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A New Block S-Random Interleaver for Shorter Length Frames for Turbo Codes

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Abstract

In this paper, we have proposed a new design of interleaver based on S-random and block interleaver. The characteristics of both block and S-random interleaver are used by this proposed interleaver. There is a large influence of free distance in turbo codes due to interleaving as it lowers the error floor. The free distance of turbo codes can be increased by designing interleaver with high spread. In this case, the overall spreading factor is increased significantly for smaller length frames also. The simulations results are compared with full S-random interleavers. The bit error rate performance of proposed interleaver for Turbo codes is much better than full s-random interleaver at the cost of small delay.

Keywords: *turbo code, S-Random interleaver, spread property, parallel concatenated convolutional code*

1. Introduction

Turbo codes [1] represent powerful error correcting codes so far. At low SNR, bit error rate is affected by medium weight code words and at high SNR, error performance is influenced by low weight code words. Due to low weight code words, a condition of low error floor is introduced. These codes well performed at low SNR due to their sparse distance spectrum.

In order to lower the error floor, increase in free distance [2] is required. It can be done either increasing interleaver size or interleaver design. Increasing interleaver size leads to longer delays and more memory requirements. So interleaver is to be designed such that error floor is reduced.

It is clearly discussed in literature that the interleaver size and structure affect the turbo code error performance considerably. At low SNR's the interleaver size is the only important factor, as the code performance is dominated by the interleaver gain. The effects induced by changing the interleaver structure at low SNR region are not significant. However, both the interleaver size and structure affect the turbo code minimum free distance and first several distance spectral lines. At high SNR's turbo code performance is dominated by the several distance spectral lines which are produced by low weight sequences. The interleaver structure affects the mapping of low weight input sequences to the interleaver output.

Unlike convolutional codes [3], turbo codes have an error floor at high SNR's i.e., the bit error rate drops very quickly at the beginning, but eventually levels off and becomes flat at high SNRs. This is due to the asymptotic performance characterized by the minimum free distances associated with the turbo codes are typically very small. The free distance of turbo code can be increased by designing interleavers with high spreads.

S-Random interleaver [4] has a good distance spectrum property and produced better results than previous interleavers. Some modifications are introduced in [5, 6] of S-random interleaver for improvement in performance. But at the same time there are two major drawbacks one is to find a good interleaver (with large spreading factor) for longer length frames, that require more computation and second is the processing delay.

In this paper, we propose a new design of interleaver referred to as block S-random interleaver. We evaluate the performance of Turbo codes with the proposed Block S-Random Interleavers (BSRI) and compare it to those with full S-random interleavers.

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This paper is organized as follows: In section II, several existing interleavers are briefly explained. The definition of interleaver spread is defined in section III. Section IV describes the algorithm for the proposed interleaver. Simulation results are compared for different designed interleavers in section V.

2. Interleavers in Turbo Codes

The general structure used in turbo encoders is shown in Figure 1. Two component codes are used to code the same input bits, but an interleaver is placed between the encoders. Generally RSC codes are used as the component codes, but it is possible to achieve good performance using a structure like that seen in Figure 1 with the aid of other component codes called Parallel concatenated convolutional code [7]. The constituent encoders in a PCCC are always recursive convolution encoders.

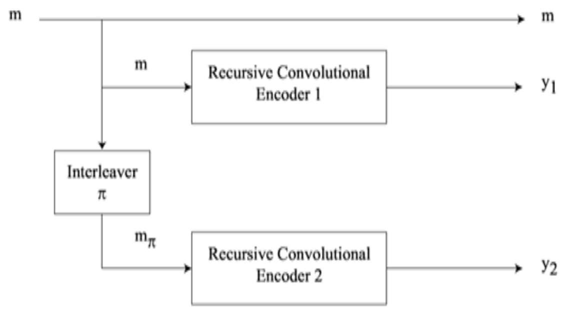

Figure 1. Parallel Concatenated Convolutional Code

Here m is input data stream and y_1 is first parity sequence after passing through Recursive convolutional encoder 1. After interleaving input data passes through Recursive convolutional encoder 2 and get second parity sequence y_2. Among several conventional interleavers we reviewed the two common interleavers as pseudo random and S- random interleaver.

1) Pseudo-Random Interleaver
   Let k denote an integer chosen from [0, N -1] and π (k) denotes its position after interleaving. For each k, a pseudo random interleaver randomly but uniquely chooses π (k) from [0, N-1].
2) S-Random Interleaver
   S-random interleavers or spread interleavers are constructed by generating random numbers from 1 to L based on an S- constraint where S is the minimum interleaving distance.

The operation of the S-random interleaver is as follows. A randomly selected integer is compared to the previously S1 selected integers. If the absolute differences between the selected integer and any of the S1 previously selected Integers are greater or equal to S2 then the randomly selected integer accepted otherwise it is rejected. An S- Random interleaver is determined based on:

$$| Ii - Ij | \leq S1 \tag{2}$$

$$| M(Ii) - M(Ij) | \geq S2 \tag{3}$$

Where Ii denotes the original index and M(Ii) is the permuted index in the interleaved sequence. When identical constituent codes are used, it is appropriate to choose S1=S2=S, where S ≤√(N/2) [10].

The major issue associated with the conventional S-random interleaver is its lack of flexibility since changing the number N requires another search of interleaver and the generated interleavers with different length should be stored in memory separately.

3. Interleaver Spread

Figure 2 shows a definition of interleaver spread. Here, the indexes 1,2,….N form the input vector of length N to be interleaved, and M is the vector after interleaving. The spread of the interleaver is defined as:

$$S = \min_{i,j,i \neq j} [|M(i) - M(j)| + |i - j|] \quad (1)$$

Pseudorandom interleavers permute the elements in a predefined random order. This interleaver requires N indexes to be stored to implement an interleaver of length of N. There is no restriction and thus may have poor distance properties, causing an error floor problem. To improve the free distance of turbo code, spread-random or Semi-random (S-random) interleavers can be used. In S-random interleaver, the permutation order is selected such that any integer in the order is at least S number of positions away from the previous S integers in the interleaver.

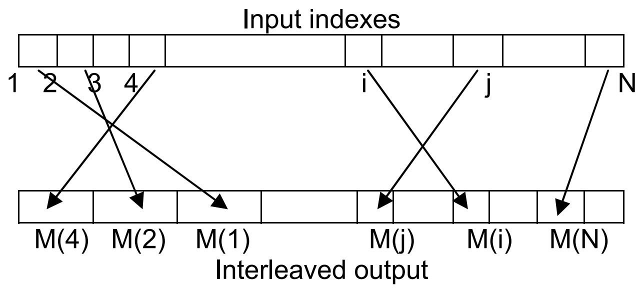

Figure 2. Spread of Interleaver

4. New Proposed Interleaver

In this section, we provide an algorithm for proposed interleaver referred to as Block S-Random Interleaver (BSRI). The characteristics of both block and S-random interleaver are used by this proposed interleaver. The detail algorithm and flowchart are stated as follows:

Step 1: Information sequence having length N is written row wise into a matrix [m, n] as shown in Figure 4. Here m and n are rows and columns of block matrix.

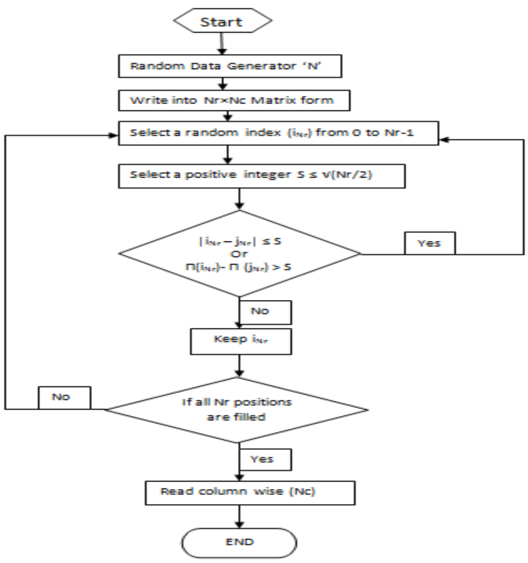

Figure 3. Flowchart for Proposed Interleaver

Example: The length of information sequence is N = 16.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

Figure 4: Information bits written row-wise

Step 2: First each rows of matrix are interleaved by fixed S-random interleaver's algorithm as shown in Figure 5. In this example spreading factor(S) ≤ √N/2 and (N= 4), S ≤ 1.414, S = 1. S_C= {2, 1, 4, 3}.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

5	6	7	8
1	2	4	3
13	14	15	16
9	10	11	12

Figure 5. Interleave Each Row Using S-Random Method

Step 3: Then, each column of matrix is read one by one and interleaved sequence is encoded by convolutional encoder. In this example, the interleaved sequence is as shown in Figure 6.

5	1	13	9	6	2	14	10	7	4	15	11	8	3	16	12

Figure 6. Read Each Column

The spread of full S-random interleaver for frame having size N is:

$$S_{SR} \le \sqrt{(N/2)} \quad (4)$$

In proposed interleaver, overall spread is dependent on size of row and spread between each row.

The information sequence having frame size N is stored in block matrix of m rows and n columns ($N= N_R \times N_C$). The overall spread of proposed interleaver is:

$$S_{BSRI} = N_C \, . \, S_R \quad (5)$$

$$S_{BSRI} = N_C \, . \, \sqrt{(N_R/2)} \quad (6)$$

Here S_{BSRI} is overall spread and S_R is spread between each rows calculated with conventional S-random interleaver. The spread of new interleaver BSRI is $\sqrt{N_C}$ times the spread of original full S-random interleaver.

Table 1. Spread for S-random and Proposed Interleaver (m=n)

Frame size(N)	Full s-random int. $S_{SR} \le \sqrt{(N/2)}$	BSRI ($N= N_R \times N_C$) $S_{BSRI} = N_C . S_R$
16	2	4
64	5	16
256	11	32
1024	22	128

5. Simulation Results

We designed Turbo encoder using recursive systematic convolutional (RSC) encoders having generator polynomial of G [1 15/13], constraint length is 4 and number of iterations is 5. The overall code rate is ½ after puncturing [8]. The frame size is taken 256.

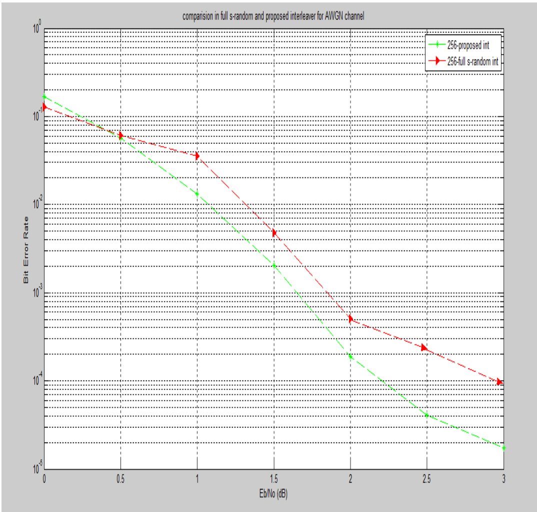

Figure 7. Comparison of BER Performances in Full S-random Interleaver and Proposed Interleaver for AWGN Channel

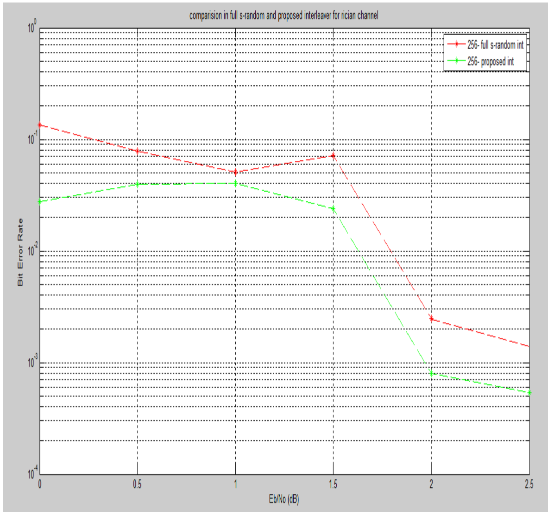

Figure 8. Comparison of BER Performances in Full S-random Interleaver and Proposed Interleaver for Rican Channel

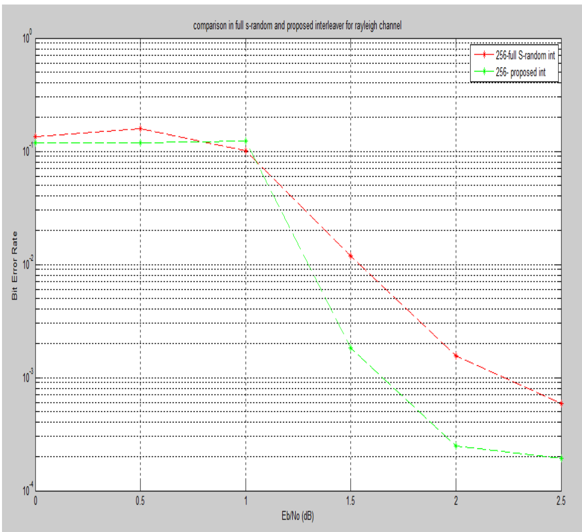

Figure 9. Comparison of BER Performances in Full S-random Interleaver and Proposed Interleaver for Rayleigh Channel

There is comparison of Bit error rate performance in full s-random interleaver and proposed interleaver for AWGN channel and fading channels. The performance of the proposed interleaver is more than full s-random interleaver as shown in Figure 7, Figure 8 and Figure 9.

6. Conclusion

In this paper, we proposed a new interleaver that is based on both block and S-random interleaver. In proposed interleaver, as the overall spread factor is $\sqrt{N_C}$ times the spread factor (S_{SR}) in full S-random interleaver. This is another way to improve the free distance of turbo code and hence it will improve Bit Error Rate performance of Turbo codes. The simulation results show that for smaller frames (256) also, the BER performance of proposed interleaver is better than full S-random interleaver. The error floor starts at BER 2.10^{-4} as compared to 5.10^{-4} for full S-random i.e. BER is improved 2.5 times. On the other hand for a BER of 10^{-4}, a coding gain of 0.875 dB is achieved by new interleaver as compared to the S-random interleaver for non-fading AWGN channel. The similar improvements are evident for fading channel cases also.

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