Iterative Decoding Termination Schemes for Turbo Code Performance Optimization In Mobile Wi-Max Environment

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Abstract

Use of turbo codes is more popular in most of the wireless applications, because of its greater Error control ability. The BER performance reaches to the Shannon's channel capacity limit. Turbo code implementation using SISO decoders with iterative MAP decoding algorithms introduces large time delay to recover the transmitted information bits. This results in increasing Wi-Max system complexity and storage requirement (Memory size). In this paper, the efforts have been made to propose the methods for effective termination of iterations to make the decoder efficient, in terms of reduction in the time delay and the requirement of memory size while maintaining the BER performance. Authors have propose various termination techniques which help in reducing the complexity as compare to conventional MAP decoding algorithm for same BER performance.

Keywords: *Turbo code, Iterative decoding, MAP Algorithm, Termination detection schemes*

1. Introduction

In advanced wireless communication network system such as Wi-Max, the error control code used for controlling the signal errors is turbo code. Using turbo code one can think of reaching capacity limit defined by the Shannon for low power transmission [1]. Turbo code provides high data rates for low order modulation schemes such as BPSK or QPSK [2]. Turbo code is implemented by employing (i) Parallel concatenated encoder structure and (ii) Soft input soft output iterative decoders [2], [3]. This decoder uses Maximum A Posteriori (MAP) decoding algorithm to generate the soft output. The operation of the turbo decoder is based on iterative decoding which is considered as the main feature of turbo codes. Since the MAP decoding algorithm needs relatively large number of iterations to achieve the expected BER performance at low SNR [4]. This leads to excessive time delay and computational complexity for deciding the system performance. The overall system complexity increases with the number of iterations carried out. Hence to reduce the number of iterations a scheme for fixed number of iteration is planned to get expected BER at relatively low SNR. The scheme describes the procedure for termination of iterations. When decoder approaches the performance limit of the system, no significant improvement is expected for further iterations, so it is better to stop the decoder operation. Based on this, the performance limit threshold of the system has been decided for a scheme with fixed number of iterations and the decoded output of such scheme send for further processing in the system.

In order to reduce average computational time without degrading the system performance, turbo decoder terminates the iterations for each individual frame immediately after receiving the bits as estimated. The decoder complexity can be reduced by effective termination schemes. The authors have proposed various schemes for effective termination of iterations which are refer to as decoder stopping rule [5]. This will improve the turbo code performance in the field of mobile Wi-Max. The BER vs. SNR characteristics for the system using each stopping rule is simulated and relative comparison is carried out to discuss the system performance.

2. Turbo Decoder

Turbo decoder extracts the systematic bits and recursive bits from the received information. A block diagram of turbo decoder is as shown in figure 1. The input to the turbo decoder is the received sequence (R_k) consisting of systematic and recursive bits. Decoder consists of two soft-input soft-output decoders namely DEC1and DEC2. DEC1 decodes sequence from recursive systematic encoder1 while DEC2 decodes sequence from recursive encoder2 of turbo encoder. Each of the decoder operating with Maximum A Posteriori (MAP) Algorithm in an iterative decoding process. The DEC1 receives systematic sequence and parity sequence as inputs and generates the soft estimated output called extrinsic data which is label as EXT1. For first iteration this does not contains any information. The output sequence of DEC1 is interleaved and passed as input to second decoder DEC2. The systematic received bits and parity bits also input to DEC2 with the interleaved form of the extrinsic information EXT1from the first decoder DEC1 [3].

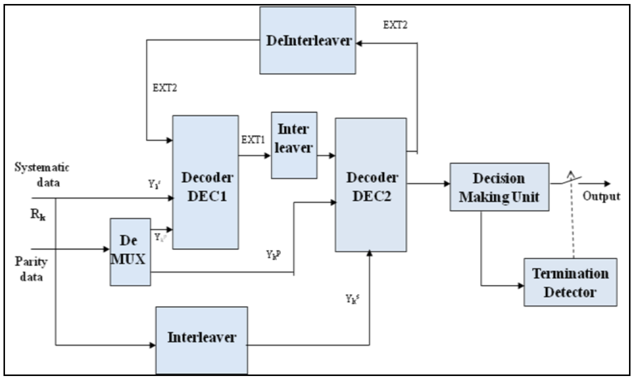

Figure 1: The structure of Turbo Decoder.

The DEC2 produces the soft estimated output called EXT2 which then de-interleaved and feedback to DEC1. This procedure is repeated in an iterative manner and continues until the bit error rate is zero (converges). At the end of decoding process simple threshold operation is performed to carry out hard decision on the soft output of the second decoder DEC2 [4].

This paper modifies the turbo decoder structure by implementing the termination detector and decision making unit. Termination detector is comparing the soft estimated output of decoder DEC2 for individual frame of current iteration to the threshold defined by the termination schemes [5]. Decision maker unit performed hard decision on the soft output of second decoder and stop the process of iterative decoding [7].

2.1 MAP Algorithm

In turbo decoding process, encoded information sequence (X_k) is transmitted over an AWGN channel and a noisy signal (Y_k) is received at the destination. In general, each decoder computes the Log Likelihood Ratio (LLR) to pull out the information data bit from received signal (Y_k). The LLR is calculated for each bit (d_k) of data block length N is defined in equation (1) [1].

$$L(d_k) = Log\left[\frac{\Pr \; d_k = 1 \; |Y}{\Pr \; d_k = 0 \; |Y}\right] \qquad (1)$$

Where Pr ((d_k=1)|Y) is A Posteriori Probability (APP) of the information input data at time k (d_k). APP is the measure of probability of correct decision that helps the MAP algorithm to minimize the bit error probability [4], [11]. The MAP decoding algorithm can uses a recursive technique and estimate the forward, backward and branch metric for each encoder state at time k [4],[12] is defined in equation 2. The Map algorithm calculates the LLR for each received data bit as

$$L(d_k) = \ln\left[\frac{\sum_{S_k}\sum_{S_{k-1}} \gamma_1 \; S_{k-1}, S_k \; \alpha \; S_{k-1} \; \beta \; S_k}{\sum_{S_k}\sum_{S_{k-1}} \gamma_0 \; S_{k-1}, S_k \; \alpha \; S_{k-1} \; \beta \; S_k}\right] \qquad (2)$$

Where α is the forward state metric, β is the backward state metric, γ is the branch metric and S_k is the encoder trellis state at time k [12]. But the original MAP algorithm demands a large number of operations involving multiplication and exponentiation that needs excessive memory and more computational efforts in both forward and backward recursion. The complex mathematical calculations and computations of MAP decoding algorithm can be simplified by performing computation in the logarithmic domain [11] known as Log-MAP algorithm. Thus the MAP decoder provides soft output in terms of logarithms of APP of each data bits. This can achieved as multiplications turn into additions and additions into maximum detection with an additional correction term [11], the maximum detection operation is defined by equation 3

$$Max^* \; x, y \; = \ln \; e^x + e^y$$
$$= Max \; x, y \; + \ln \; 1 + e^{-|y-x|} \qquad (3)$$

In log-MAP algorithm, the extrinsic information can be obtained by performing subtraction between input and output of both decoders. The resultant extrinsic sequence is fedback to first decoder through the deinterleaver for further iterations. Turbo decoding algorithm carries out fixed number of iterations per frame or block typically between 6 and 15 [8]. Therefore Log-MAP algorithm requires large memory and more complex computation analysis that leads to extra time delay for decoding the transmitted information. Even though the Log-MAP algorithm produces the decoding delay with complex computation, but the BER performance of this algorithm is unmatched to other existing decoders [3]. So the Log-MAP algorithm uses in the system while the system performance does not degrades. This is possible to reduce the decoding iterations that can be achieved by terminate the operation of decoder before fixed decoding iteration. Author has suggested various iteration termination schemes in this paper.

3. Termination schemes

Iterative decoding is a key feature of turbo codes. As the number of iterations increases (within certain limit), the bit error rate (BER) of the decoder decrease. In this process a fixed number of iterations typically between 6 and 15 are chosen and each frame is decoded for these iterations.

Usually it is set with the worst corrupted frames in the received data [7].

In the received information, it may possible that some of the frames don't have errors or most of the frames content least errors that need lesser number of iterations to converge. It would reduce the average computation without performance degradation. Thus we can improve the average decoding speed and decrease the power consumption of turbo decoder. It is possible if the termination scheme with a variable number of iterations per frame is implemented [6]. The decoder terminated the iterations for each individual frame immediately after the bits are correctly estimated [5], [6]. This is impractical when the transmitted bits are unknown. Various schemes have been proposed to control the operation of termination detector. We refer these methods as Stopping Criterion for iterations in turbo decoder are define as

i. Cyclic Redundancy Check (CRC).
ii. Cross Entropy (CE).
iii. Sign Change Ratio (SCR).

3.1 Cyclic Redundancy check

This is a simple criteria based on hard decisions. In this approach, CRC bits are added to the end of each information frame. Modified frame is sent to the turbo decoder through the channel. At the decoder end, CRC bits are used for checking the errors and decoder makes the hard decision. Decision maker unit compare hard decisions of two successive Iterations. It stops the decoder operation when results of two conjugative frames in the iterations are same (In other words, CRC bits are error free) [7], [14].
This theme uses limited CRC bits for the determination of errors. Large bits are not economical because that degrades the transmission efficiency [14]. Therefore this technique is not applicable for the large frame size.

3.2 Cross Entropy (CE)

The cross entropy (CE) advice by Hagenauer, Offer and Papke is the useful criterion for iterative decoding [11]. This scheme is based on determining the Cross entropy between estimated output of two different SISO decoders. The CE between two estimated output distributions $L_2(d)$ and $L_1(d)$ of a received data sequence $d= \{d_1, d_2 \ldots\ldots d_N\}$ is defined as

$$Y_{CE} = E_p\left\{Log\frac{L_2(d)}{L_1(d)}\right\} \qquad (1)$$

Where E_p denotes the expectation operation perform over estimated output $L_2(d)$. Since d is independent and distributed identically then the equation (1) can rewritten as

$$Y_{CE} = \sum_k E_p\left\{Log\frac{L_2(d_k)}{L_1(d_k)}\right\} \qquad (2)$$

In turbo decoder, using an iterative decoding algorithm, the CE between estimated output distributions of two decoders at i^{th} iteration can be approximated as

$$T(i) = \sum_k^N \left\{\frac{\left|\Delta L_{e2}^{(i)}\hat{d}_k\right|^2}{\exp\left|L_1^{(i)}\hat{d}_k\right|}\right\} \qquad (3)$$

Where N is the frame length, $\Delta L_{e2}^{(i)}(\hat{d}_k)$ denoted as difference of extrinsic LLR between present (i) and previous (i-1) iteration of detected information bits (d_k) generated at the output of second decoder. Whereas $L_1^{(i)}(\hat{d}_k)$ is the extrinsic LLR of received information generated by the first decoder at i^{th} iteration. Cross entropy of estimated LLR *T(i)* is calculated for each frame in an iteration [6]. The result of each iteration is compared with a threshold in terms of *T(1)*. Iterative decoding stops when the value of *T*(*i*) (much smaller) is measure in the range of threshold define as $(10^{-2} \sim 10^{-4})$T(1). The mean of which two extrinsic distribution are closed enough and result of that decision maker unit stop the further iterations and hard decision send to the output port. CE reduces the average iterations and complexity with performance degradation.

3.3 Sign Change Ratio

A practically simple and computationally effective scheme for CE termination is Sign Change Ratio (SCR) scheme. The scheme directly focuses on number of sign changes of extrinsic LLR of each data bit in an iteration. It gives number of sign changes s (i) for the extrinsic information for two successive iterations. The number of sign changes s (i) decides the threshold for turbo decoder termination of iteration process [6], [12]. The necessary condition to fulfill this is s (i) ≤ Q*N. Where, Q => Constant, ranges from 0.005 to 0.03 i.e. 0.005≤ Q ≤ 0.03, and N => Frame size. In our case, it comes out to be 19.2(Upper limit) taking Q as 0.03 and 3.2 (lower limit) for Q as 0.005 at 640 bits frame size. Instead of computing cross entropy the scheme suggested for the count of sign change in extrinsic LLR for successive iterations. Hence SCR more effectively reduces the computational efforts.

4. Simulation Results

The simulation is carried out using MATLAB version 7.10 using turbo codes for following specifications

- Code rates --- 1/3
- Encoder shift register --- 3.
- Generator Polynomials --- 13_{dec} and 15_{dec}.
- Digital Modulations --- BPSK/ QPSK.
- Signal to Noise Ratio --- 0 - 2.0 dB
- Turbo decoding algorithm --- Log-MAP.
- Amount of Information --- 640 bits/ Frame.
- Terminations schemes --- CRC, CE and SCR.

Using the above parameters, the simulation of the Wi-Max system [3] using turbo code is set for desirable (fixed) number of iterations. Turbo decoder uses Log-MAP algorithm. Decoding algorithm is modified by implementing the termination schemes as mentioned above. Termination scheme updates the system performance at lower SNR ranges from 0 to 2 dB. The BER performance of these three methods has been shown in Figure 2. We can observe that performance of CE is more effective towards minimum values of SNR due to soft estimation of received bits. Due to hard estimation, the CRC and SCR provide quite poor performance but relatively better than original decoding algorithm.

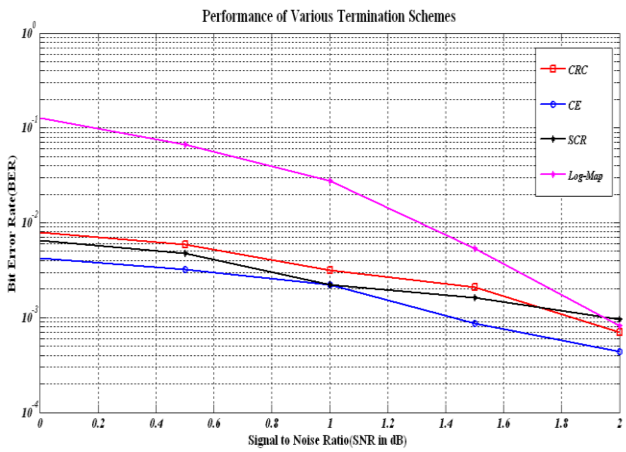

Figure 2: BER Performance of Various Termination Schemes.

The numbers of iterations consumed by each stopping method with respect to error probability are tabulated in the table1. CE operating on soft estimation of received data consumed comparatively less iterations towards lower values of SNR as observed in table1. The Bar diagram in percentage saving of computational analysis due to reduced iterations is shown in figure 3. The CE provides smooth functioning of decoder with soft estimation. These termination methods produced minimum number of decoding Iterations, decoding delay, memory requirement and the hardware complexity provided for optimizing turbo code performance of the Wi-Max system.

Table 1: Iterations consumed for various termination schemes.

SNR\Methods	CRC	CE	SCR
0.1 dB	9	7	8
0.5 dB	4	6	5
1.0 dB	4	4	5
1.5 dB	3	3	4
2.0 dB	3	3	3

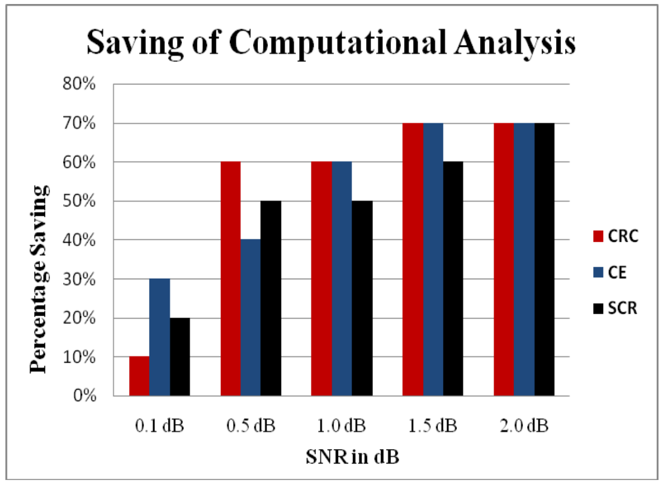

Figure 3: The saving of computational analysis.

4. Conclusions

BER Performance of turbo codes is improved by Iterative Decoder. Map Decoding Algorithm is implemented to get soft estimated output. Turbo MAP decoder achieves better performance with quite higher complexity that reduces the coding efficiency. Various termination schemes are implemented that helps to minimise (i) The number of decoding Iterations required, (ii) Decoding Delay, (iii) Memory requirement and (iv) The hardware complexity. Cross entropy is most effectively performed towards very low SNR with respect to system stability. Turbo codes approaches channel capacity at very low SNR ranges from 0 to 2 dB. Termination schemes speedup the turbo decoder iteration process and promises to minimise the iteration time delay without degrading the Wi-Max system performance.

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