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Simulation of Turbo Convolutional Codes for Deep Space Mission

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Abstract
In satellite communication deep space mission are the most challenging mission, where system has to work at very low Eb/No. Concatenated codes are the ideal choice for such deep space mission. The paper describes simulation of Turbo codes in SIMULINK . The performance of Turbo code is depend upon various factor. In this paper ,we have consider impact of interleaver design in the performance of Turbo code. A details simulation is presented and compare the performance with different interleaver design .
Keywords: Eb/No, PCCCs, HCCCs, SCCCs, SNR, AWGN,

I. Introduction

The usefulness of concatenated codes was first noticed by Forney in [1]. In general, the concatenation of convolutional codes can be classified into three categories,i.e., PCCC, SCCC and hybrid concatenated convolutional codes (HCCC). The constituent convolutional codes (CCs) used in each scheme fall into several classes of systematic, nonsystematic, recursive and non-recursive schemes. Systematic convolutional codes have their inputs appear directly at the output, while non systematic convolutional codes do not have this property. A non-recursive encoder does not have any feedback connection while a recursive encoder does. In general, nonsystematic non-recursive CCs perform almost the same as equivalent systematic recursive CCs since they exhibit the same distance spectrum. In the original turbo code, two identical recursive systematic convolutional (RSC) codes were used. Several other authors have explored the use of nonsystematic recursive CCs as the constituent codes, e.g., Massey and Costello [2, 3]. In [4, 5],Benedetto et al. and Perez et al. showed that recursive CCs can produce higher weight output codewords compared to nonrecursive CCs, even when the input information weight is low. This is a major advantage in a PCCC system since low input weight codewords dominate the error events. In addition, PCCC requires a long information block in order to perform well in the low SNR region. In this case, recursive CCs can provide an additional interleaving gain that is proportional to the length of the interleaver while nonrecursive CCs cannot .Therefore, RSCs are preferable in practice as the constituent code for a PCCC or the inner code for an SCCC or HCCC. Detailed treatments of the constituent CC encoder can be found in Lin and Costello [6] and many excellent references within, e.g., [4, 7]. In the following sections, we will examine the structure for each scheme. We assume that these systems consist of only two CCs. Extension to multiple CCs is straightforward and have been investigated in a number of references [8, 9].

II. Parallel Concatenated Codes :

Parallel-Concatenated Convolutional Codes (PCCC), know as *turbo codes*, allows structure through concatenation and randomness through interleaving. The introduction of turbo codes has increased the interest in the coding area since these codes give most of the gain promised by the channel-coding theorem.

The CCSDS Telemetry Channel Coding Recommendation [1] establishes a common framework and provides a standardized basis for the coding schemes used by CCSDS Agencies for space telemetry data communications. This standard traditionally provides the benchmark for new and emerging coding technologies Turbo codes have an astonishing performance of bit error rate (BER) at relatively low Eb/N0. Turbo codes were chosen as a new option for this standard in 1999, only 6 years since their official presentation to the international community: this was the first international standard including turbo codes. The reason was the significant improvement in terms of power efficiency assured by turbo codes over the old codes of the standard. Figure.1 shows complete SIMULINK model of CCSDS compline turbo encoder and decoder.

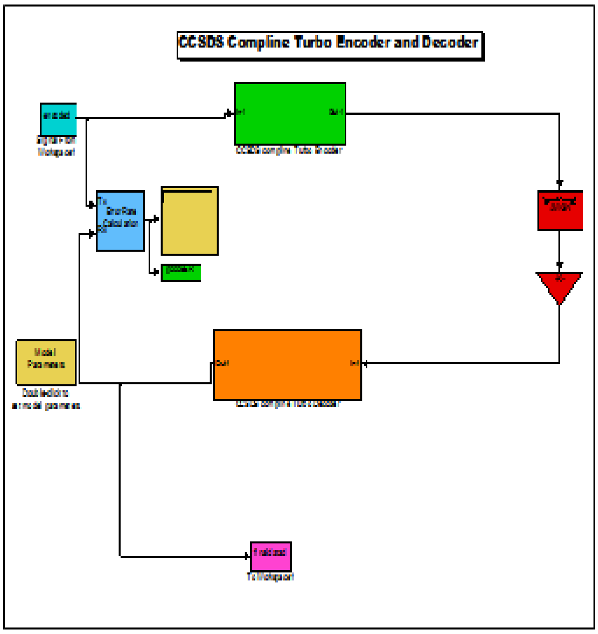

Figure.1 CCSDS Compline Turbo Encoder and Decoder

2.1 Turbo Encoder and Decoder

In this case, two RSCs of rates Ri = $1/n_i$ and i € {1, 2} are connected in parallel. The interleaver π interleaves the uncoded message **u** = $\{u_0, u_1, . . . , u_{N-1}\}$, of length N before entering into the second encoder. If the constituent encoders are RSC codes and no termination of the constituent codes is performed, the overall code rate R for this PCCC scheme is

$$R = \left(\sum_{i=1}^{2}\frac{1}{Ri} - 1\right)^{-1} \quad (1)$$

Clearly, the code rate R in (1) is less than the individual code rate R_n of each constituent encoder. For example, the PCCC in [10] uses two identical constituent RSC encoders of rate 1/2 each. Since the two RSC encoders produce the same original message **u** at the output (one interleaved and one not interleaved), one of them is therefore deleted. Applying (1), the overall code rate is equal to 1/3.

This low rate system offers very strong protection to the transmitted message. Generally, the lower the code rate, the higher the protection to the transmitted data. In practice, a low code rate system is used when the SNR is low or the bandwidth is large. However, a low code rate is inefficient in a bandwidth limited system due to the extra redundancy in the coded message. A higher coding rate is necessary for achieving higher bandwidth efficiency.

Optimally, a high code rate concatenated system should use high rate constituent CCs with the largest effective distance d_{eff}, where d_{eff} is the smallest Hamming weight of codewords with input weight two [11]. However, due to the constraints of the decoder, i.e., the trellis branch complexity increasing almost exponentially with respect to the input into the encoder, implementation of these systems are not normally used in practice. In past, several authors have tried to use the dual code [12, 13] to design very high rate turbo codes with low decoder complexity. However, the implementation of the decoder is not easy because the estimation of the branch and state metrics in the decoder requires a very high level of accuracy.

A simple technique to obtain a higher code rate using the same low rate constituent code is called puncturing. Referring to Figure 2, certain parity bits (C11 and C22) are deleted from the encoded sequence before going into the multiplexer. The advantage of this puncturing technique is that it requires no changes in the decoder, i.e., the same rate 1/2 decoders can be used for different higher code rates. This is especially useful in an adaptive system where code rates need to be varied depending on the channel conditions. The penalty to pay for puncturing a low rate encoder to a higher rate encoder is that the system performance is degraded in comparison to a similar high rate encoder without puncturing. This is due to a lower d_{eff} or a larger number of effective nearest neighbours N_{eff} of the punctured code. In addition, when RSC codes are used, there are two choice either deletion of the parity bits or deletion or deletion of systematic bits .However in general deletion of parity bit is compared to systematic bits is preferred. This restricts us from choosing an optimal puncturing matrix for a very high code rate, e.g., $k/(k + 1)$, since many parity bits are required. In this paper .we will compare the performance of both type of puncturing structure.

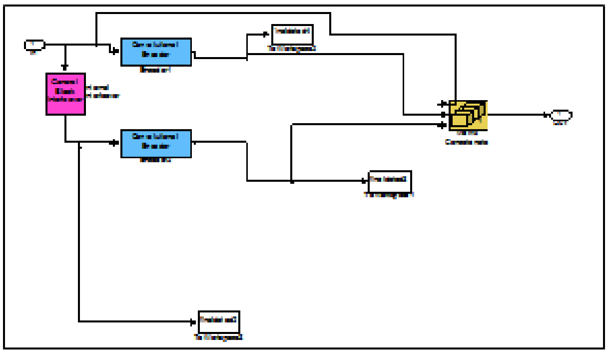

Figure.2 CCSDS compline Turbo Encoder

To investigate the "goodness" of turbo code performances, it is useful to compare them against the channel coding theoretical limits. For a fixed code-rate k/n and a specific constellation, the ideal spectral efficiency η (measured in bps/Hz) is computed by referring to ideal Nyquist base-band filters. For 4-PSK constellations the following expression results:

$$\eta = {}_{2}\frac{k}{n}$$

Consider the transmission of a binary turbo code over the AWGN channel by a Gray labelled 4-PSK. At very high signal-to-noise ratios (SNR), that is very low error rates, the code performance practically coincides with the union bound, truncated to the contribution of the minimum distance . The FER and BER code performance can then be approximated by:

$$FER \cong \frac{1}{2} A_{\min}\, erfc\left(\sqrt{d_{\min} \frac{k}{n} \frac{E_b}{N_o}}\right) \quad (2)$$

$$BER \cong \frac{1}{2} \frac{w_{min}}{k}\, erfc\left(\sqrt{d_{\min} \frac{k}{n} \frac{E_b}{N_o}}\right) \quad (3)$$

Where $A_{\min}$ is the code *dominant multiplicity* (number of codewords with weight $d_{\min}$), and $w_{\min}$ is the code *dominant information multiplicity* (sum of the Hamming weights of the $A_{\min}$ information frames generating the codewords with weight $d_{\min}$). When comparing the simulated curves with Eq. 2 and 3 a small fixed penalty (usually less than 0.25 dB for turbo codes) must be also taken into account, due to the sub-optimality of iterative decoding.

Figure 3. shows a SIMULINK model of CCSDS compline Turbo decoder, Here puncturing is done on parity bits . The puncturing matrix in this case is [1 0 1 1 1 0] . Figure 4 shows a SIMULINK model of a turbo decoder, where systematic bits are not send from encoder side. So there is no puncturing and depuncturing involve. Figure 5 shows the comparative performance of two cases. Result shows that deletion of parity bit will be preferred over systematic bits.

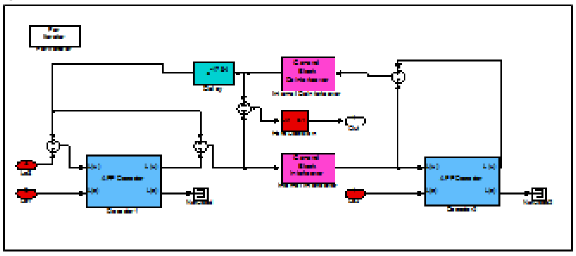

Figure 3 CCSDS compline Turbo Decoder

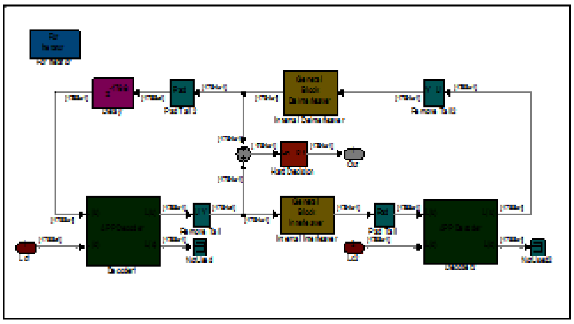

Figure 4. Turbo Decoder without transmission of systematic bits

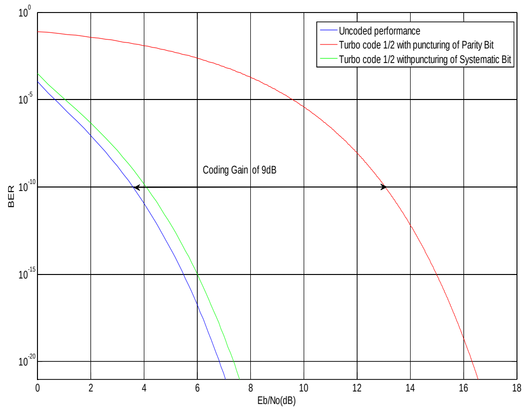

Figure. 5. Comparative performance analysis of different turbo codec

III. Effect of interlever design on Turbo code

The performance of Turbo code is highly depend upon interleaver design. The error floor problem of Turbo code can be solved by using proper interlever design. Figure 6 shows the performance of turbo code with different interlever. The code rate for all cases is 1/2 and total decoding iteration is set to 6. The frame length is set to 1784 Bits. . Table 1 shows the error free performance analysis of Turbo codec with respect to different interleavers. It can be easily seen that performance of random interleaved Turbo codec is superior compare to other interleaved Turbo codec. Hence random interleaver is the suitable choice for Turbo codec.

Table: 1 Packet size : 1784 Bits, BER=10^{-6}

S.No	Interleaver Type	1st iteration (Eb/No)	2nd iteration (Eb/No)	3rd iteration (Eb/No)
1	Pseudo random	4.4	3.3	2.1
2	Matrix	5.5	4.8	3.9
3	Helical	5.2	4.7	3.8
4	Circular	5.6	5.0	4.3
5	Algebraic	5.1	4.2	3.5

IV. Conclusion

A detailed simulation result are presented for Turbo concatenated code structure for deep space mission . Simulation result shows that for identical code rate, the performance of parity puncture Turbocode is superior compare to date puncture code structure. Simulation result also shows that random interleaver is the ideal choice for Turbo concatenated code structure.

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