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New Puncturing Pattern for Bad Interleavers in Turbo-Codes

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Abstract: This paper presents a new method of puncturing for worst interleavers. We study via simulation the effect of different combinations of tow puncturing patterns and three classes of interleavers on the performance of punctured turbo-coded systems. The interleavers types are uniform, *S*-random and odd-even random. The effect of new puncturing pattern is evaluated and shown to be ameliorated the performance of turbo-coded systems.

Keywords: Turbo-code, Interleavers, Puncturing, Uniform, *S*-random, Odd-even.

1 Introduction

The turbo codes constitute a family of error correcting codes which make possible to achieve the theoretical limit of correction predicted by Shannon there is more than 50 years. These codes, invented at the beginning of the years 1990, are obtained by the concatenation of two or several convolutional codes of low complexity, separated by a interleaving function introducing the diversity. Their decoding calls an iterative process (or turbo) using two or several elementary decoders which exchange information of reliability, called (extrinsic information), in order to improve the correction with the iterations. Posterior researches are mainly related to: study the significant parameters of the code and other research orientations. Among these parameters there is puncturing. In the turbo-decoders, the aim of the interleaving technique is the decorrelation of the soft decisions available at output of the decoders of Berrou-Adde [1]. Let us note that in the turbo-coder, the interleaver ensures a significant distance from all the not-null words of code compared to the null vector [4], and this increases the free distance from the code [1,2].

They studied the effect of puncturing on the turbo-codes according to the following criterion: the power of coding is uniformly distributed to all the bits of information [3]. Recalling that puncturing is used to increase the rate of code, and it increases also the groups of error at output of the elementary decoder.

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However, it remains to see the effect of the puncturing on the BER for information bit for each bit position in the frame with several categories of interleaving, which is not studied in other work. A new puncturing method is proposed in this paper based in the following criterion:

Balance the BER for each bit position in the frame.

The analysis of this interaction is difficult; however, our simulation can provide useful insights and suggest fruitful directions for theoretical researches. In this article, we have the results of work relating to the new puncturing pattern for bad interleavers in turbo-codes. Section II details the principle of the transmission system used for simulation. Section III has the various results on the punctured turbo-codes while playing on the interleaver, and which rate is 1/2. Their performance were evaluated in the presence of a Gaussian channel. In section IV we investigated the Bit error rate for each bit position in the frame and suggest the new puncturing pattern and give the results of performance.

2 The Transmission System Used for Simulations

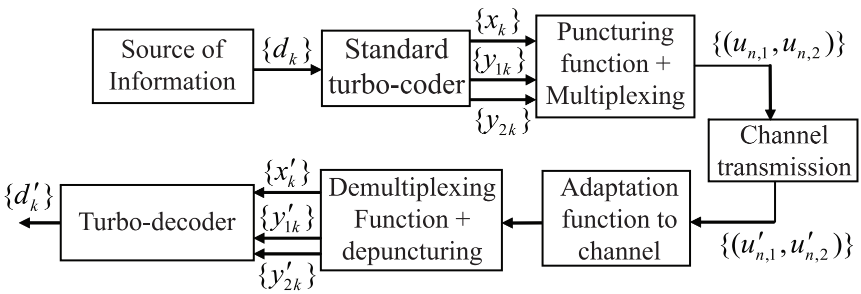

Fig. 1 – *A block diagram of a communication system.*

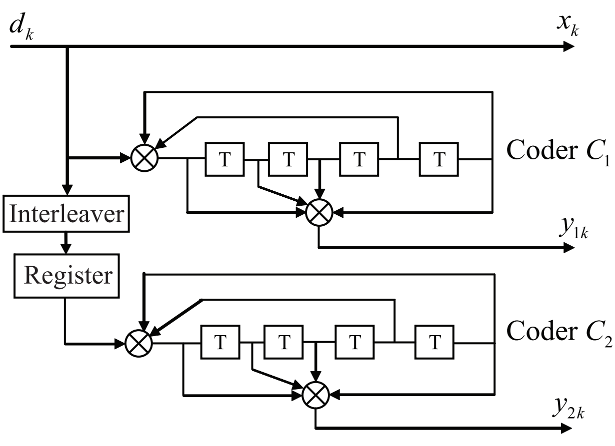

Fig. 2 – *Standard turbo-coder structure.*

Fig. 1 represents the transmission system for which we evaluated the Binary Error Rate (TEB) after decoding. The binary symbols resulting from the source of information constitute the sequence of data to be transmitted. The coder of channel receiving these data is a standard turbo-coder of rate 1/3 [4]. it is obtained by parallel concatenation of two Recursive systematic convolutional codes (RSC), of rate 1/2, constraint length $K = 5$, and generating polynomials (23,35), separated by an interleaver (Fig. 2). The code RSC, which has these generating polynomials, is powerful in terms of the free distance and of the factor of diversity.

2.1 The puncturing

Using the technique of puncturing, it is possible to provide a different turbo-coders of various rate, starting from only one standard code which rate is generally equal to 1/3. The codes obtained present performance very close to those obtained with optimal codes (not punctured) of the same rate. However, in condition that the matrix of puncturing are well selected. This puncturing technique makes it possible to simplify the trellis since in each state converges, only, two branches and not 2^M branches as for an optimal code of rate *M*/*N*. This decreases the complexity of decoding using the soft output Viterbi algorithm (SOVA). Moreover, the same turbo-decoder can then be used for a whole of compatible punctured codes. A simple method consists to puncture only the parity bits which differs from the information bits, in this case we should choose a puncturing matrix with information bits coefficient equal to 1. Such a matrix is known as "*invariant*" and this technique of puncturing is called "parity data puncturing", noted PDP will be adopted during the simulation of the transmission system described previously. The classical puncturing mask used in our simulation to obtain a code rate 1/2 is as follows: for the first and the second convolutional coder are 10 and 01 respectively. Several works showed the improvement of the performance in these turbo-codes by using an odd-even interleaver.

2.2 The interleaving

There are two families of interleavers: block interleaving and convolutional interleaving. For example, the block interleaving family includes several types of interleaving like the classical interleaver (uniform), pseudo-random (Berrou-Glavieux), random... etc. We are mainly interested in block interleaving. To have more details, we will be able to refer to [5].

A uniform interleaver has a period or size N_b describes by a matrix of size $L \times C$. This type is characterized by a process in which the data are written by line in this matrix and then these data are read by column:

$$\pi(k) = L(j-1) + i - 1, \quad k = 0,1,\ldots,N_b - 1, \text{ where: } i = (k+1) \operatorname{div} C = j',$$

$$j = (k+1) \text{ Modulo } C = i',$$
$$i = 1, 2, ..., L, \quad j = 1, 2, ..., C,$$

where i, j: are respectively the line and the column of writing. And i', j': are the line and the column of reading. We note that $A \operatorname{div} B = [A / B] + 1$. The pseudo-random interleaver is used by Berrou and Glavieux in the first turbo-code and it is a uniform interleaver modified to limit a two-dimensional correlation of errors. The random interleaver is generated using a purely random vector [6]. The *S*-random interleaver is a random interleaver with a restriction of his dispersion capacity [5, 6]. For the turbo-code of rate $R = 1/2$ (with puncturing), the odd-even interleaver makes an improvement of the performance [6]. It is generated with the following condition: the bits having odd positions (respectively even) are permuted to odd positions (respectively even).

3 The interleaver Influence on the Performance

In this part, we evaluate, by simulation, the performance of the turbo-decoder using Berrou-Adde decoders placed in cascade to realize an iterative decoding [4]. The binary symbols from the channel coder are modulated by a modulation QPSK, and transmitted with puncturing on an Additive White Gaussian Noise channel (AWGN). In this case, the received signal is in the form:

$$u'_{n,1} = \left(2u_{n,1} - 1\right) + z_{n,1},$$
$$u'_{n,2} = \left(2u_{n,2} - 1\right) + z_{n,2},$$

where $z_{n,1}$ and $z_{n,2}$ are two centered and independent Gaussians noises, whose variance is according to the signal noise ratio (SNR). It is interesting, to study the influence of interleaving on the turbo-code performance considered, varying the three following parameters: Regularity of the interleaver, dispersion capacity "*S*" and the odd-even propriety.

The types of interleavers used in this part are as follows: the uniform interleaver, random odd-even, and *S*-random. Fig. 3 represents the curves of the Bit Error Rate (BER) after decoding according to the SNR, for 10 iterations $P = 10$ (module of decoding), and for size of interleaving frame equal to 1024, by using the tree types of interleaving quoted above with classical puncturing.

In view of the results presented on Fig. 3 (with a Gaussian channel), the random odd-even interleaver seem very effective element in the punctured turbo-code system, While the uniform does not gives good performance in this case. In odd-even interleaver all the even positioned bits are mapped to even positions and all the odd positioned bits are mapped to odd positions. This interleaver with the classical puncturing leads to each information bit having one parity bit. In other words an even protection of each bit of information and an overall increase in performance compared to an interleaver without this constraint.

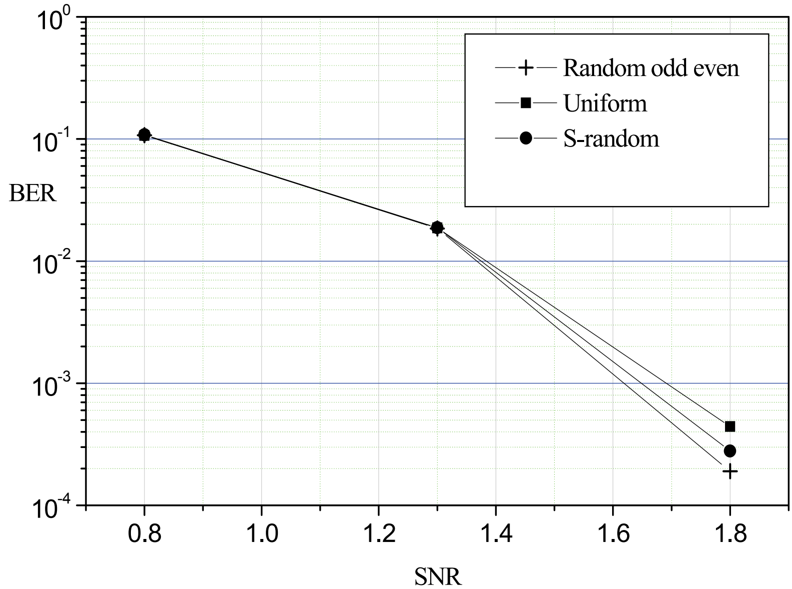

Fig. 3 – *The interleaver influence on the performances o*f *Turbo-code of rate* $R = 1/2$ *and size interleaver* 1024 *with classical puncturing.*

4 Bit Error Rate for Each Bit Position and New Puncturing Pattern

Fig. 4 was plotted from simulation results for a uniform interleaver at $\text{SNR} = 1.8\,\text{dB}$. The plot represents the BER for information bit for each bit position in the frame. In order to produce the plot, 1600 frames of length 1024 were decoded in one iteration.

It is apparent from the figures that BER is very low for the termination of the frame.

So, we suggested a method of puncturing consist to let the N firsts bits in the first parity codeword without puncturing, and puncture the all N last bits in the frame. The mask of puncturing become as follows: for the first and the second parity codeword respectively

$$\underbrace{11\ldots1}_{N\text{ bits}}\,0101\ldots\underbrace{00\ldots00}_{N\text{ bits}}$$

$$101010\ldots\ldots\ldots\ldots1010$$

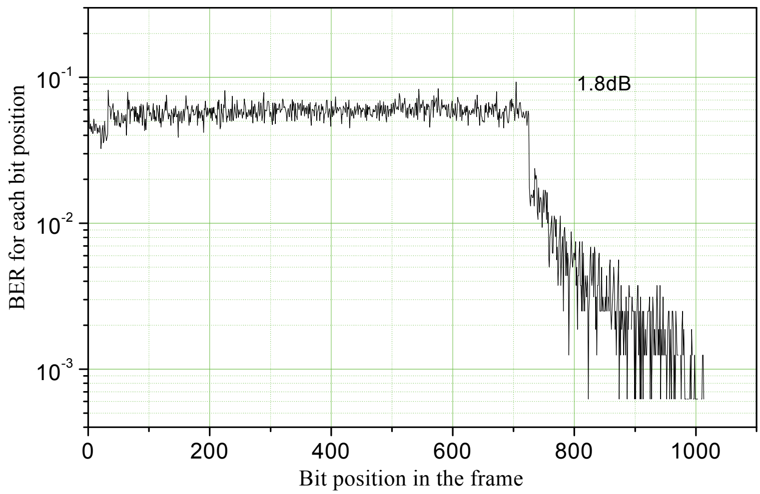

Fig. 4 – THE BER *for information bit for each bit position in the frame for uniform interleaver*, SNR = 1.8dB.

4.1 Uniform interleaver

Fig. 5 represent the curves of the Binary Error Rate (BER) after decoding according to the SNR, for 10 iterations $P=10$, and for size of interleaving frame equal to 1024, using the uniform interleaving with classical and new puncturing pattern ($N=5,10$). In this section, we discuss the simulation result for different combinations of interleavers and puncturing rules, at low SNR (0.8dB) as well as moderately high SNR (1.3dB and 1.8dB).

The uniform interleaver with new puncturing provides the lowest BER compared to the classical puncturing for moderately high SNR (Fig. 5). This phenomenon could be manifestation of the increased protection of *N* firsts bit of information. This is achieved by the increase of parity bits for these *N* bits of information.

With classical puncturing each bit of information has one parity bit, and with new puncturing each bits in the *N* firsts bit of information has one or two parity bit and each bit in *N* last bits has one parity bit at most, in other words we increases the protection of information in the beginning and decrease the protection in the termination of the frame. This leads to the balance of the BER for each bit position in the frame (Fig. 4) since it is very high in the beginning and very low in the termination of the frame.

Fig. 5 show that the uniform interleaver with new puncturing pattern for $N=10$ has the best performance compared with the same puncturing for $N=5$ and $N=20$. This shows that the parameter *N* must not exceed 10 for this size of frame.

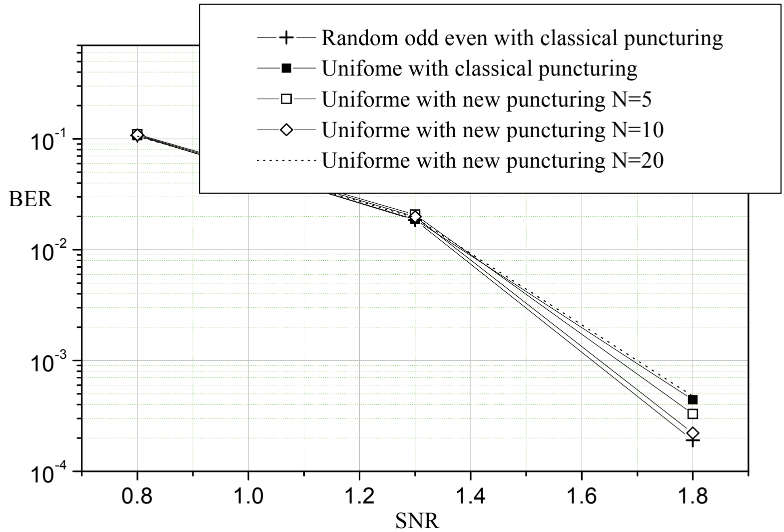

Fig. 5 – *Turbo-code performances of rate* $R = 1/2$ *and uniform interleaver of size* 1024 *with new and classical puncturing.*

4.2 *S*-random and random odd-even interleavers

Fig. 6 represent the curves of the Binary Error Rate (BER) after decoding according to the SNR, for 10 iterations, and for size of interleaving frame equal to 1024, using the *S*-random and random odd even interleaving with classical and new puncturing pattern ($N = 10$).

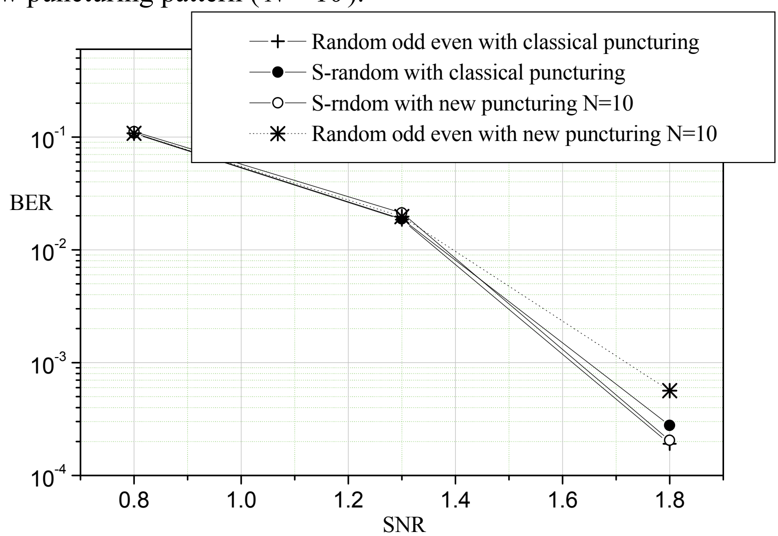

Fig. 6 – *Turbo-code performances of rate* $R = 1/2$ *and S-random and random odd-even Interleavers of size* 1024 *with new and classical puncturing.*

The *S*-random interleaver with new puncturing provides the lowest BER compared to the classical puncturing for moderately high SNR (Fig. 6). The reason is the same that the uniform interleaver. At the same time, the random odd even interleaver with the classical puncturing has the best performance compared with the new puncturing. Because it is adapted with the classical puncturing pattern according to their definition (Section 3) [3,6].

5 Conclusion

We have presented a new method of puncturing for turbo-codes. This method is based on the balance of the BER for each bit position in the frame. Simulation results indicate an improved asymptotic performance for classical interleavers (uniform, *S*-random) associated with new puncturing method, so this puncturing pattern ameliorates the performance of bed interleavers combined with classical puncturing. The BER of uniform and *S*-random interleavers associated with new puncturing is nearly equal to the BER ofodd-even interleaver combined with classical puncturing which performed the best.

To provide more insight into the proposed method, we investigated the Bit error rate for each bit position in the frame. In particular, we studied the balance of this BER while varying on the puncturing pattern. This article shows that we can still improve the performance of the turbo codes by studying the puncturing methods.

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