Method of adaptation of interleaving/deinterleaving devices in wireless data transmission systems with LDPC codes

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Abstract

The article proposes a method for adapting interleaving/deinterleaving devices in wireless data transmission systems with LDPC codes under conditions of a priori uncertainty by changing the type of interleaving/deinterleaving device to increase the reliability of information transmission.
The method is based on calculating the value of the normalized Log-Likelihood Ratio (LLR) and based on it, the type of interleaving/deinterleaving device is selected. This method allows to increase the reliability of information transmission.

Keywords

LDPC codes, Log-Likelihood Ratio, Interleaver, Deinterleaver, Decoding, Parity-check matrix

1. Introduction

The rapid development of wireless technologies (Wi-Fi, WiMAX) and mobile communication technologies (5G) made it possible to implement them in various spheres of life.

Namely:

1. in healthcare: development of patient monitoring systems [1], telemedicine, etc.;
2. agriculture: development of resource optimization and control systems for harvesting and increasing yields and assessing efficiency [2];
3. industry: development of production line control systems and real-time equipment monitoring systems [3];
4. logistics and transport: development of autonomous vehicle control systems [4];
5. Internet of Things (IoT) [5, 6];
6. smart cities: energy consumption monitoring and energy saving systems, security systems [7];
7. virtual and augmented reality [8];
8. telemetry, data collection and storage systems [9, 10].

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Given the high level of technology adoption in our present day and the need to ensure and improve the quality of data transmission, there is a need to use LDPC codes [11, 12], which are used in the 5G standard [13, 14]. Also, they were adopted by WiMax [16], Wi-Fi [15-17] and DVB-S2 [18] technologies. LDPC codes were chosen due to their lower complexity compared to turbo codes (TC) and high efficiency at high coding rates compared to TC (R = 3/4, 5/6, etc.).

Also, to increase the reliability of information transmission, it is advisable to use an interleaving device. It performs a permutation of bits of an information sequence according to a certain principle and its main function is to reduce the number of group errors by distributing them over time. Interleaving devices have found significant implementation in LDPC codes [19-21] and TC [22-24].

A sufficient number of various types of interleaving devices have been developed, which may differ in the principle and algorithm of interleaving. Fig. 1 presents the classification of interleaving devices according to the principle (algorithm) of permutation of bits in the information sequence.

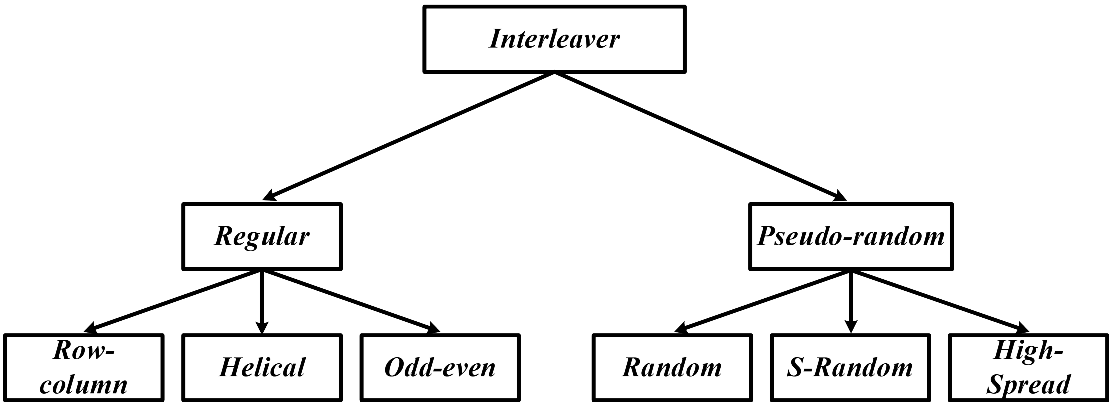

Figure 1: Classification of interleaving devices

In regular interleaving devices, the permutation of bits in the information sequence is performed analytically. That is, the block size or a mathematical formula can be used to permute the bits. They are less complex to implement than pseudo-random interleaving devices, but also have lower efficiency [25, 26].

Pseudo-random interleaving devices permutate bits in an information sequence according to a pseudo-random principle. The main difficulty in implementing this type of interleaver is that for each data block it is necessary to store an interleaving table, which is required for the deinterleaving operation. This type of interleaver is more efficient than regular interleavers and performs more bit spacing within a block. The S-random interleaving device is one of the most efficient due to the variable bit spacing parameter in the information sequence.

Given their efficiency and properties, it is advisable to use them to increase the reliability of information transmission in wireless data transmission systems.

2. Analysis of research and publications

In [20], a method using LDPC codes and interleavers was developed. The method uses different types of interleavers, with an initial selection of a specific type of interleaver without further adaptation, which is a disadvantage due to the inexpedient use of computing resources.
In [27], the use of LDPC codes and interleaving devices is considered. The use of interleaving devices and the min-sum decoding algorithm improves performance and reaches the efficiency level of the sum-product algorithm (SPA) decoding algorithm. The main disadvantage is the choice of a specific type of interleaving device without further modification or adaptation, which can cause increased use of computational resources and an unreasonable increase in computational complexity for LDPC code decoding methods.
We see that interleaving devices are used without further adaptation or possible change of the type of interleaving device, which can lead to inefficient use of computing resources and increased time for data decoding.

3. Formulation of the problem

The purpose of the article is to develop a method of adapting interleaving/deinterleaving devices in wireless data transmission systems with LDPC codes in conditions of a priori uncertainty by changing the type of interleaving/deinterleaving device to increase the reliability of information transmission.

4. Presentation of the main material

Fig. 2 shows a structural scheme diagram of a modified LDPC code encoder including an interleaving device and a control unit for changing the type of interleaver.

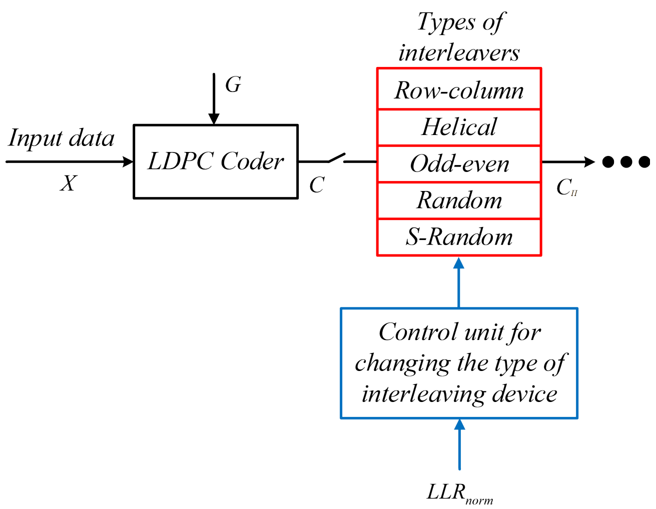

Figure 2: Structural scheme of a modified LDPC code encoder

The encoder input receives an information sequence *X* and transmits a generator matrix *G*, which is created based on the parity-check matrix *H*. Using the generating matrix *G*, the information block is encoded and the output is the encoded data block *C*. An encoded sequence is transmitted to the input of the interleaving device, where bits are permuted depending on the type of interleaving device. And from the output of the interleaving device we obtain an interleaved coded C_{Π} block. Next, the block is transmitted to the modulator and then passes through the channel, where further demodulation, displacement, and decoding are then performed. At the output, the decoding is estimated by calculating the normalized *LLR* LLR_{norm}, where $LLR_{norm} \in [0,1]$. Depending on the value LLR_{norm} the type of interleaving/deinterleaving device is selected.

Fig. 3 shows a structural scheme of a modified LDPC code decoder for iteration *I*, including the deinterleaving device and the control unit for changing the type of deinterleaving device.

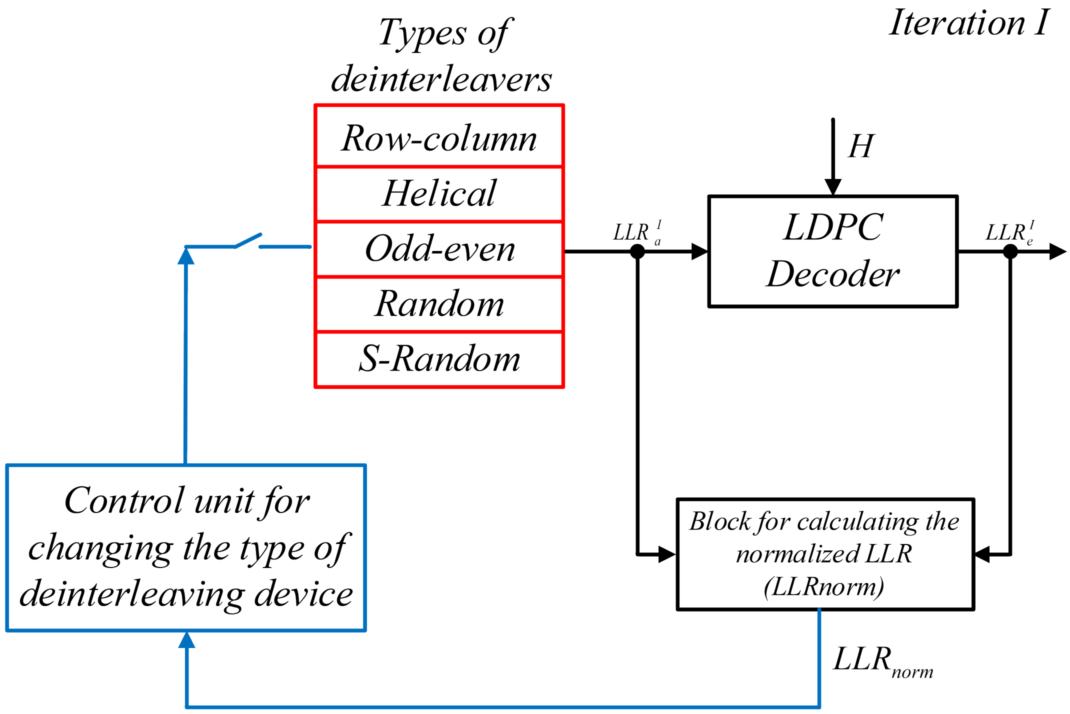

Figure 3: Structural scheme of a modified iterative LDPC decoder

The input of the deinterleaving device receives a coded sequence from the channel, where, depending on the type of deinterleaving device, bits are rearranged to their initial positions. We obtain a vector of a priori values *LLR* LLR_a^I. For further decoding process, a vector of a priori values of the *LLR* LLR_a^I is transmitted to the decoder input and parity-check matrix *H*. As a result of the decoding process, a vector of a posteriori values of the *LLR* LLR_e^I is obtained at the output. Vectors of a priori/posteriori values of *LLR* LLR_a^I / LLR_e^I are sent to the calculation block of the normalized *LLR* LLR_{norm}.

Algorithm for implementing the method of adaptive selection of the type of interleaving/deinterleaving device:

1) Formation of the input information sequence:

$$X = \{x_1, x_2, \ldots, x_u\}, \tag{1}$$

where $u \in \overline{1,U}$, U – the number of bits in the input information sequence.

2) From the channel output, we form the a priori values of the *LLR* LLR_a:

$$LLR_a = \{LLR_a(x_1), \ldots, LLR_a(x_u)\} \tag{2}$$

3) From the decoder output we obtain the posteriori values of the *LLR* LLR_e:

$$LLR_e = \{LLR_e(x_1), \ldots, LLR_e(x_u)\} \tag{3}$$

4) We calculate K_Σ the number of sign changes LLR_a / LLR_e:

$$sign(LLR_a) \neq sign(LLR_e) \Rightarrow K_\Sigma = K_\Sigma + 1 \tag{4}$$

5) We calculate the normalized value LLR_{norm}:

$$LLR_{norm} = \frac{K_\Sigma}{U}, \tag{5}$$

where U – the number of bits in the input information sequence.

6) Based on normalized value LLR_{norm}, we select the type of interleaving device:

$$\begin{cases} LLR_{norm} \geq 0.5 \rightarrow SRandom \\ 0.25 \leq LLR_{norm} < 0.5 \rightarrow Random \\ 0.15 \leq LLR_{norm} < 0.25 \rightarrow Row - column \end{cases} \tag{6}$$

5. Analysis of the results

A simulation model was developed in the QT Creator 6.7, with the help of which the results of the method were evaluated. Decoding algorithm – Sum-product algorithm.

Fig. 4 shows the result of the developed method in comparison with the standard algorithm. The bit error probability P_B was estimated from the signal-to-noise ratio SNR.

The Consultative Committee for Space Data Systems (CCSDS) standard parity-check matrix was used, U = 128 bits, encoding rate R = 1/2.

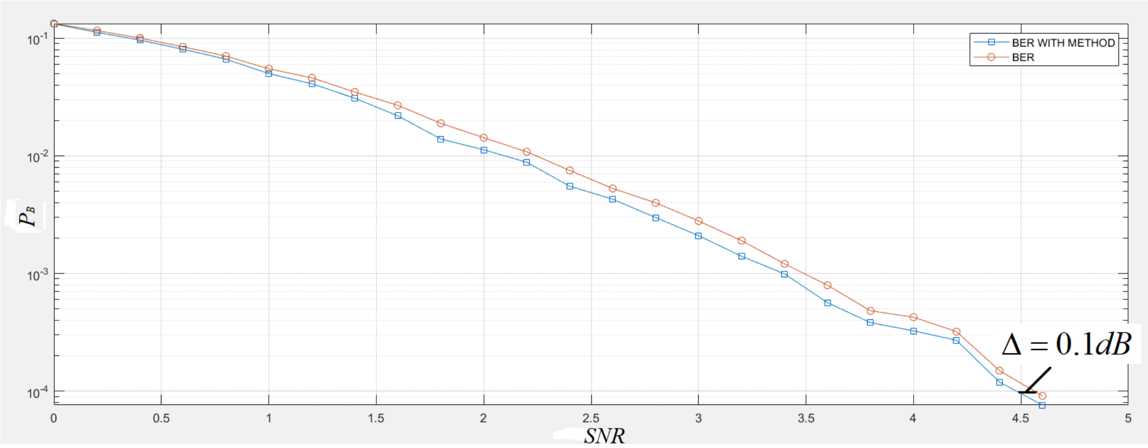

Figure 4: Graph of the dependence of the probability of bit error of decoding on the signal-to-noise ratio

For the probability of bit error in decoding $P_B = 10^{-4}$, the developed method provides an energy gain $\Delta = 0.1dB$.

6. Conclusions

1. The article proposes a method for adapting interleaving/deinterleaving devices in wireless data transmission systems with LDPC codes under conditions of a priori uncertainty by changing the type of interleaving/deinterleaving device to increase the reliability of information transmission.

2. Using the developed method allows obtaining an energy gain of 0.1 dB for the CCSDS standard code U = 128 bits and coding rate R = 1/2.

3. Further research is planned on the topic of multiparameter adaptation of wireless data transmission systems, including interleavers.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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