Review on Role of Turbo Encoder and Decoder in LTE Network

Lekha S. Yeldi, Jagdish D. Kene

Abstract—**In order to have a reliable communication, channel coding is defined to be effective solution. The turbo code is a powerful coding technique among various correction codes therefore it is widely accepted in wireless communication networks. Turbo encoder and decoder are the recent development in the area of forward error correction codes that helps to achieve Shannon-limit performance. The turbo encoder and decoder provide good performance in Wimax/LTE network to fulfill the requirement of high throughput. The decoding algorithms are the key feature of the turbo codes to improve BER performance of the wireless networks. We will find the best possible option of turbo code to have an optimized performance.**

Index Terms— **Turbo codes, turbo encoder, turbo decoder, decoding algorithm.**

I. INTRODUCTION

The availability of wireless technology has revolutionized the way communications is done in our world today. Cellular and other technology makes it possible for people to be connected to the rest of the world from anywhere, anytime. All these wireless networks demand for high rate of transmission quickly, timely and accurately. For providing the good accuracy or to recover the original signal at the receiver end, forward error correction codes have been implemented. There are several types of error correcting techniques used like convolutional coding, but it fails to maintain the lower values of signal to noise ratio as the length of code increases. So a new version of coding called turbo coding was introduced that can achieve a level of performance that comes closer to theoretical bounds than more conventional coding systems [2]-[6].

Turbo codes were first introduced in 1993 by Berrou, Glavieux and Thitimajshima, and provide optimal performance approaching the Shannon limit[1]. Turbo codes are the most efficient types of Forward Error-Correcting (FEC) channel codes. Since the emergence of digital communication systems, there has been a need for error correction. This is due to the non-ideal nature of practical communication channels, which are often corrupted by noise. Error correction attempts to compensate for the errors introduced by this noise. The advantages of forward error correction are that a back-channel is not required and retransmission of data can often be avoided (at the cost of higher bandwidth requirements, on average). FEC is therefore applied in situations where retransmissions are relatively costly or impossible. The channel coding scheme for Long Term Evolution (LTE) is turbo coding. The iterative decoding mechanism, recursive systematic encoders and use of interleavers are the characteristic features of turbo codes.

In this paper we represent the structure of turbo encoder and decoder and their operations. The operations of turbo decoder are defined by various decoding techniques.

II. STRUCTURE OF TURBO ENCODER

The figure1 shows the general structure of turbo encoder. The turbo encoders are designed from two or more recursive systematic convolutional encoders connected in parallel concatenation form separated by an interleaver.The code is in systematic form i.e. the input bits also occur at the output. The recursive systematic encoder is typically of code rate ½ and it is termed as component encoder. The input bits are represented by a binary sequence $d_k = [d_1, d_2, \text{--------} d_n]$. The input sequence is fed to the convolutional encoder ENCODER1 and generates the coded bit stream X_{k1}. The input data is then interleaved i.e. the data bits are loaded row-wise and read out column wise. To improve the performance of turbo codes an interleaver is used. The most commonly used interleaver is row-column interleaver. The bits are often readout in a pseudo random manner. The interleaved data sequence is passed to the second convolutional encoder ENCODER2 and coded bit stream X_{k2} is generated. The coded data sequence (X_k) is multiplexed and punctured before it is to be sent across physical channel consisting of systematic code bits (X_{sk}) and parity bits obtained from the first encoder (X_{pk1}) and second encoder (X_{pk2}). The multiplex and puncture operation is employed to extract the systematic bits and recursive bits from the received information. These will be used by the decoder to ensure the data is error free when it arrives at the end user terminal. Turbo codes can perform effectively at low signal to noise ratio (SNR) with small number of low weight code wards. This small minimum distance code limits the performance of turbo codes at higher SNR. Therefore turbo codes can employ to reduce the multiplicity of low weight code wards [14].

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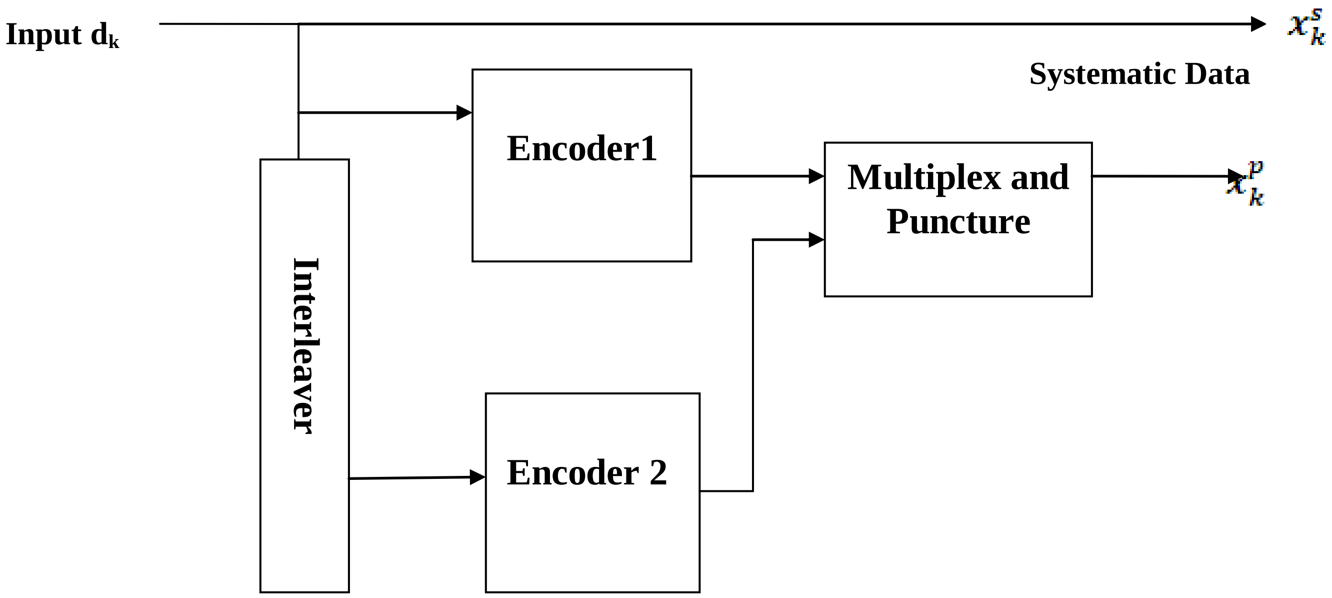

Fig.1. Turbo Encoder [13]

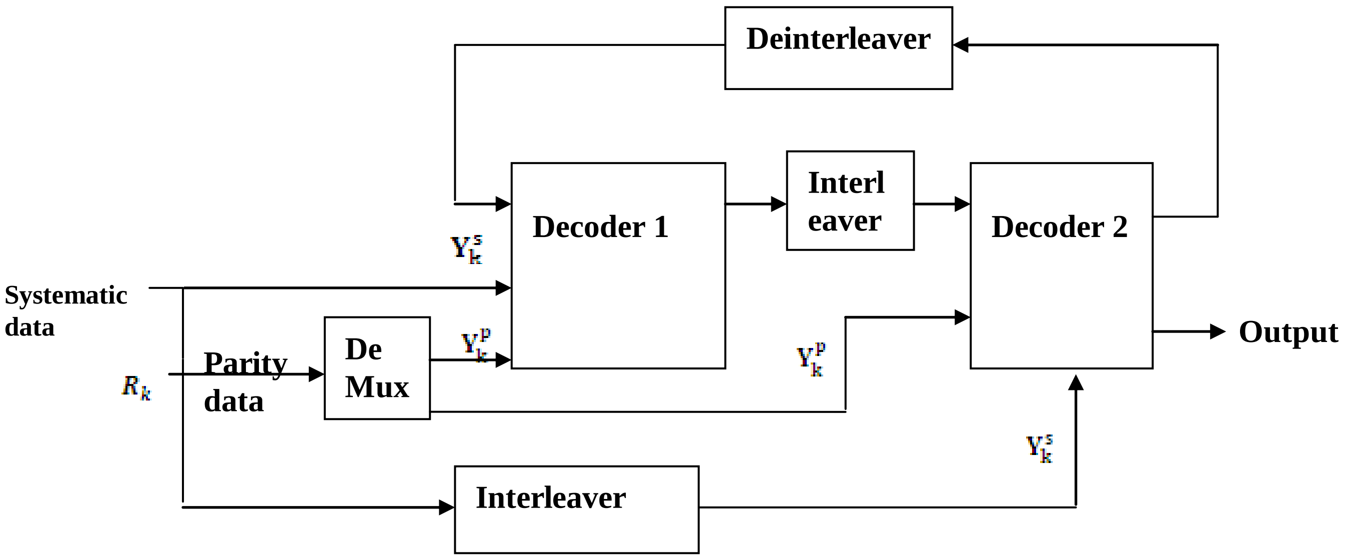

Fig 2 Turbo Decoder [14]

III. STRUCTURE OF TURBO DECODER

The main operation of turbo decoder is to reestablish the transmitted input data from the received systematic bits and multiplexed recursive parity bits, even though it is corrupted by noise. The turbo decoder consists of two single soft-in-soft-out (SISO) decoders serially connected via an interleaver identical to one in encoder and a corresponding deinterleaver as shown in figure 2.The input to the turbo decoder is the received sequence represented as $R_k = [Y_{sk}, Y_{pk}]$. The DECODER1 decodes sequence from ENCODER1 while DEC2 decodes sequence from ENCODER2. Each of the decoder acting as Maximum A Posteriori (MAP) decoder. The received sequence systematic value and received parity sequence are the input to the DECODER1. The DECODER1 generates the sequence are of soft estimate EXTRINSIC1 is called extrinsic data which does not contains any information. The output sequence of DECODER1 is interleaved and then passed to second decoder DECODER2. DECODER2 takes as its input systematic received bits Y_{sk} and parity bits Y_{pk} along with the interleaved form the extrinsic information EXT1provided by the first decoder DECODER1. The DECODER2 produces the output which when de-interleaved using inverse form of interleaver (load in column and read out in row). This consists of soft estimates EXTRINSIC2 of the transmitted data sequence (d_k) is feedback to DECODER1. This procedure is repeated in a 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 DECODER2 [12]-[16].

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IV MAP ALGORITHM

To decode the received sequence an algorithm is used called as Maximum a Posteriori (MAP). This decoding algorithm was proposed by Bahl, Cocke, Jelinek and Raviv in 1974 based on a posteriori probabilities later on known as the BCJR,MAP or forward-backward algorithm. There are several simplified versions of the MAP algorithm, namely the log-MAP and the max-log-MAP algorithms [20]. The MAP algorithm is to minimize the symbol error rate for the decoding of trellis and block codes. As the data is received the operation of the decoder is to determine the most likely input bits (original/uncoded information sequence), based on the received symbols. The soft outputs from the decoders are typically represented in terms of the so-called log likelihood ratios (LLRs), the polarity of which gives the sign of the bit, and the amplitude the probability of a correct decision. The LLRs are simply, as their name implies the logarithm of the ratio of two probabilities. For example, the LLR L (d_k) for the value of a decoded bit d_k of data block length N is given by

$$L(d_k) = log\left[\frac{P_r(d_k = 1)/Y}{P_r(d_k = 0)/Y}\right] \quad (1)$$

Where P_r ((d_k=1)|Y) is A Posteriori Probability (APP) of the information input data at time k (d_k).When LLR is equal to 1 then the decoder gives entire received data. The two possible values of the bit d_k are taken to be 0 and 1, as this simplifies the derivations that follow MAP algorithm.

The decoder of Fig. 2 operates iteratively, and in the first iteration the first decoder takes channel output values only and produ the second iteration can begin, and the first decoder decodes the channel outputs again, but now with additional information about the value of the input bits provided by the output of the second decoder in the first iteration. This additional information allows the first decoder to obtain a more accurate set of soft outputs, which are then used by the second decoder as a priori information. This cycle is repeated and upon every further iteration the bit-error rate (BER=) tends to decrease. However, typically a gradually diminishing incremental BER reduction is attained. Hence, a tradeoff between the complexity imposed and the BER attained must be struck .The MAP algorithm calculates the LLR for each data bit given as

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

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 trellis time k.

V. MAX-LOG-MAP ALGORITHM

As the MAP algorithm cannot perform in real systems and is considered to be complex the Max-Log-MAP algorithm was proposed by Koch and Baier and Erfanian. It is the simplification method of MAP algorithm by transferring the recursions into the logarithmic domain without reducing its accuracy. The MAP algorithm calculates the a posteriori LLRs L(d_k)using (2). To do this it requires the following values.

1) $\alpha(s_{k-1})$**values**, which are calculated in a forward recursive manner,

2)$\beta(S_k)$ values, which are calculated in a backward recursion.

3) branch transition densities which are $\gamma(S_k,S_{k-1})$

The Max-Log-MAP algorithm simplifies this by transferring these equations into the logarithmetic domain and then using the approximation

$$\ln\left(\sum_i e^{x_i}\right) \approx \max_i(x_i)$$

where max(x_i) means the maximum values of x_i.

Max-Log-Map is given as

$$L(d_k) = \max_{\substack{(S_k,S_{k-1})= \\ d_k=1}}((\gamma_1(S_{k-1},S_k) + \alpha_{k-1}(S_{k-1}) + \beta_k(S_k)) - \max_{\substack{(S_k,S_{k-1})= \\ d_k=0}}((\gamma_0(S_{k-1},S_k) + \alpha_{k-1}(S_{k-1}) + \beta_k(S_k)) \quad (3)$$

The above terms are maximized over a group of transitions that have occurred with d_k=1 and that with d_k=0. For both of these groups the transition giving the maximum value of is calculated and the a posteriori LLR is based on only these two best transitions.

VI LOG MAP ALGORITHM

The Max-Log-MAP algorithm gives a slight degradation in performance compared to the MAP algorithm due to the approximation of (3). When used for the iterative decoding of turbo codes, Robertson et al. [11] found this degradation to result in a drop in performance of about 0.35 dB. However, the approximation can be made exact by using the Jacobian logarithm

$$\ln(e^{x_1} + e^{x_2}) = \max(x_1,x_2) + \ln\left(1 + e^{-|x_1-x_2|}\right)$$

$$= \max(x_1,x_2) + f_c(|\, x_1 - x_2 \,|) \quad (4)$$

where $f_c(x)$ can be thought of as a correction term. This is the basis of the Log-MAP algorithm proposed by Robertson, Villebrun, and Hoeher. The Log- MAP algorithm is only slightly more complex than the Max-Log-MAP algorithm, but it gives exactly the same performance as the MAP algorithm. Therefore, it is a very attractive algorithm to use in the decoding of an iterative turbo decoder.[21]-[23]

VII. SIMULATION RESULT

The simulation results have been studied from the paper of P. Robertson, E. Villebrun, and P. Hoher [12].The simulation results of the BER performance of log map and max-log Map is shown in figure 3.They showed that the log map can be implemented more easily and gives a desired bit error rate with low SNR. It also performs with a small number of states and even additional complexity is reduced. The paper also showed the results of log-Map with quantized levels with different values of forward state metric, backward state metric and branch state metric.

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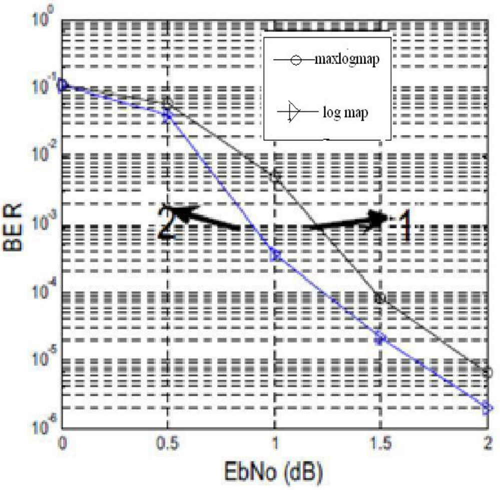

Fig3. Comparison of BER performance over high SNR [12]

VII CONCLUSION

Turbo codes are a very powerful error correction coding scheme in area of Communication system for improving the throughput in the upcoming 4G standards. It can approach to near Shannon limit capacity on maximum achievable data transfer rate over a noisy channel. The decoding algorithm that best suits with low bit error rate is the log MAP as compared to max-log map and MAP.

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