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A Review of Turbo Codes for 4G Networks and Beyond

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***Abstract*: Turbo codes have become an active area of research owing to the fact that they come closest to the Shannon's limit for codes. This paper presents a comprehensive survey on turbo codes. The paper begins with an introduction of turbo codes followed by its applications and advantages. Subsequently, prominent work in the field is cited in brevity as literature review. The various approaches of the work have been exemplified. Finally a conclusion is presented pertaining to the topic. It is expected that the paper will render useful insights into the functioning and utility of turbo codes.**

***Keywords*: Turbo Codes, Bit Error Rate (BER), Signal to Noise Ratio (SNR).**

1. Introduction

Turbo codes are often viewed as a parallel concatenation of convolution codes. They are of great interest as they come very close to the Shannon's limit. The aim of channel coding is often to enhance reliability of communication even at low values of signal to noise ratio. One of the major challenges is to evade the conflict of randomness and complexity of code design. Turbo codes can be visualized as a parallel concatenation of convolution codes and generally render exceptionally good BER performance at low SNR values. [1] The codes exhibit very good performance for both AWGN and Rayleigh channels in terms of approaching the Shannon's limit. Interleaving is used to render randomness to the code and it follows a concatenated structure. In general Turbo Codes are very close to Shannon's limit mathematically defined as:

$$C = Blog_2(1 + \frac{S}{N}) \tag{1}$$

Here,
C is channel capacity
S is signal power
N is noise power
B is bandwidth
The Shannon's limit is BER of almost 10^{-5} (ideally 0) for $\frac{E_b}{N_0}$ = 0 dB for binary modulation. [1]
The above limit corresponds to a binary rate R=1/2 convolution encoder which has a constraint length K and Memory M=K-1.

Assuming that the bit d_k is the input to the encoder at time k, we have the codeword C_k which is binary coupled: [2]

$$X_k = \sum_0^{k-1} g1_i d_{k-1} \text{ mod.2 } g1_i = 0,1 \tag{2}$$

$$X_k = \sum_0^{k-1} g2_i d_{k-1} \text{ mod.2 } g2_i = 0,1 \tag{3}$$

Where,

$$G_1: \{g_{1i}\} \tag{4}$$
$$G_2: \{g_{2i}\} \tag{5}$$

G1, G2 are two code generators generally expressed in the octal form.
The Convolutional encoders are used in a parallel structure with an interleaver to introduce randomness. Fig. 2 exhibits the structure of the coding mechanism.

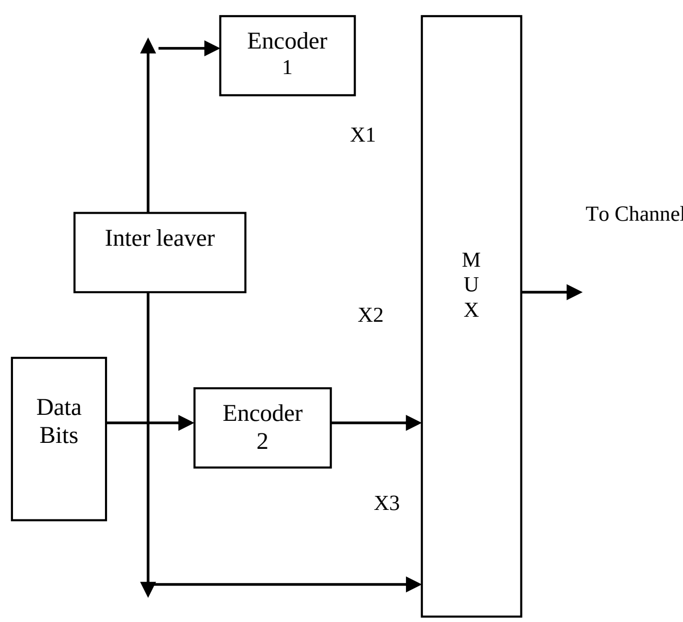

Fig.1. Structure of Turbo Code Encoder [2]

As shown in Fig. 2, encoder1 outputs the systematic and recursive convolution sequences, while encoder2 outputs the recursive convolution sequence only after discarding the systematic sequence [3]. A typical example where the turbo encoder and decoder are used is depicted in the Fig. 2.

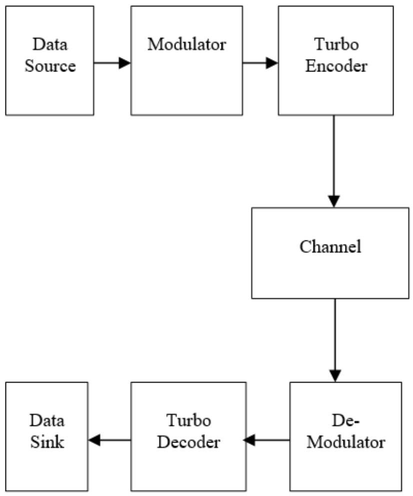

Fig. 2. Use of turbo code encoder and decoder in communication system [2]

The turbo encoder is used after the modulator block and before the channel. There are various schemes to implement the turbo encoding among which the most commonly used are: [2]

- *Maxium Aposteriori Probability (MAP):* In this technique, the core idea is to use the maximum-likelihood algorithm to find out the most probable information bit that was transmitted. The MAP technique tries to reduce the bit or symbol error probability.
- *Log-MAP:* This technique avoids the approximations used in the Max-Log-Map algorithm by using a corrective function when a maximization operation is reached.
- *Max-Log-Map:* This technique is a modification or derivative of the MAP algorithm wherein the computations are in the logarithmic domain. Hence it eases out the operations which are to be implemented.
- *Soft Output Viterbi Algorithm (SOVA):* In this algorithm, an asymptotic version of the maximum likelihood algorithm is used for moderate and high SNR values. This approach finds the most probable information sequence within a transmitted code sequence. The different algorithms generally differ in the complexity of implementation which is estimated in terms of the following parameters v.i.z. additions, multiplications, max operations, look ups and exponentiation.

For a random channel, the turbo decoder is made up of the random variables x_k and y_k defined mathematically as:

$$x_k = (2d_k - 1) + i_k \quad (6)$$
$$y_k = (2Y - 1) + q_k \quad (7)$$

Here,

k is the time index
i_k and q_k are independent noises in the channel with noise variance σ^2
The turbo decoder is based closely on the encoding mechanism. It is depicted in the figure below.

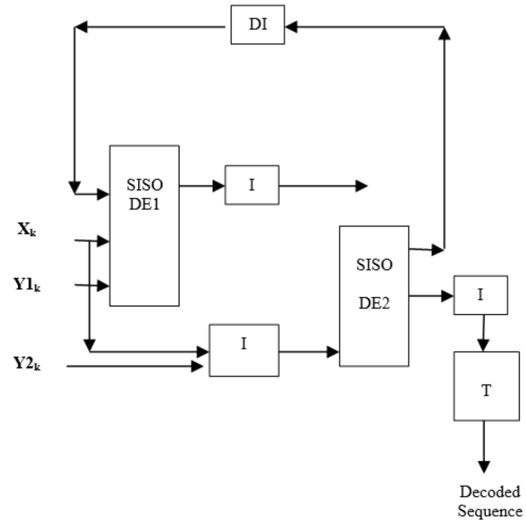

Fig.3. Structure of Turbo Decoder [2]

The different acronyms used in the above diagram are:

- SISO: Soft Input Soft Output
- I: Interleaver
- DI: De-Interleaver
- DE1: Decoder_1
- DE_2: Decoder_2
- T: Threshold or Decision Device

The above figure illustrates the iterative decoding procedure of by dint of Soft Input- Soft Output decoding mechanism. The SISO Decoder_1 is responsible for generating the soft output. Subsequently, the extrinsic information is produced. The second decoder uses the extrinsic information after interleaving. The second decoder then generates the extrinsic information with interleaving and in a feedback loop passes it on to the first decoder. There are several applications of turbo encoding such as:

- Deep Space Communication
- Digital Video Broadcast
- W-CDMA etc.

The challenging aspect remains the decision to stop the iterative decoding process.

2. Previous work

In 2014, Michael Lentmaier et al. [3] carried out investigation based research on the spatial computing aspect that could work well the BCC ensemble. Parallel working codes could also get the data right but the braided Convolutional codes actually worked well to decipher other mechanisms. The security aspect has been given value and obtained significant extensions for the threshold values. The Maximum a posteriori threshold also exhibited immensely good results with the high optimized outcomes. The density evolution has to be observed keenly to be applied. Over all this research highlighted the areas of betterment of the channel coding schemes and suggested scope of extensive research. It gave good accuracy and outcomes as required.

In 2018, CHAOFAN CHEN et al. [4] presented about the Polar Codes attracting concern and attention in the recent times. Especially in the forthcoming 5G wireless networks their adoption and use has been garnering attention. The studies prior to the recent ones though put more weight on the coherent polar codes that always was based on presence of perfect channel state information. But in this case, authors research on the utility of PCs in non coherent systems. The concatenation of a binary differential phase shift keying (BDPSK) demodulator is performed with a polar decoder to form the non-coherent detector, where application of successive cancellation (SC) is carried out. It works perfectly as the on coherent system is the newer approach and also yield a good performance oriented methodology.

In 2017, Saeedeh Moloudi et al. [5] puts forth the fresh concept of spatially coupled turbo like codes (SC-TCs). Mainly in this method the spatial coupling of parallel concatenated codes (PCCs) is taken into consideration and also the serially concatenated codes(SCCs). Moreover, two extensions of the braided Convolutional codes are also made and added. These codes exhibit an inbuilt spatially coupled structure and also show improvement in the belief propagation (BP) thresholds. The DE i.e. the density evolution equations for SC-TCs is derived and their unique behavior is evaluated. It is a bit asymptomatic on the binary erasure channel. The numerical results illustrate that belief propagation shows threshold saturation and the uncoupled occurrence of the ensembles are also very demanding. So this proved a good approach for its improvement.

In 2017, Suihua Cai et al. [6] put forth the block Markov superposition transmission of BCH (BMST-BCH) codes, that can be made to get a very low and reduced error floor measure. For minimal complexity in the implementation, they designed a very less complex iterative sliding window decode algorithm that really showed improved outcomes. The forecast of the error floor rate can be carried out by a lower bound pproach and the waterfall improvement can be evaluated and a quick simulation method is revised for the same. The decoding scheme can give upto NCG of nearly 10.85%. Their design is comparatively flexible and overheads and latencies can be managed with better network resources and schemes.

In 2016, Gianluigi Liva et al. [7] enunciated the block codes design for the brief data blocks i.e. for less than thousand data bits. It is a problem that has been an active research area that has garnered importance due to latest technical developments in the wireless communication networks. In this mechanism of work, few of the latest constructed codes are reviewed that aim the short block type and comparison is performed with traditional error correcting methods and with finite blocks of length. More improvements are being made in this work area to bring in room for better scope of improved outcomes. The theoretical aspect has also been used for the proper methods and other areas are being focused like the decoding.

In 2016, Erdal Arıkan et al. [8] explained the "turbo revolution" of 1993 and also they rediscovered the low density parity check (LDPC) codes after that. The channel coding area has seen a lot of modernization and technical advancements in the recent couple of years. The code designs earlier were thought to be of limited performance that made them fall short of few decibels in measurement. And their capacity suffered as a consequence. The invention of the turbo codes broke the belief about the coding mechanisms by attaining a performance of 0.5Db in the capacity perspective. The different capacity schemes also performed well making use of the LDPC codes in along with the message intricacy that could go further well. These advances made it easier for better flexibility and management of the code thresholding also made significant improvement.

In 2015, Boulat A. Bash et al. [9] proposed a mechanism on encryption based security types. It is useful as it can secure against decoding that is unauthorized. But lesser possibility of interception is mainly ensured by strong communication. It is important for secure communication and exchange o messages for the robust secure ways of work. Privacy is important for users so it is necessary to get that right too. Encrypted data safeguards the information and limits intruders from attacking it. With new wave of technologies, new challenges have also surfaced and it has become mandatory to get better secure methods to combat newer and complex challenges. So mainly in this paper the authors gave an idea on implementing such a robust and secure encryption based model that showed good results.

In 2015, Zunaira Babar et al. [10] discussed the area of high detection intricacy that has been the chief challenge in the nearby future. The Gigabit frameworks have to be strongly handled and improvised in order work in tandem with other structures and types of domain. Here a quantum based detector can go a long in getting the outcomes right on time. It can detect signals in the range of hundreds attributing to its parallel working feature. The EXIT chart predictions also have a strong foothold in the entire functioning of the system. The optimization outcomes and values are well represented by these charts. They provide an insight into mechanism of the QTC. So it is very important to get that in place. The schemes proposed by the authors in this paper highlight the coding issues and the thresholding values. But the end result is quite assuring and justifying. It yields good optimization.

In 2018 Lei Yang et al. [11] presented a new kind of partially information coupled (PIC) Turbo codes for improvement in the transport block error rate meant for LTE systems. This was an efficient method where the coupling of every two CBs in continuity is done and partial data bits are shared. This kind of mechanism introduces a fresh taner graph of the PIC Turbo code. It is a sort of a feed forwarding and feed backing method that exploits the necessities of the CBs.

In 2014, Tsung-Yi Chen et al. [12] studies about the compatible LPDC codes that worked very precisely with coding methods. These were termed as the protograph based Raptor like codes. Their designing was mainly based on binary odes for the some specific channels. The parity bits were taken into consideration and exclusive –OR operations were performed. This method gave a glimpse into the unique codes. They outperformed the other conventional codes in terms of throughput and flexibility.

Table 1
Comparative complexity tabulation for different decoding mechanisms

	MAP	Log-Map	Max Log-Map	SOVA
Addition	$2.2^{K}.2^{V}$	$6.2^{K}.2^{V}+6$	$4.2^{K}.2^{V}+8$	$2^{K}.2^{V}+9$
Multiplications	$5.2^{K}.2^{V}+8$	$2^{K}.2^{V}$	$2.2^{K}.2^{V}$	$2^{K}.2^{V}$
Max. Operations	-	4.2^{V}-2	4.2^{V}-2	2.2^{V}-1
Look-ups	-	4.2^{V}-2	-	-
Exponentiation	$2.2^{K}.2^{V}$	-	-	-

Table 1 illustrates the comparative complexity for different decoding mechanisms. As can be observed from Table-1 that different algorithms have different complexities and hence should be adopted accordingly. The complexities are estimated in terms of the various operations which need to be performed. The evaluation of any algorithm needs to consider the amount of operations which need to be performed. With an eye on the computational complexity, it can be seen that the SOVA algorithm is computationally less complex relatively and also attains good BER performance.

The above description reveals that turbo codes are extremely effective in achieving low BER performance even at extremely low SNR values. There are different algorithms available to implement turbo codes with their own merits and de-merits. Hence a meticulous decision should be taken for the implementation of turbo codes. The approach proposed for future researchers is attaining even lower BER for similar values of SNR.

3. Conclusion

It can be concluded from the previous theoretical discussions that turbo codes are extremely effective for their near Shannon limit of BER and SNR requirement. However, different variants of the decoding process pose different complexities and hence one needs to choose a technique as per the system requirements. This paper has presented latest trends in the domain with its salient feature. Finally a complexity analysis has also been presented for easy reference.

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