbols to tone down the effect of ISI. Performance of Turbo Codes in OFDM System is observed for different digital modulation schemes in Additive White Gaussian Noise (AWGN) channel.**

***Index Terms*—Turbo Codes, OFDM, Inter Symbol Interference, AWGN and Log-Map Decoder**

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) [1] is a multi-carrier technique and is used nowadays in many applications like for Asynchronous Digital Subscriber Line (ADSL) and DSL broadband access, 802.11g/n, 802.16e (WiMAX) and 802.20 (MBWA), etc [2]. Its increased demand in digital communication is because it provides high data rate transmission in a given bandwidth of the channel thereby increasing the spectral efficiency. Because of OFDM, IEEE 802.11 data rate has increased to 54 Mbps from 11 Mbps [3].

OFDM has improved performance over FDM because of having multiple subcarriers modulated by data. These subcarriers have sin(x)/x spectrum and are orthogonal to each other. This Orthogonality between the subcarriers is provided by the Inverse Fast Fourier Transform (IFFT) [4] block at the transmitter side and can be proved between any two subcarriers by using the following property of Orthogonality

$$\int_0^T \sin(2\pi \mathrm{mt/T})\sin(-2\pi \mathrm{nt/T})\mathrm{dt} = 0, m \neq n$$

The subcarriers are modulated with the data symbols. So an OFDM symbol is comprised of data symbols from N subcarriers. To mitigate the effect of Inter Symbol Interference (ISI), guard interval with the length greater than the delay spread of the channel is introduced between the adjacent OFDM symbols. As the hardware usually processes signals in a continuous fashion, so the guard interval is never left empty but is filled with the cyclic prefix to prevent malfunctioning of the hardware.

In this paper encoder comprised of the parallel concatenated Recursive Systematic Convolutional (RSC) codes is integrated at the transmitter side of OFDM system, which encodes the message bits. These parallel concatenated convolutional encoders have usually small constraint length because an increase in constraint length introduces computational complexity and delay in turbo coding. In parallel concatenation, both encoders and decoders are synchronized with the same frequency clock [5]. At the receiver side the filtered signal is fed to the elementary decoders and the output is a soft decision by working on the signal's amplitude. The decoding is done iteratively between the two elementary Log-Map decoders. The error performance of the system is enhanced by increasing the number of iterations of the decoding process.

The remaining paper is organized as follows. In Section II, the OFDM system model is discussed. Section III presents Turbo Codes along with Turbo encoder and Log-Map decoder. The Simulation results are discussed in Section IV and concluding remarks are presented in Section V.

II. OFDM SYSTEM

The OFDM system model used in this paper is shown in the Figure 1.The randomly generated data is first passed through the Turbo encoder where redundancy is added to the bits to reduce the effect of noise that is induced by the channel and to make error detection and correction possible. The code rate of 1/3 is used and the generator matrix with the constraint length

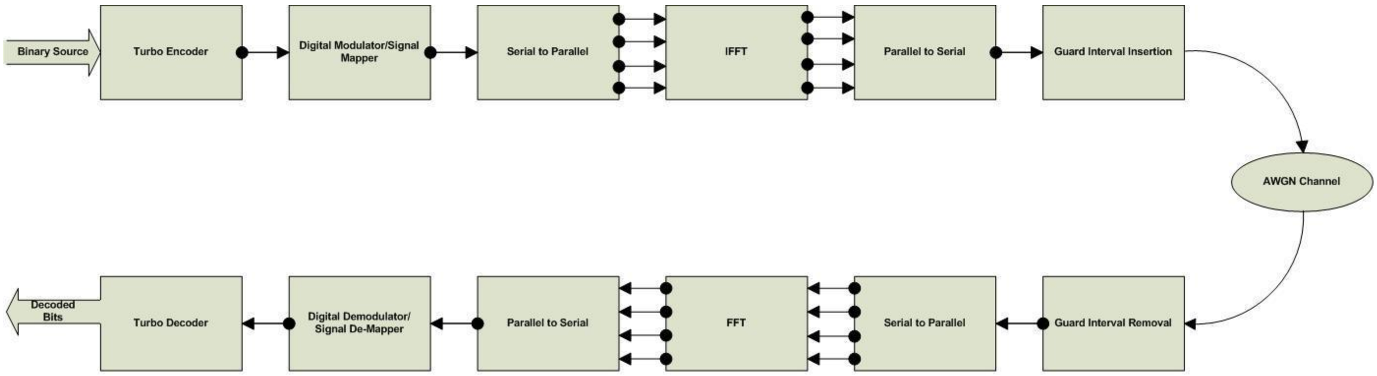

Fig. 1: Proposed Turbo-Coded OFDM System

K=3 is used. Thereafter, the encoded data is passed through signal mapper block where bits are grouped together and modulated by different digital modulation schemes. The data symbols are than passed through serial to parallel block where it is reshaped and then IFFT is applied. At the output of IFFT block $Z_k(M)$ OFDM symbol is generated which contains data symbols from each sub-carrier given as:

$$Z_k(M) = \{Z_k(0), Z_k(1), ..., Z_k(N-1)\}^T \qquad (1)$$

For the input signal *z(k)* with the sub-carriers k=0,1,2,…..N-1, the IFFT with size N produces at the instant k the OFDM modulated symbol by:

$$Z_k(M) = \frac{1}{N}\sum_{k=0}^{N-1} z(k) e^{-\frac{2\pi j}{N}} \qquad (2)$$

Thereafter, the OFDM symbol is passed through guard interval insertion block where cyclic prefix is added to it for combating the effect of ISI. The signal then passed through AWGN channel gets corrupted by noise. At the receiver side, first cyclic prefix is removed and after serial to parallel conversion it is passed through the OFDM demodulation block that is the FFT block. It is then brought back to serial form and then passed through signal de-mapper where it is digitally demodulated. At the end it is passed through turbo decoder block, which consists of two elementary decoder that exchanges extrinsic information with each other to reliably detect the data. The results are taken for different number of iteration of Log-Map decoder using different digital modulation schemes.

III. TURBO CODES

Turbo codes are Forward Error Correction (FEC) codes that show high performance that is close to the Shannon limit [6]. Its integration into the OFDM System has improved the error performance of system, resulting in the reduction of energy requirement for transmitting data. It was first introduced in 1993 by Claude Berrou *et al.* [7] and by then it has been worked to achieve near Shannon's bound performance by increasing the complexity of decoding algorithms. The interleaving of data at the encoder side and iterative decoding has helped it to achieve high error correction performance in a system [7-9]. Turbo codes have been introduced in Parallel Concatenated Convolutional Codes (PCCC) configuration and Serially Concatenated Convolutional Codes (SCCC) configurations. PCCC have RSC codes concatenated in parallel and have better performance at lower Signal-to-Noise Ratios (SNR). While SCCC have only the inner code as RSC code, it shows better performance at high SNRs [10]. In this paper PCCC configuration is used. Encoding of the data is done by using PCCC and decoding is done iteratively by using divide and conquer strategy via Log-Map decoding algorithm. By increasing the iterations, the decoder comes up with more accurate detection of data and, therefore, resembles with the turbo engines used in various vehicles now-a-days that is why it is named as Turbo Codes.

A. Encoding

For the encoding purpose Turbo encoder is used in this paper which is formed by the parallel concatenation of two RSC encoders having an S-random interleaver between them as shown in Figure 2. In [11], different interleavers performance is evaluated and the S-random interleaver outperformed in that. The interleaver purpose is to scramble the data bits for the encoder EC2 so the output of EC1 and EC2 is different and to make possible divide-n-conquer strategy at the decoder side. The input bit stream $B_k = \{B_0, B_1, ..., B_N\}$ is passed through the turbo encoder where the two RSC encoders EC1 and EC2 generate the parity bit streams $C_k^1 = \{C_0^1, C_1^1, ..., C_N^1\}$ and $C_k^2 = \{C_0^2, C_1^2, ..., C_N^2\}$ respectively. For generating the parity bit streams the RSC encoder use the generator matrix [1 1 1 1;1 1 0 1] [12].

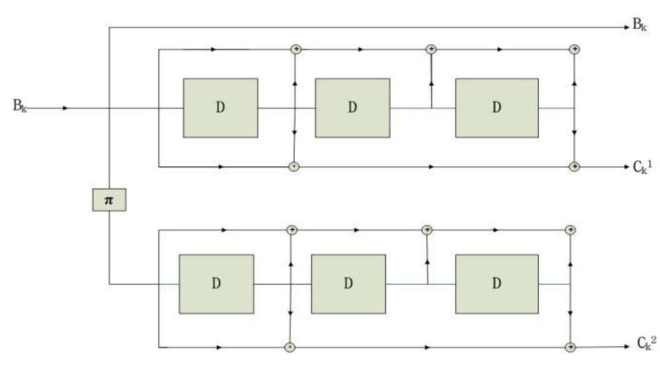

Fig. 2: Turbo Encoder with the code rate of 1/3

So at the output of turbo encoder with the code rate 1/3 we have the following bit stream X= {$B_0\, C_0^1\, C_0^2\, B_1\, C_1^1\, C_1^2\, B_2\, C_2^1\, C_2^2$.....}, the superscript indicates the parity bit from the corresponding encoder and the subscript indicates the time index.

B. Turbo decoding

For the decoding purpose of Turbo Codes in this paper, Log-Map decoder is used. The Log-Map decoder is comprised of two elementary decoders separated by an interleaver as shown in Figure 3 [12]. Each one uses Log-Map algorithm and calculates the Log-likelihood ratio also called the extrinsic information or a-posteriori value. The interleaved/de-interleaved version of this extrinsic information called the a-priori value is fed to the elementary decoders along with their corresponding systematic and parity bit for calculating their own extrinsic information. So there is a continuous exchange of this extrinsic information for specified number of iteration between the two component decoders and at the end the DEC2 outputs a hard decision of bits. The Log-Map decoder calculates the Log-likelihood ratio by dividing the trellis diagram into two paths, the best path with the probability of one and the best path with the probability of zero, then it finds the Log-likelihood ratio of these two paths separately and finds there difference to find the extrinsic information.

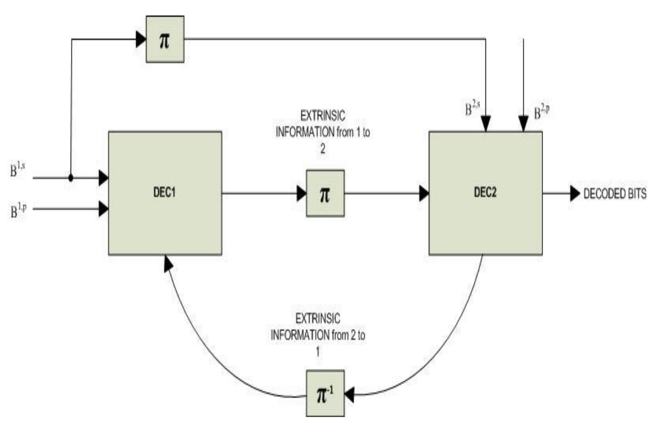

Fig. 3: Turbo Log-Map Decoder comprised of two component Decoders

IV. SIMULATION RESULTS

The simulation for our Turbo Coded OFDM System is done in MATLAB 7.0 ® using different digital modulation schemes for different iterations of Log-Map decoder which is discussed as follow:

A. Uncoded OFDM

For the Uncoded OFDM, the OFDM Symbol with 512 subcarriers is taken. The guard interval length of 128 subcarriers is chosen to combat the effect of ISI.

Figure 4 shows the simulated curves for the Uncoded OFDM. It is observed that the performance degrades as we move towards the higher modulation schemes; the reason for this degradation is the close placement of data symbols in a

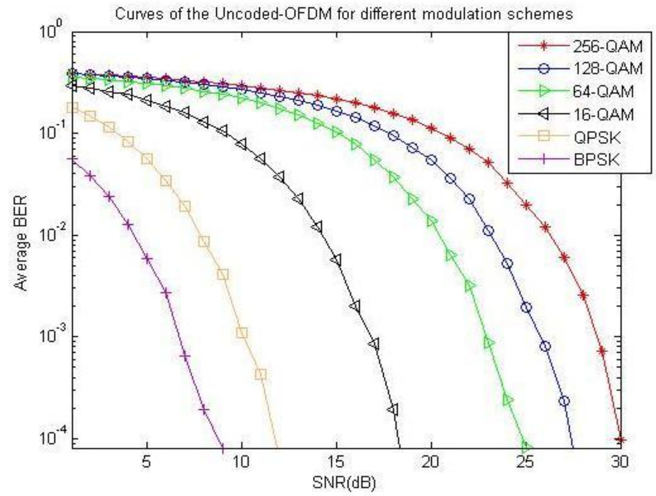

Fig. 4: Uncoded-OFDM for different digital modulation schemes

constellation diagram which brings the decision boundaries close to each other resulting in the error performance degradation.

B. Turbo Coded OFDM

Now Turbo Codes is incorporated with the same OFDM system as discussed above and the new system performance is observed for the same digital modulation schemes using different number of iterations of Turbo decoder. We will also discuss the importance of iteration in achieving more coding gain for the same BER. 1, 2, 4, 8 and 20 iterations of Log-Map decoder are used to attain an appropriate coding gain.

When Figure 5 is compared with Figure 4, we see that by increasing the number of iterations, the coding gain is increased which improves the error performance of the system. This is because of the sharing of extrinsic information also called Log-Likelihood ratio between the two elementary decoders that helps to improve the error correction performance of the system by increase in iterations. For the BER of 10e-2.6, coding gain of 3.1 dB is achieved from 8 iterations. The number of iterations is fixed to 7 in WiMAX technology.

The SNR vs BER curves of the QPSK shown in Figure 6 have the same trend as of BPSK curves. The simulated results for 16-QAM, 64-QAM, 128-QAM and 256-QAM with the same parameters of Turbo-Coded OFDM System are shown in Figures 7, 8, 9 and 10. When these figures compared with [13] at the BER of 10e-3 shows approximately coding gain of 3.9 dB for BPSK, 3.1 dB for QPSK, 1 dB for 16-QAM and 2.3 dB for 64-QAM for 2-iterations of Log-Map decoder. These figures when compared with Figure 4 show that as we shift to higher modulation schemes, the increase in coding gain is more when compared to the lower modulation schemes. This is because of increased chances of error in the higher modulation schemes resulting in less coding gain by using Turbo Codes as compared to previous modulation schemes. The specific modulation schemes can be chosen by the system designer based on the factors like bandwidth, complexity, data rate, throughput, etc because they are linked with each other.

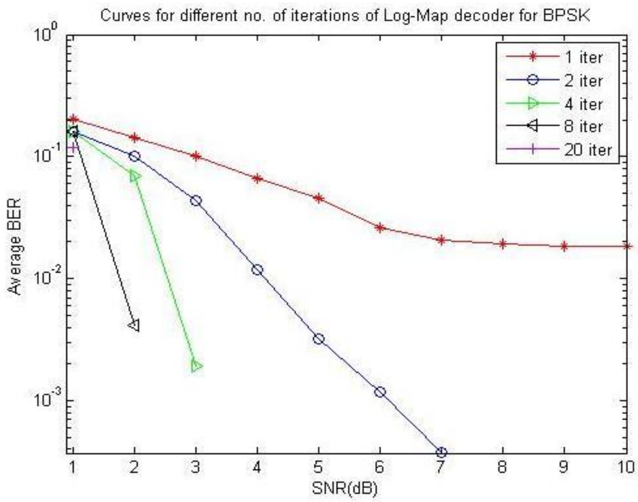

Fig. 5: Turbo Coded OFDM for BPSK Modulation

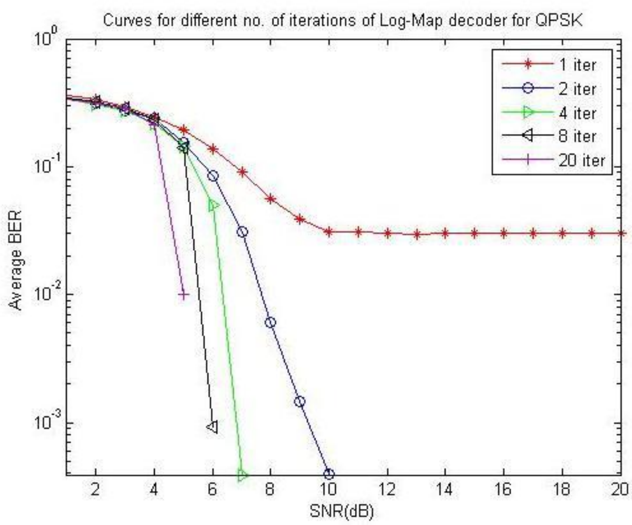

Fig. 6: Turbo Coded OFDM for QPSK Modulation

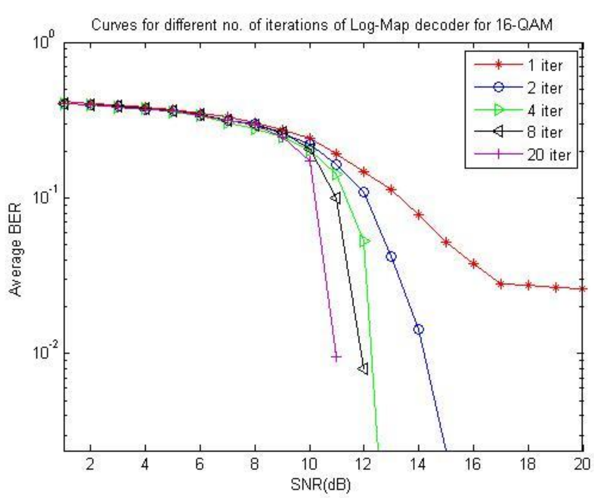

Fig. 7: Turbo Coded OFDM for 16-QAM Modulation

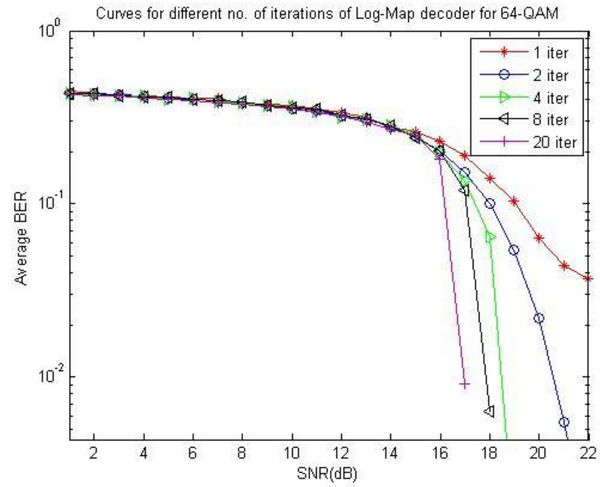

Fig. 8: Turbo Coded OFDM for 64-QAM Modulation

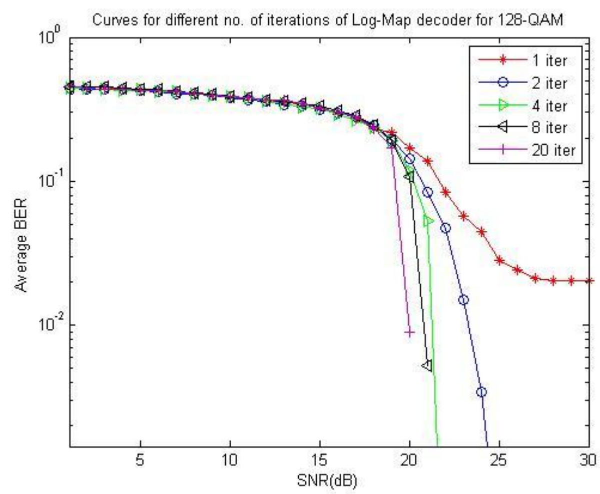

Fig. 9: Turbo Coded OFDM for 128-QAM Modulation

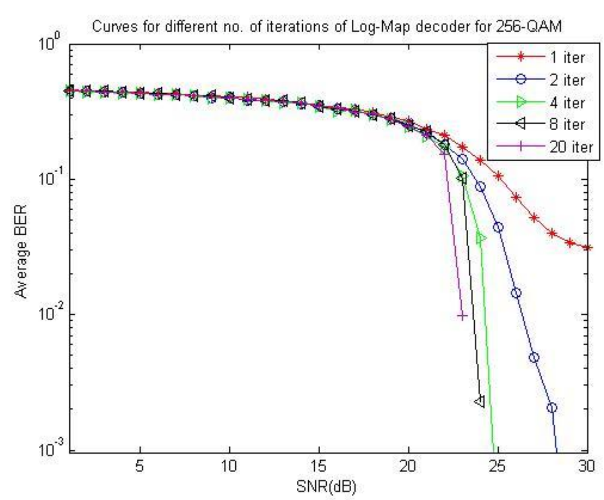

Fig. 10: Turbo Coded OFDM for 256-QAM Modulation

V. CONCLUSION

The Average BER versus SNR curves for different iterations of Log-Map decoder is obtained for different digital modulation schemes. It is seen that Turbo Codes have significantly improved the error performance of OFDM system by achieving large coding gains. Similarly the error performance degradation and larger coding gain is obtained as we move towards the higher digital modulation schemes. The performance degradation is mainly because of the close placement of modulated symbols that results in more chances of error.

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