# Tourbo Codec OFDM for SDR Application in AWGN channel

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***Abstract*—** In this paper, we propose convolutional turbo codec OFDM for SDR application, due to its excellent error correction and transmission speed. The SDR throughput under a desired bit error rate of an OFDM system has been enhanced by adding convolutional turbo code. The simulation is done over AWGN channel with BPSK, QPSK, 16-QAM scheme.

***Keywords***-Bit error rate; Orthogonal frequency division multiplexing; Turbo code; Software defined Radio

## I. INTRODUCTION

There is a growing need for quick and accurate transmission of information in wireless mode. In the 1980s, Orthogonal Frequency Division Multiplexing (OFDM) has been studied for high speed modems [1], digital mobile communications [2] and high-bit rate digital subscriber lines (HDSL)[3]. With technological advances, OFDM has become a standard to achieve high data rates. The primary advantages of OFDM are its multipath delay spread tolerance and efficient spectral uses by allowing overlapping in the frequency domain. The use of IFFT and FFT in OFDM makes it computationally efficient [4]. In OFDM a large number of low bit rate carriers are transmitting in parallel using synchronized time and frequency, forming a single block of spectrum [5, 6].

The present work uses turbo code as the forward error correction code to achieve near Shannon's limit in the turbo cliff region. Here we use parallel concatenated convolutional codes (PCCC) [7, 8, 9, 10] and term it as convolutional turbo code (CTC). In turbo code, the non systematic code transform to systematic codes[11, 12, 13]. By using soft input soft output (SISO) decoding instead of hard decision decoding, the decoder uses the probabilities of the received data to generate soft output which is similar to the transmitted bit. Due to its excellent error correction performance this code find applications in W-CDMA, UMTS, CDMA 2000, DVB RCS, IEEE 802.16E,Wi-Max, for voice and data transmission.

The term 'software radio' was proposed by a team at the Garland Texas Division of E- systems Inc. (now Raytheon) in 1985 [14]. This Radio was a digital baseband receiver that provided programmable interference cancellation and demodulation for broadband signals. The first readymade software-defined radio was introduced by Peter Hoeher and Helmuth Lang, in 1988, at the German Aerospace Research Establishment in Germany. The first paper on this topic was published in 1992 [15] by Joseph Mitola. Mitola envisioned an ideal software radio, with radio hardware consisting of just an antenna and analog-to-digital converter (ADC) on the receive side, and digital-to-analog converter (DAC) and antenna on the transmit side, with all other processing being handled via reprogrammable processors. As this system is not completely realizable so in Europe and USA the defence sectors partially adopted this type of software in their communication devices.

SpeakEasy [16] was one of the first public software radios used by the US military to emulate 10 existing military radios, operating in frequency bands between 2 MHz and 2 GHz by use of programmable processing. For which they could easily incorporate new coding and modulation standards. In the SpeakEasy project there were two phases; in first phase (From 1992 to 1995) the problem initiated due to its cryptographic processor could not change content fast enough to keep several radio conversations on the air at once. The aim of the second phase was to make this software radio smaller, light weight and cheaper. Also they tried to make this radio reconfigurable for which several conversations are done at once by the help of open software architecture. This type of radio went into production within the 4 MHz to 400 MHz range only at that time.

During 2002, GNU Radio was formed to provide a means to bypass the perceived threat of the United States (US) Federal Communications Commission (FCC) broadcast flag (an instruction to the copying or distributing device) [17, 18]. In this system all non-exempt devices are obliged by US law.

For wireless applications Blaickner *etal*[19] Presents selected baseband processing and error correction solution by using a WCDMA transceiver. The concept and the prototype of the units was designed and verified by high level design methods.

A doctoral thesis[20] is available for measuring memory and processor use for a SDR based on the OSSIE framework running on a Linux based computer. The work in this thesis provides background on tools and techniques that are useful for other platforms for evaluating SDR systems. Implementation of a software defined radio (SDR) based on state-of-the art digital signal processors (DSPs), which are linked serially to PCs has also been investigated. Some scientists had contributed to hardware agnostic SDR API [21].

The ultimate goal of Software Radio is to provide a single radio trans-receiver which can play the roles of cell phone, wireless fax, wireless videoconferencing unit, wireless Web browser, Global Positioning System (GPS) unit, and other functions, operable from any location on the surface of the earth, and as well as in space [22]. That is SDR is flexible to support all transmission technologies like GSM, CDMA, UMTS, HSPA etc. Keeping these in views for SDR application, this work purposes channel coding using turbo code with OFDM, for error correction in any band of consideration and to get high transmission data rate.

## II. TURBO ENCODING AND DECODING

### A. Turbo encoding

Figure 1 shows a block diagram of the encoder, which precedes the digital modulator. The encoder for a turbo code is a parallel concatenated convolutional code. The binary input data sequence is $d_k = (d_1....d_N)$. This input sequence passes into the input of a recursive systematic encoder 1 which generates a coded bit stream, $x_{k1}^p$. Then the input data sequence is interleaved, i.e. the bits are read out in a pseudo-random manner so as to spread the positions of the input bits. The interleaved data sequence is passes through a second recursive convolutional (RSC) encoder 2 to generate second coded bit (parity bit) stream, $x_{k2}^p$**.** The outputs from both RSC encoders are then punctured in the next block. This puncturing is necessary for two reasons: (i) the coded bits need to fit the available bits in the physical channel for rate matching. (ii) to make different redundancy versions by adding more parity bits when the decoder fails to decode the transmitted bits. Further Puncturing can also prioritize between systematic bits and parity bits. Besides the systematic bits, the puncturer output is the other input to the multiplexer. The multiplexer output is the generated turbo code.

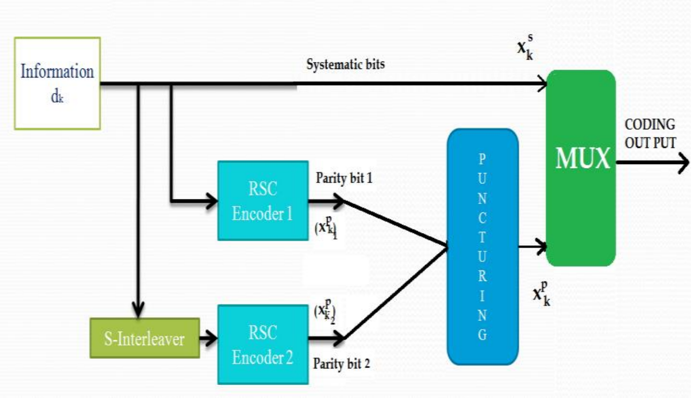

Figure 1. Structure of a turbo encoder

### B. Turbo decoding

Figure 2 shows the block diagram of a turbo decoder, which succeeds the de-multiplexor following the digital demodulator. The input to the decoder i.e. output of the de-multiplexor is a sequence of received code, $R_k = \{y_k^s, y_k^p\}$ obtained from the demodulator [8, 23, 24]. The turbo decoder consists of two component decoders *DCO*1(to decode sequences from *RSC Encoder* 1), and *DCO*2 (to decode sequences from *RSC Encoder* 2). Each of these decoder uses Max-Log-MAP algorithm for decoding. The soft input soft output decoder *DCO*1 takes as its input the received sequence of systematic values $y_k^s$ and the received sequence of parity values $y_{k1}^p$ belonging to the first RSC encoder 1. The output of *DCO*1 is a sequence of soft estimates *EXTN*1 of the transmitted data $d_k$. *EXTN*1 and *EXTN2* are fully uncorrelated and are known as extrinsic data. The interleavers, interleave this information in an identical manner to the encoder (Figure 1), which then goes to the second decoder *DCO*2. The inputs of *DCO2* consists of systematic received values $y_k^s$, sequence of received parity values $y_{k2}^p$ (from the second RSC encoder 2) and the interleaved form of the extrinsic information *EXTN*1(provided by the first decoder). De-interleaving the outputs of *DCO*2 using an inverse form of interleaver, results in soft estimates *EXTN*2 of the transmitted data sequence $b_k$. This extrinsic data is fed-back to *DCO*1. This decoding process iterates which improves the BER performance of the Turbo codes, since the estimates of two decoders start converging to $b_k$ after several iterations.

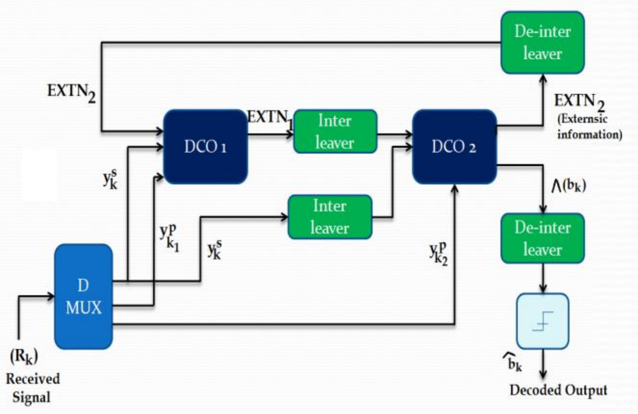

Figure 2: Block diagram of Turbo Decoder

On convergence *DCO*2 outputs a value $\Lambda(b_k)$( a log likelihood representation of the estimate of $b_k$). This log likelihood value takes into account the probability of a transmitted '0' or '1' based on systematic information and parity information from both component codes. More negative values of $\Lambda(b_k)$ represent a strong likelihood that the transmitted bit was a '0' and more positive values represent a strong likelihood that the transmitted bit was a '1' was transmitted. $\Lambda(b_k)$ is de-interleaved so that its sequence coincides with that of the systematic and first parity streams. At the end a simple threshold operation on the result produces hard decision estimates( $b_k$) of the transmitted bits.

## III. TURBO CODED OFDM

In the Coded OFDM (COFDM) system the error control coding and OFDM modulation processes work closely together[6, 25]. Addition of a guard band, to the start of each symbol, further improves the effect of ISI on an OFDM signal. This guard period is a cyclic copy that extends the length of the symbol waveform. The application of guard band does not minimize the effects of noise and multipath fading in the channel. Therefore the transmitted signal arriving at the receiver also contains burst error. The BER(which is inversely proportional to transmitting power and directly proportional to the symbol rate) characterizes the errors in the demodulated data. Thus, protection of the data from bursty transmission errors, needs efficient channel coding (error correction coding) for design of a communication system with an acceptable BER. However, uncoded OFDM systems do not perform well in fading channels. Use of an interleaving technique along with coding may result in the independence among errors by affecting randomly scattered errors. We use the combination of convolutional turbo codes with the OFDM transmission is so called convolutional Turbo Coded OFDM (CTC-OFDM). This code can give significant improvements in terms of lower energy needed to transmit data and excellent error correction, in personal communication devices.

## IV. SIMULATION AND ANALYSIS

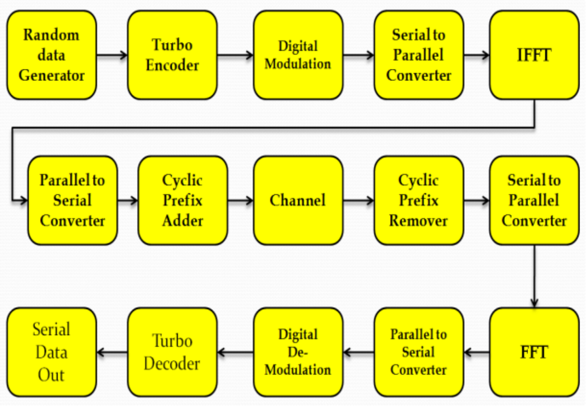

Figure 3: Turbo coded OFDM model

### A. *Simulation parameters*

| parameters | values |
|---|---|
| Modulation scheme | BPSK, QPSK, 16-QAM |
| Turbo code rate | 1/2 |
| SISO decoder | Max-Log- MAP |
| Code generator | {11111,10001} |
| interleaver | Pseudo random |
| Channel | AWGN |

Table 1: Simulation parameters

### B. *Algorithm for Simulation*

We evaluate the performance of CTC-OFDM (Figure 3) through MATLAB simulation. The simulation follows the following process.

1. Random generation of information bits.
2. Use of RSC turbo encoder with the specific generator matrix to encode the information bits.
3. Modulating encoded bits using BPSK/QPSK/16-QAM modulation.
4. Conversion of Serial bits to parallel bit stream.
5. Generation of OFDM signals with zero padding using IFFT .
6. Serial transmission of signal using parallel to serial convertor.
7. Introduce noise to simulate AWGN channel errors.
8. Perform reverse operations for decoding the receive sequence at the receiver side.
9. Compare the decoded bit sequence with the original one to count numbers of erroneous bits.
10. Plot BER versus $E_b/N_0$ from that calculated error.

### C. *Results and Discussion*

The results from different simulations show the performance of the proposed codec for improving the SNR (approaching the Shannon limit of 2.5dB) in achieving a reference BER of $10^{-5}$. The Figure 4 and table 2 show that for uncoded transmission the BER is more than$10^{-2}$ with SNR of about 7dB. But using single iteration Turbo code with BPSK it approaches BER of $10^{-5}$ with an improvement in SNR(5 dB). The SNR further improves to around 4 dB after 3 and 5 iteration without any significant effect of BER. After the 10th iteration there is substantial improvement in SNR (of around 2.6 dB). This indicates that the uncoded transmission is disadvantageous in comparison to the turbo codec BPSK transmission in AWGN channel, because of high SNR which can result reduced longevity of battery.

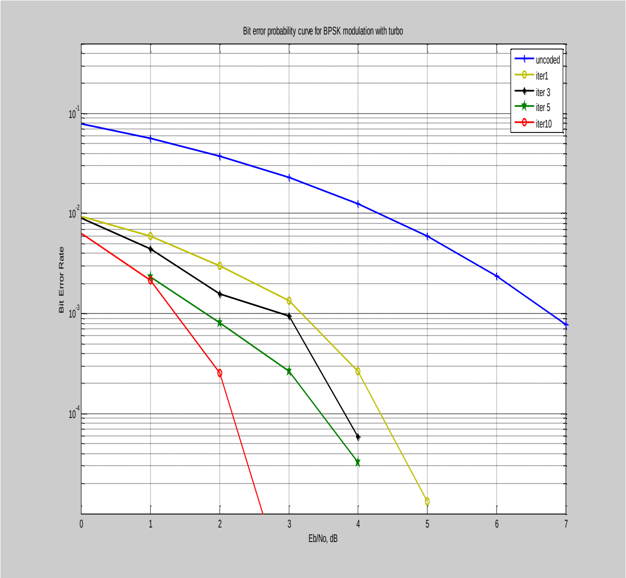

Figure 4: Effects of iterations on BER performance using Turbo code in AWGN channel

| Iteration performed | SNR for $10^{-5}$ BER in dB |
|---|---|
| Un-coded | **>7** |
| 1 iteration | ~5 |
| 3 iteration | >4 |
| 5 iteration | >4 |
| 10 iteration | ~2.6 |

Table 2: SNR comparison of different iterations for Turbo code under AWGN channel

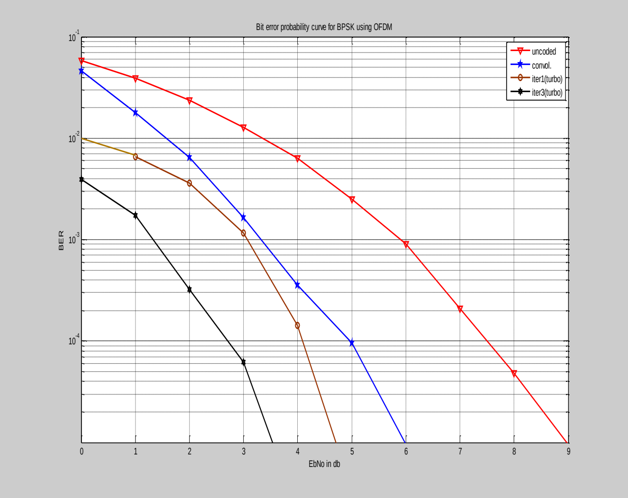

Figure 5: Effects of iterations on BER performance using Turbo codec OFDM and convolutional code with BPSK in AWGN channel

The Figure 5 and table 3 show that for uncoded transmission with OFDM and BPSK the BER is about $10^{-5}$ with SNR about 9dB. After implementing convolutional code we are able to achieve same BER at reduced SNR of 6dB. By using single iteration turbo codec OFDM with BPSK The

SNR further improves to 4.6 dB to achieve the reference BER of $10^{-5}$. The SNR reduced about 3.5dB by implementing turbo code with 3 iteration. Hence turbo codec OFDM, with BPSK modulation give performance improvements of 5.5 dB with 3 iteration over the un coded system.

| **Coding technique use** | **SNR for $10^{-5}$ BER in dB** |
|---|---|
| Un coded | ~9 |
| Convolutional coded | ~6 |
| Turbo coded(iteration 1) | ~4.6 |
| Turbo coded (iteration 3) | ~3.5 |

Table 3: SNR comparison of different iterations for Turbo coded OFDM under AWGN channel with BPSK modulation

The Figure 6 and table 4 show the uncoded transmission with QPSK modulation achieved the reference BER of $10^{-5}$ at SNR 11.5 dB. For SNR of around 3dB the uncoded transmission has better performance than the convolutional coded transmission. As the SNR increases convolutional code gives better performance than the uncoded one. Single iteration turbo code with QPSK achieves the same BER at SNR of 7.3 dB. The SNR further improves to around 6.9 dB in 3 iterations without any significant effect of BER. It shows that turbo codes with QPSK modulation using 3 iterations improves performance by 5 dB over the conventional codes.

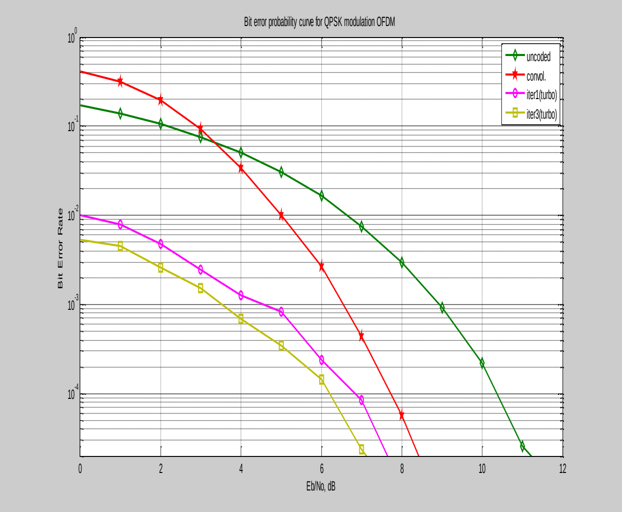

Figure 6: Effects of iterations on BER performance using Turbo codec OFDM and convolutional code with QPSK in AWGN channel

| **Coding technique use** | **SNR for $10^{-5}$ BER in dB** |
|---|---|
| Un coded | ~11.5 |
| Convolutional coded | ~8.5 |
| Turbo coded(iteration 1) | ~7.3 |
| Turbo coded (iteration 3) | ~6.9 |

Table 4: SNR comparison of different iterations for Turbo coded OFDM under AWGN channel with QPSK modulation.

The Figure 7 and table 5 show that for uncoded transmission the BER is $10^{-5}$ with SNR of about 19.5 dB. The BER of uncoded QAM shows better performance than the convolutional code while SNR is below 12 dB, after which there is a significant change resulting in the same BER with SNR of 16.5 dB. Single iteration Turbo code with 16-QAM approaches BER of $10^{-5}$ and improves SNR to 8.5 dB. As the number of iterations increases to 3, the SNR reduces to 7dB to achieve reference BER of $10^{-5}$. Hence the use of turbo codec OFDM with 3 iteration and 16-QAM, can give performance improvements of 12.5 dB over the uncoded system.

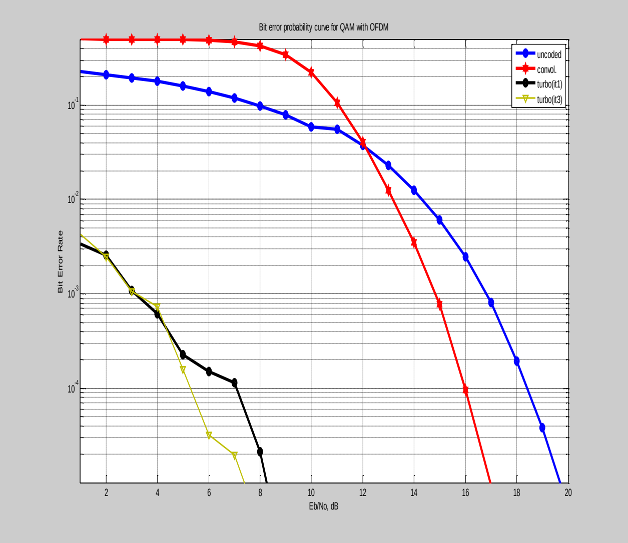

Figure 7: Effects of iterations on BER performance using Turbo codec OFDM and convolutional code with 16-QAM in AWGN channel

| **Coding technique use** | **SNR for $10^{-5}$ BER in dB** |
|---|---|
| Un coded | ~19.5 |
| Convolutional coded | ~16.5 |
| Turbo coded(iteration 1) | ~8.5 |
| Turbo coded (iteration 3) | ~7 |

Table 5: SNR comparison of different iterations for Turbo coded OFDM under AWGN channel with 16-QAM modulation

## V. CONCULSION

This paper has discussed a complete turbo coding using recursive systematic convolutional code. This concept is then tied with OFDM with target based modulation scheme. The entire simulation is done on MATLAB. First we developed an OFDM system model then try to improve the performance by applying forward error correcting codes to our un-coded system. From the study of the system, it can be concluded that we are able to improve the performance of un-coded OFDM by convolutional turbo coding scheme. Due to all the algorithms of CTC-OFDM (a) are written in software, (b) gives excellent error correction (low BER with low SNR), and (c) OFDM in the algorithm gives faster communication, so we think that it can be implemented in software defined radio application for future communication.

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