Performance of Turbo Encoder and Turbo Decoder using MIMO Channel

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Abstract: ***LTE (Long Term Evolution) is the upcoming standards towards 4G, which is designed to increase the capacity and throughput performance when compared to UMTS and WiMax. Turbo codes are a high performance forward error correction at a given code rate. The principle of turbo code permits near approach to Shannon limit, which describes the maximum capacity of the channel. The decoder systems are compared for complexity as well as for equal numbers of iterations. The following figure shows the bit error rate performance of the parallel concatenated coding scheme in an AWGN channel over a range of Eb/No values for two sets of code block lengths and number of decoding iterations. Results show that less complex decoder strategies produce good results for voice quality bit error rates. Simulation of Turbo Encoder and Viterbi Decoder with soft and hard decoding a posterior probability (APP) Decoder has been implemented in Matlab. The result of the Viterbi Decoder using Soft Decision is better than that of the Viterbi Decoder using Hard Decision in terms of the Bit Error rate (BER). Also the simulation of PCC Turbo Coder and APP Decoder was performed and the comparison shows that performance `with MIMO channel is found to be better than without MIMO.***

Keywords: Convolutional Interleaver, Turbo encoder, Turbo decoder, MAP decoder, 3GPP LTE Advanced, OSTBC Encoder

1. LTE Advanced Introduction

LTE-Advanced (LTE-A) is the evolved version of LTE that is being developed by 3GPP [1]. LTE-A will meet or exceed the requirements of the International Telecommunication Union (ITU) for the fourth generation (4G) radio communication standard known as IMT-Advanced. LTE-Advanced is being specified initially as part of Release 10 of the 3GPP specifications, with a functional freeze targeted for March 2011. The LTE specifications will continue to be developed in subsequent 3GPP releases.

Long Term Evolution offers some excellent advantages over current 3G systems including higher throughput, plug and play compatibility, FDD (Frequency Division Duplexing) and TDD (Time Division Duplexing), low latency and lower operating expenditures. It also offers legacy modes to support devices operating on GPRS systems, while supporting seamless pass through of technologies operating on other older cellular towers.

The aggressive performance of LTE depends on the physical layer technologies like Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO) systems, correct antennas to attain these target levels. The main target is to reduce the system complexities and provide adaptable spectrum deployment in new or existing frequency spectrum and enabling the co existence with 3GPP Radio Access Technologies (RATs).

LTE-A builds on the LTE OFDM/MIMO architecture to further increase data rate. It is defined in 3GPP releases 10 and 11. There are five major features: carrier aggregation, increased MIMO, coordinated multipoint transmission, heterogeneous network (HetNet) support, and relays. Carrier aggregation combines up to five 20-MHz channels into one to increase data speed. These channels can be contiguous or non-contiguous as defined by the carrier's spectrum assignments. With maximum MIMO assignments, 64QAM, and 100-MHz bandwidth, a peak downlink data rate of 1 Gbit/s is possible. LTE-A is forward and backward compatible with basic LTE, meaning LTE handsets will work on LTE-A networks and LTE-A handsets will work on standard LTE networks.

2. Turbo Codes Introduction

Turbo codes were first introduced in 1993 by Berrou, Glavieux, and Thitimajshima, [3] where a scheme is described that achieves a bit-error probability of 10-5 using a rate 1/2 code over an additive white Gaussian noise (AWGN) channel and BPSK modulation at an *Eb/N*0 of 0.7 dB. The codes are constructed by using two or more component codes on different interleaved versions of the same information sequence.

Turbo codes are a high performance forward error correction at a given code rate. These codes are especially used in deep space satellite communication and the application, which requires reliable transformation of information over the communication links in the presence of data corrupting noise. At present, these codes are competing with Low Density Parity Check (LDPC) codes, which produce similar performance.

Turbo code implementation is by a parallelconcatenation of two recursive systematic convolutional encoder codes depend on pseudo-random permutation (the interleaver). The encoder performs a long bit information frame. The interleaver to produce permuted frame interleaves this input bit. The first encoder RSC1 encodes the original input and the interleaved frame (permuted frame) is encoded by RSC2. Then the two encoded bits are merged together with the real input bits to produce the output.

2.1 Fundamental Turbo Codes

The fundamental turbo code encoder is built using two identical recursive systematic convolutional (RSC) codes with parallel concatenation [4] as shown in Figure 1.

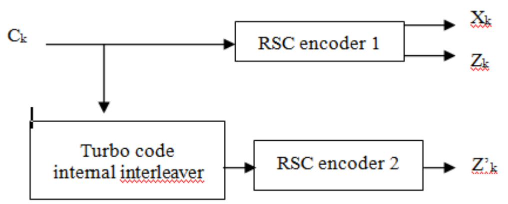

Figure 1: Fundamental of Turbo Codes

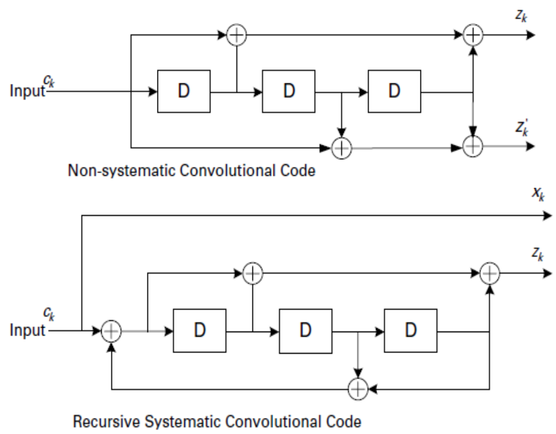

Figure 2: Conventional convolutional encoder and equivalent RSC encoder [3]

An RSC encoder is typically a rate 1/2 encoder and is termed a constituent encoder. The input to the second constituent encoder is interleaved using an internal turbo code interleaver. Only one of the systematic outputs from the two component encoders is used. This is because the systematic output from the other component encoder is just a permuted version of the chosen systematic output.

Table 1.1: Requirements for IMT-Advanced and LTE-Advanced [2]

Parameter	IMT-Advanced	LTE-Advanced	LTE
Peak data rate	1 Gbps DL 500 Mbps UL	1 Gbps DL 500 Mbps UL	300 Mbps DL 75 Mbps UL
Bandwidth	60 MHz	100 MHz	20 MHz
User Plane latency	10 ms	10 ms	10 ms
Control Plane Latency	100 ms	50 ms	100 ms
Peak Spectral Efficiency	15 bps/hz DL 7.5 bps/Hz UL	30 bps/Hz DL 15 bps/Hz UL	15 bps/Hz DL 3.75 bps/Hz UL
MIMO	4X4 DL 2X4 UL	8X8 DL 4X4 UL	4X4 DL N/A

DL- Downlink UL-Uplink

3. Turbo Decoder Structure

In this section the iterative decoding process of the turbo decoder is described. The maximum a posteriori algorithm (MAP) is used in the turbo decoder [4].

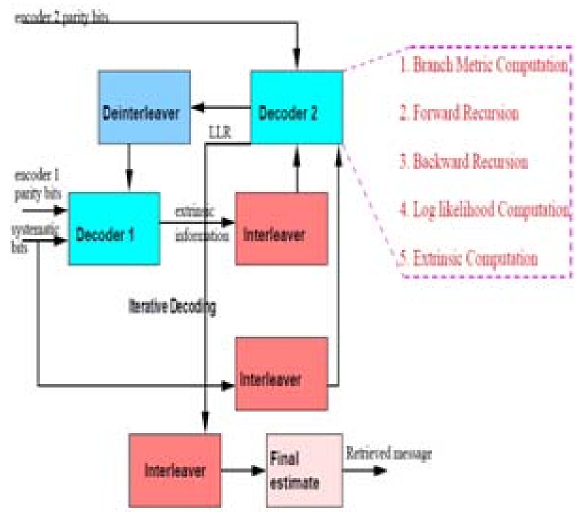

Figure 3: Decoder schematic diagram

There are three types of algorithms used in turbo decoder namely MAP, Max-Log-MAP and Log-MAP. The MAP algorithm is a forward-backward recursion algorithm, which minimizes the probability of bit error, has a high computational complexity and numerical instability. The solution to these problems is to operate in the log-domain. One advantage of operating in log-domain is that multiplication becomes addition. Addition however is not straight forward. Addition is a maximization function plus a correction term in the log domain. The Max-Log-MAP algorithm approximates addition solely as maximization. Max-Log-MAP algorithm in turbo decoder is used in our work.

4. Convolutional Interleaver

A convolutional interleaver consists of N rows of shift registers, with different delay in each row [5]. In general, each successive row has a delay which is J symbols duration higher than the previous row as shown in Fig. 4. The code word symbol from the encoder is fed into the array of shift registers, one code symbol to each row. With each new code word symbol the commutator switches to a new register and the new code symbol is shifted out to the channel. The i-th ($1 \le i \le N-1$) shift register has a length of (i-1)J stages where $J = M/N$ and the last row has M-1 numbers of delay elements.

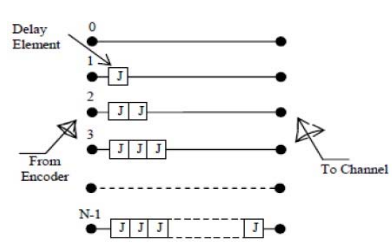

Figure 4: Convolution Interleaver

5. Software Model of Turbo Codes

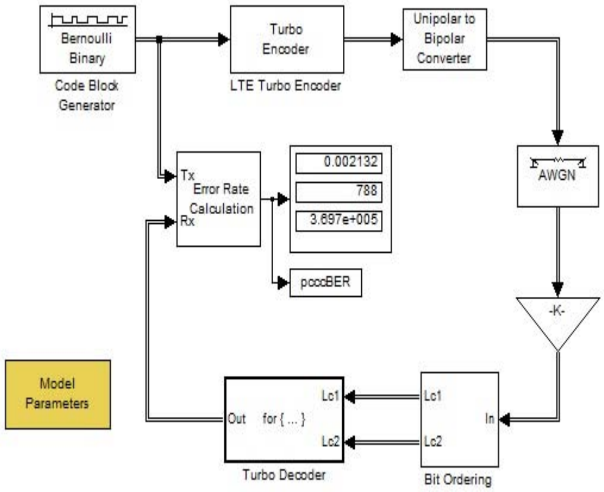

Figure 5: Parallel Concatenated Convolutional coding: Turbo codes [6]

5.1 BER Performance of PCC Codes

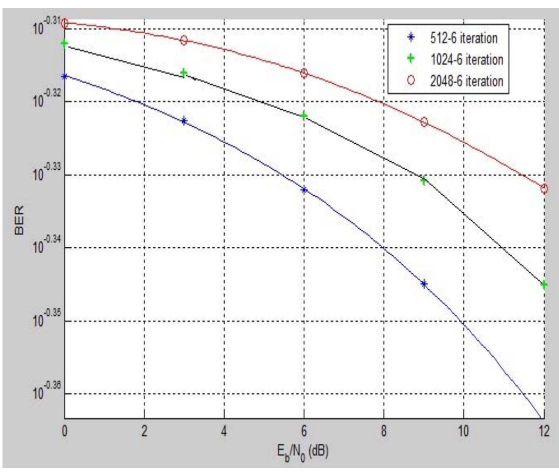

Figure 6: Plot of BER vs Eb/No for Iterative Decoding

Table 2: Results of PCCC

Block length	*512*	*BER-1024*	*BER-2048*
Eb/No	*BER*		
0	0.4825	0.4875	0.4906
3	0.4757	0.4829	0.4879
6	0.4655	0.4765	0.4829
9	0.4519	0.4668	0.4755
12	0.4327	0.4517	0.4657

5.2 Calculation Equation [8]

1. Delay D=K+14
   Where k denoted by Block sizes
2. Latency L=D / fmax s
   Where, fmax is the system clock speed.
3. Throughput Calculation
   T=k * fmax / D bps
4. Efficiency η = T/W
   Where W denoted by Bandwidth

Table 3: Calculated Parameters

Block Sizes	*Latency*	*Through Put*	*Spectral Efficiency*
512	1.461 S	350.42 Mbps	17.521 Bits/S/Hz
1024	2.883 S	355.144 Mbps	17.757 Bits/S/Hz
2048	5.727 S	357.55 Mbps	17.877 Bits/S/Hz

6. PCCC with MIMO Channel

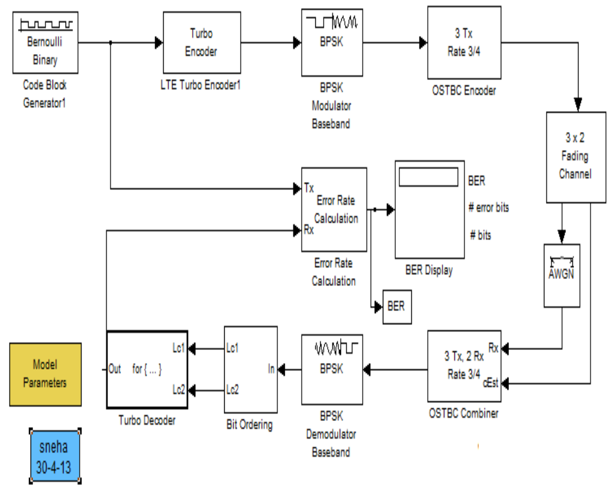

Figure 7: PCCC with MIMO channel

6.1 Overview of the Simulation

The model is shown in the following figure [7]. The simulation creates a random binary signal, modulates it using a binary phase shift keying (BPSK) technique, and then encodes the waveform using a rate 3/4 orthogonal space-time block code for transmission over the fading channel. The fading channel models six independent links, due to the three transmit by two receive antennae configuration as single-path Rayleigh fading processes. The simulation adds white Gaussian noise at the receiver. Then, it combines the signals from both receive antennas into a single stream for demodulation. For this combining process, the model assumes perfect knowledge of the channel gains at the receiver. Finally, the simulation compares the demodulated data with the original transmitted data, computing the bit error rate. The simulation ends after processing 100 errors or 1e6 bits, whichever comes first.

6.2 BER Performance of PCCC with MIMO Channel

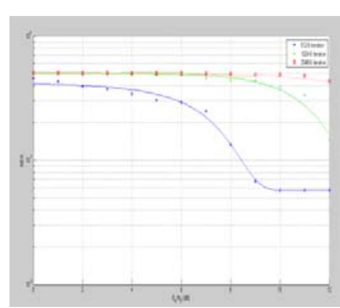

Figure 8: Plot of BER vs Eb/No PCCC with MIMO channel

Table 4: Result of PCCC with MIMO Channel

Block length *Eb/No*	*512* *BER*	*BER-1024*	*BER-2048*
0	0.4550	0.5	0.5048
1	0.4296	0.4980	0.5043
2	0.3945	0.4980	0.5034
3	0.375	0.4951	0.5053
4	0.3417	0.4921	0.5034
5	0.3046	0.4843	0.5024
6	0.2910	0.4746	0.5
7	0.2480	0.4589	0.4990
8	0.1334	0.4414	0.4946
9	0.0677	0.4355	0.4877
10	0.0576	0.3857	0.4877
11	0.0576	0.3339	0.4760
12	0.0576	0.1464	0.4345

6.3 BER Performance of PCCC of with and Without MIMO Channel

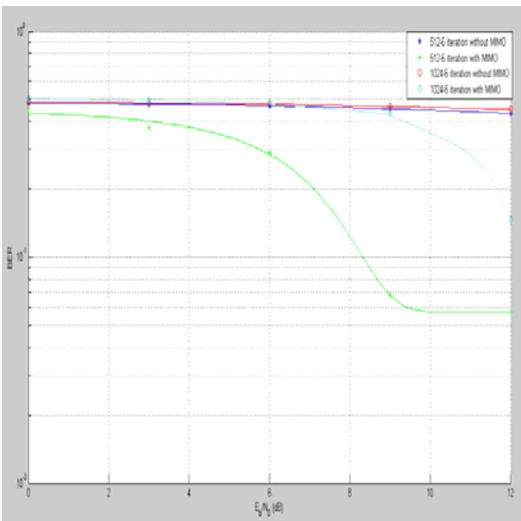

Figure 9: Plot of BER vs Eb/No PCCC with and without MIMO channel

Table 5: Result of PCCC with MIMO Channel

Block length Eb/No	*512 BER without MIMO*	*512 BER with MIMO*	*1024 BER without MIMO*	*1024 BER with MIMO*
0	0.4809	0.4550	0.4867	0.5
3	0.4772	0.375	0.4821	0.4951
6	0.4672	0.2910	0.4758	0.4746
9	0.4538	0.0677	0.4653	0.4355
12	0.4327	0.0576	0.4505	0.1464

7. Conclusion

It has been concluded that the decoding performance improves with an increase in the block lengths. For larger block lengths the BER is found to be less for a given value of Eb/No .Here the computation time varies as the number of samples per frame increases these cases also provide the BER of order 10^{-3}. As Shown in Result BER Performance of Turbo code with MIMO Channel is Batter than without MIMO Channel.

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