PROPOSED DETERMINISTIC INTERLEAVERS FOR CCSDS TURBO CODE STANDARD

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ABSTRACT

It is well known that an interleaver with random properties, quite often generated by pseudo-random algorithms, is one of the essential building blocks of turbo codes, however, randomly generated interleavers has a lack of a compact representation that leads to a simple implementation. Especially for satellite application, we avoid using memories to save a look-up table, but the best way to do is to generate these interleavers on the fly from simple algorithms. One of those algorithmic interleavers is used by CCSDS (Consultative Committee for Space Data Systems). In this paper, several deterministic interleavers will be suggested of length matched with CCSDS standards to be used in the satellite applications and their performances were compared with CCSDS interleaver performance. The minimum Hamming distance and their multiplicities are the criteria for comparison. The simulation results show a larger minimum distance which leads to decrease the error floor to be applicable in satellite new missions. Moreover, the results give a larger minimum distance by factor of 1.12dB compared with the CCSDS interleaver. The suggested deterministic interleaver can be used in turbo code systems without any encoder/decoder configurations change or adding any system complexity. The simulation is applied for frame length 1784, and code rate 1/2.

Keywords*; (turbo codes, CCSDS, algorithmic interleaver)*

1. INTRODUCTION

Turbo codes play a major role in the error channel coding scheme used in wireless communication. Turbo codes emerged in 1993 [1] and since this year it becomes a popular area of communications research. Due to their performances, turbo codes are being accepted as standards by many organizations such as UMTS, DVB and CCSDS [2] to be used in satellite channel coding after it achieved many successions in a lot of missions including SMART-1 launched in September 2003, and NASA's MESSENGER, launched on August 2004.Turbo code is the most adaptable error coding scheme used to give performance very close to Shannon's capacity with large interleavers In Satellite applications, we avoid using pseudo-random interleavers which has a lack of a compact representation and a simple implementation, but, we are looking for deterministic algorithms to generate these interleavers on the fly from simple algorithms [3].]. This paper proposes deterministic interleavers with large minimum distance to improve the performance of Turbo code in the reign of high Eb/N0 by lowering the error floor, while reduction the error floor allows the performance curve to reach lower Bit Error Rate (BER) below 10^{-10} for future Satellite missions [4]. In this paper, computer searching algorithm has been developed to optimise turbo code parameters (interleavers models, feed-back polynomial, and feed-forward polynomial) for frame length and code rate constraint. The selectivity criteria based on two steps; first, the code minimum distance and its multiplicity, second, Bit Error Rate simulation performance with Eb/No combined with. Both criteria putting together to have a complete picture of the code performance in a wide range of Eb/N0

This paper is organized as follows; the turbo code CCSDS standard is reviewed in Sect 2. Explanation of interleavers design is made in Sect 3. The analysis of the results in Sect 4; finally, conductive conclusions are done in Sect 5.

2. TURBO CODES CCSDS STANDARD PARAMETERS

Standardization of turbo codes by the CCSDS organization was remarkable efficient process, because there are relatively few parameters must be determined to define a turbo code. In fewer than six years from the initial discovery of turbo codes in late 1993, a CCSDS standard has been issued the family of turbo codes that are depicted in Fig. 1.The turbo codes parameters that are chosen for CCSDS standards are the constraint length, frame lengths, code rate, the feed-back and the feed-forward polynomials, puncturing pattern and the interleaver type. Table I summarizes the CCSDS turbo code parameters [2].The CCSDS interleaver is an algorithmic interleaver. Fig.2&3 shows the CCSDS deterministic interleaver algorithm and its permutation distribution for the frame length 1784 [2].

TABLE I. CCSDS TURBO CODES STANDARD PARAMETERS.

Code type	Systematic parallel concatenation turbo code
Number of components codes	2 (plus an uncoded component to make the code systematic).
Type of component codes	Recursive convolutional codes.
Number of states of each convolutional component code	16
Nominal1 Code Rates	r = 1/2, 1/3, 1/4, or 1/6 (selectable).
Interleaver length k	1784,3568,7136,or 8920
Interleaver type	Algorithmic

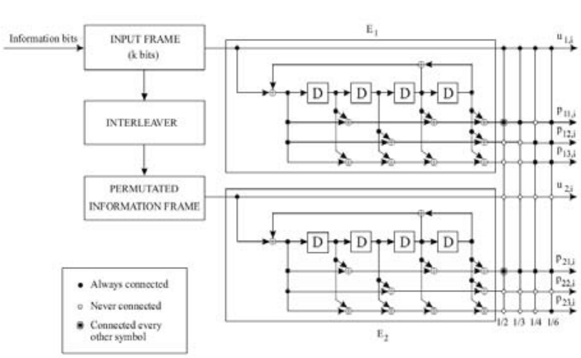

Figure 1 CCSDS turbo code encoder.

Algorithm.1 for CCSDS Deterministic interleaver

$$Frame\ length = 1784 = 8 * 223 \therefore k_1 = 8; k_2 = 223$$

$$let\ P_1 = 31, P_2 = 37, P_3 = 34, P_4 = 47, P_5 = 53,$$

$$P_6 = 59, P_7 = 61, P_8 = 67$$

$$For\ s = 1:1784$$

$$m_1 = mod\left(\frac{s-1}{2}\right) \quad , i_1 = floor\left(\frac{s-1}{2 \cdot k_2}\right)$$

$$j_1 = floor\left(\frac{s-1}{2}\right) - i_1 * k_2 \ \ , t = mod\left(\frac{19 i_1 + 1}{k_1/2}\right)$$

$$q = mod\left(\frac{t}{8}\right) + 1, \ c = mod\left(\frac{p_q \cdot j_1 + 21 \cdot m_1}{k_2}\right)$$

$$\therefore \pi(s) = 2 \cdot \left(t + c \cdot \frac{k_1}{2} + 1\right) - m_1$$

Figure 2 CCSDS Deterministic Interleaver algorithm

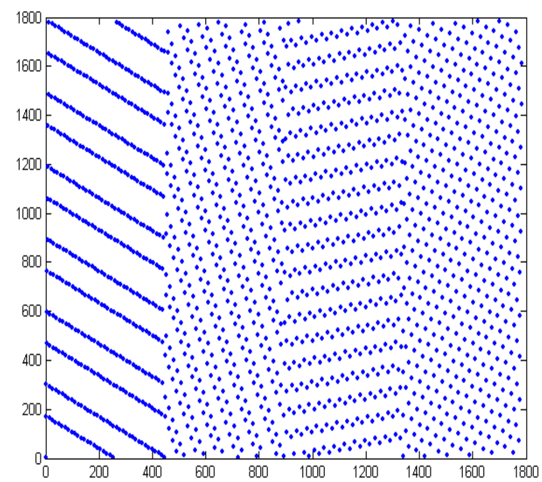

Figure 3 CCSDS algorithmic interleaver.

3. EXPLANATION FOR ALGORTHMIC INTERLEAVER DESIGN FOR CCSDS

In this paper, Gaussian normal distribution function will be assumed for the frame index and a computer searching algorithm was developed to find the set of interleavers (models of interleavers). The selective criteria of these models are minimum distance and multiplicities for all suggested algorithmic interleavers and polynomials for turbo codes [5], [6]. The minimum distance calculation and its multiplicity were calculated based on the method proposed in [7]. Fig. 4&5 shows the proposed deterministic interleaver model and its permutation distribution. The outputs of computer simulation are tabulated in table II and by using a computer simulation the best collection model of interleaver and polynomial was selected.

Algorithm.2 proposed Deterministic interleaver

$$k_1 = 8; k_2 = 223, \quad P_q = 31$$
$$For\ s = 1{:}1784$$
$$m_1 = mod\left(\frac{s-1}{2}\right)$$
$$i_1 = floor\left(\frac{(s-1)\cdot k_2}{2}\right)$$
$$j_1 = floor\left(\frac{s-1}{2}\right) - i_1 * k_2$$
$$t = mod\left(\frac{19i_1+1}{k_1/2}\right)$$
$$c = mod\left(\frac{p_q \cdot j_1 + 113 \cdot m_1}{k_2}\right)$$
$$\therefore \pi(s) = 2\cdot\left(t + c\cdot\frac{k_1}{2} + 1\right) - m_1$$

Figure 4 proposed Deterministic Interleaver algorithm

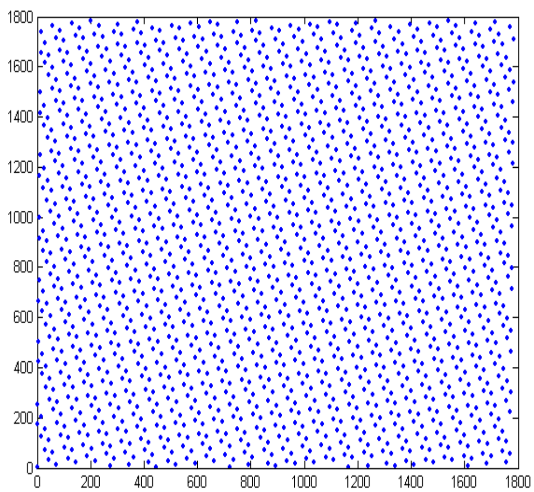

Figure 5 Suggested Deterministic Interleaver Model-6.

4. ANALYSIS OF THE RESULTS

Actually Turbo codes are characterized by coding gains extremely large for low/medium signal-to-noise ratios (high/medium error rates) very close to the theoretical Shannon limits. However, it is well known that their performance may be not as good at very high signal-to-noise ratios (very low error rates), where the "error floor" phenomenon occurs. The use of primitive feed-back polynomial in the component of turbo code gives better performance either you are aiming for decreasing error floor or improving BER in the water fall region [8]. Also we find that, for choosing of feed-forward polynomial, it is based on what you are aiming in your design, if your design is aiming for decreasing error floor in the region of high signal-to-noise ratios, you have to select the primitive feed-forward polynomial. But if your design is aiming for improving BER in the region of low/medium signal-to-noise ratios, you have to choose the non-primitive feed-forward polynomial.

In the region of high signal-to noise ratio, the performance of any binary code is dominated by its minimum distance d_{min} (the minimum Hamming distance between code words) and its multiplicity values, A_{min} (number of code words with weight d_{min}) and W_{min} (sum of the Hamming weights of A_{min} information frames generating the code words with weight d_{min}).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 [9]. The BER code performance can then be approximated by equation (1)

$$BER \approx \left(\frac{1}{2}\right)\frac{w_{min}}{K}\ erfc\left(\sqrt{d_{min}\ \frac{k}{n}\frac{E_b}{N_0}}\right) \quad (1)$$

Where: k/n is the code rate and K is the information frame length. The code minimum distance and multiplicities in table II were used in Equ.1 to calculate the asymptotic error floor at high signal to noise ratio. The results of Equ.1 are plotted in Fig. 6 to choose interleavers model which has lower error floor. Equ.1 allows obtaining a good approximation of the code performance in the region of very high signal to noise ratio without resorting to exhausting simulations. Table II summarizes the minimum distances and the multiplicities for the all suggested modified algorithmic interleavers and polynomials for turbo codes.

TABLE II. THE MINIMUM DISTANCES AND THE MULTIPLICITIES FOR SOME MODIFIED ALGORITHMIC CCSDS INTERLEAVERS.

Frame length K	*Code rate*	*Feedback polynomial FB*	*Feed-forward polynomial FF*	*Interleaver Model Number*	d_{min}	A_{min}	w_{min}
1784	½	10011	11011	Model-1	15	2	6
1784	½	10011	11011	Model-2 (CCSDS)	17	2	6
1784	½	10011	11101	Model-3	16	1	1
1784	½	10011	11001	Model-4	17	1	1
1784	½	10011	11101	Model-5	18	1	1
1784	½	10011	11001	Model-6	22	1	1

The analytical error floor curves provide useful information about the code behavior at high signal to noise ratio and it is used with the code simulation in the low/medium signal-to-noise ratios to elaborate complete picture for the code performance.

Table II shows that the best model which has larger minimum distance and gives lower error floor compared to Model-2 (M2) for the CCSDS is model-6 (M6) which has parameters (d_{min}=22, A_{min}=1, W_{min}=1). The performance comparisons are shown in Fig. 7.

Also from Table II with the help of simulation, we find that model-4 (M4), which has parameters (d_{min}=17, A_{min}=1, W_{min}=1), gives better performance in the region of water fall compared to Model-2 (M2) for the CCSDS and the performance comparison shown in Fig. 8.

The improvement in error floor of the suggested interleaver in model-6 is computed using Equation. (2).

$$\Delta d_{min} = 10\log\left(\frac{d_{min}\ (new\ interleaver)}{d_{min}\ (CCSDS\ interleaver)}\right) = 10\log\left(\frac{22}{17}\right) = 1.12\ dB. \quad (2)$$

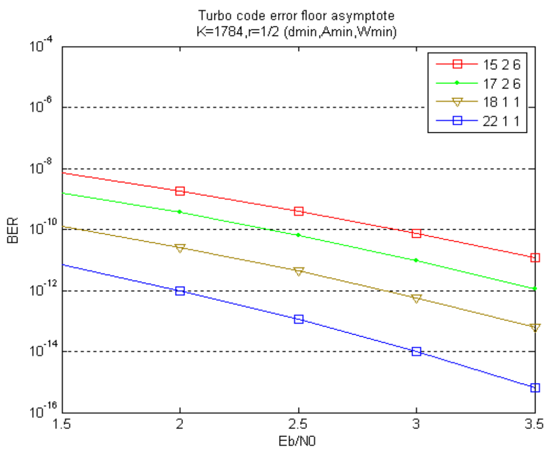

Figure 6. Analytical error floor Asymptote for K=1784, r=1/2 for different parameter (d_{min},A_{min},W_{min}).

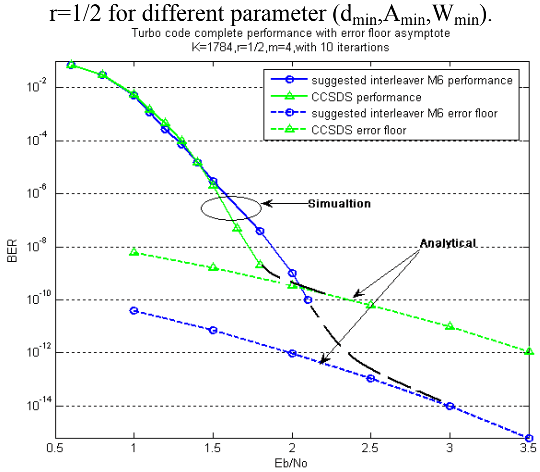

Figure 7. performnance comparison for CCSDS turbo code with suggested interleaver M6,K=1784, r=1/2 (better in error floor region)

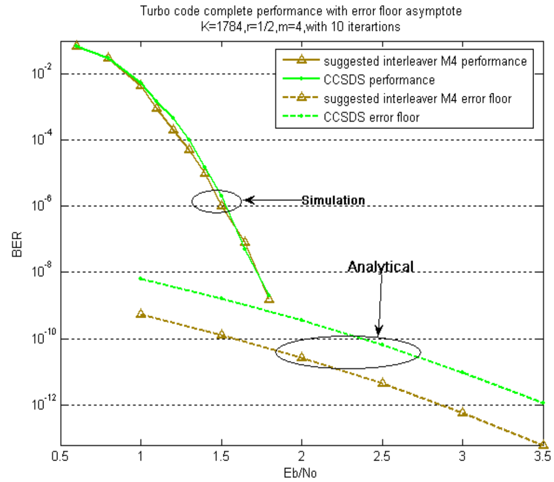

Figure 8. performance comparison for CCSDS turbo code with suggested interleaver M4,K=1784, r=1/2 (better in water fall region)

5. CONCLUSIONS

In this paper, some deterministic interleavers were suggested and their performance was simulated and compared with the one used in the CCSDS standard. Simulation results, shows that the model-6 (M6), that has interleaver parameters (d_{min}=22, A_{min}=1, W_{min}=1), has higher minimum distance which means lower error floor than the original configuration CCSDS by a factor of 1.12dB in the region of high Eb/No. This means that we can use it in the new CCSDS earth observation missions which need BER≤10^{-10}. Moreover, simulation results show that the Model-4 (M4) for interleaver parameters (d_{min}=17, A_{min}=1, W_{min}=1) has slightly better performance than the conventional CCSDS interleaver in the region of BER=10^{-3} to 10^{-6} but with lower error floor.

Those achieved results can be applied to the turbo code systems without any encoder/decoder configurations change or any additional system complexity.

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