Adaptive Selection of Turbo Code Parameters in Wireless Data Transmission Systems

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Abstract The article proposes a method for multilevel parametric adaptation of the turbo code codec in wireless data transmission systems. The choice of the actual parameters of the turbo code depends on the values of the normalized number of changes of the sign in the posterior-a priori the log likelihood ratio (LLR) for transmitted data bits of the turbo decoder. The results of simulation showed that the application of the method of multilevel parametric adaptation of the turbo code codec reduces the number of errors by 2–3.3 times, and also makes it possible to increase the reliability of information transmission in comparison with the known results, for example, the fourth generation 4G LTE-Advanced mobile communication.

Keywords Turbo codes · Wireless networks · Posterior-a priori the log likelihood ratio · Reliability of information transmission

1 Introduction

Mobile communications and wireless data transmission systems are widespread in our time and continue to develop intensively.

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S. Shkarlet et al. (eds.), *Mathematical Modeling and Simulation of Systems*, Lecture Notes in Networks and Systems 344, https://doi.org/10.1007/978-3-030-89902-8_20

One of the main and urgent tasks is to increase the reliability of information transfer. It is possible to achieve an increase in reliability through the use of error-correcting codes, such as: convolutional codes, low-density parity-check codes (LDPC codes), Hamming codes, polar codes, turbo codes (TC), Reed-Solomon codes, etc. The most effective are TC and LDPC codes.

TCs are adopted by the mobile communication standards of the third generation 3G UMTS [1], the fourth generation 4G (LTE-Advanced) [2] and the fifth generation 5G [3]. They are inferior in energy efficiency to the Shannon boundary of 0.5 dB for a channel with additive white Gaussian noise at a coding rate $R = 1/3$ [4, 5].

LDPC codes [6] are accepted by the 10GBase-T [7], WiMax [8], Wi-Fi [9], DVB-S2 [10] standards. They are somewhat inferior to TC at a low signal-to-noise ratio.

It should also be noted that polar codes are gaining popularity [11]. They are currently being considered for possible adoption in future sixths generation 6G mobile standards.

In wireless data transmission systems of the fourth generation 4G [12–16] and the fifth generation 5G, single-layer parametric adaptation schemes for TC codecs are used for adaptation, in which only the coding rate R changes.

Consequently, it becomes necessary to implement schemes for multi-level parametric adaptation of TC codecs.

2 Analysis of Research and Publications

The work [17] presents an adaptive algorithm for discrete optimization of signal structures and coding rate of error-correcting code for DS-CDMA systems. Depending on the signal-to-noise ratio values, the error probability value is calculated for various signal modulation schemes and compared with the specified value. The required parameters are selected depending on the comparison results. In this case, channels with Additive White Gaussian noise (AWGN) and Rayleigh fading are considered.

In [16], an algorithm is presented for discrete optimization of the coding rate using a pseudo-random interleaver depending on the value of the error probability.

Work [18] presents a HARQ (hybrid automatic repeat request) system with soft/hard decision-making during decoding. Soft decoding decision making is limited by signal-to-noise ratio of 1.4 dB. The adaptation process is as follows: the size of the information block and the coding rate change depending on the signal-to-noise ratio. In this case, a channel with an AWGN is considered.

In [19], LDPC codes are used and an AWGN channel is considered. The main idea of this work is the real-time evaluation of the signal-to-noise ratio and further adaptation depending on this value. As an indicator of the reliability of information in the work, the average probability of a bit error of decoding $P_{B\,\mathrm{dec}}$ was chosen.

In [20], LDPC codes are also used and one-level parametric adaptation of the coding rate R is applied. The choice of the optimal coding rate is done by comparing the current bit error with table values.

3 Formulating the Goals of the Article

The purpose of the article is to develop a method for multilevel parametric adaptation of a turbo code codec in wireless data transmission systems depending on the values of the normalized number of changes in the sign of a posteriori-a priori LLR about the transmitted data bits of the TC decoder.

4 Presentation of the Main Material

In Fig. 1 a block diagram of a modified TC encoder is shown. The encoder refers to schemes PCCC—parallel concatenated convolutional code. A block of data K is fed to the block generator. In the block generator additional service information is added to the data and the sequence $\overline{X}^C$ is obtained. Then $\overline{X}^C$ is fed to the first recursive systematic convolutional encoder (RSCE-1) and a serially connected interleaver and the second encoder (RSCE-2). Depending on the normalized value of the LLR decisions Q are made about changing the number of iterations, the type of interleaver, and the RSCE polynomials. $Q = \left\{\overrightarrow{Q_1}, \overrightarrow{Q_2}, \overrightarrow{Q_3}\right\}$, where $\overrightarrow{Q_1}$ is the change of the number of iterations, $\overrightarrow{Q_2}$ is the change of the interleaver, $\overrightarrow{Q_3}$ is the change of the RSCE polynomial.

The input of each decoder gets the information received from the output of the corresponding RSCE and taking into account the passage of the channel with AWGN.

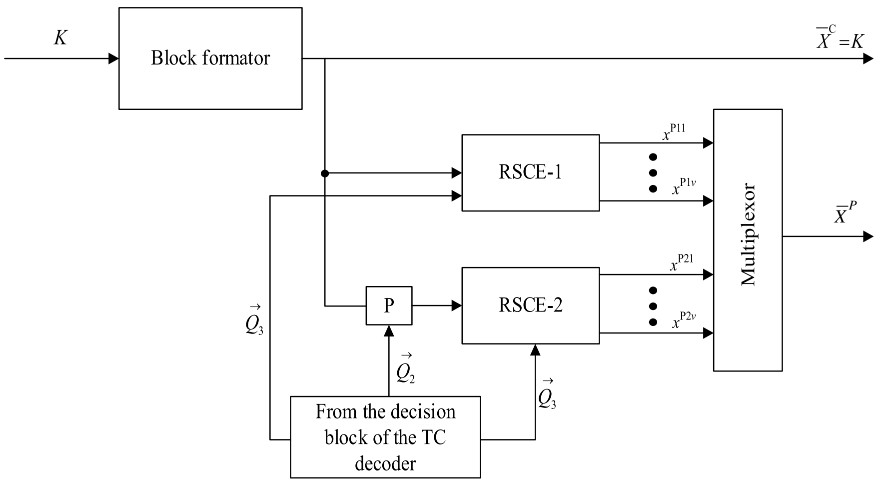

Fig. 1 Block diagram of the modified TC encoder

An iterative decoder consists of interconnected component decoders. One iteration includes two serially connected component decoders, two interleavers and deinterleavers. The interleaver and deinterleaver in the TC decoder circuit converts the error packets at the output of the current decoder into single errors, that greatly facilitates and improves the operation of the next decoder [21].

The block diagram of a modified iterative turbo code decoder with a decision maker block, which contains a module for calculating the normalized number of changes in the sign of a posteriori-a priori LLR F^{*}, is shown in Fig. 2.

Logarithmic relation likelihood function $L(x_t)$ about transmitted bit x_t in general, is defined as follows [22, 23]:

$$L(x_t) = L_c(x_t) + L_a(x_t) + L_e(x_t), \tag{1}$$

where $L_c(x_t)$—channel information, $L_a(x_t)$ and $L_e(x_t)$ a priori and the posterior LLR data bit x_t respectfully. If $L\left(x_t^C\right) \geq 0$, it is considered that bit $x_t^C = 1$ was transmitted, else $x_t^C = 0$.

In Fig. 3 a block diagram of module for calculating the number of changes in the sign of a posteriori-a priori LLR $F^{d,j}$ for a d decoder, $d \in \overline{1, 2}$ and j decoding iterations, $j \in \overline{1, I}$.

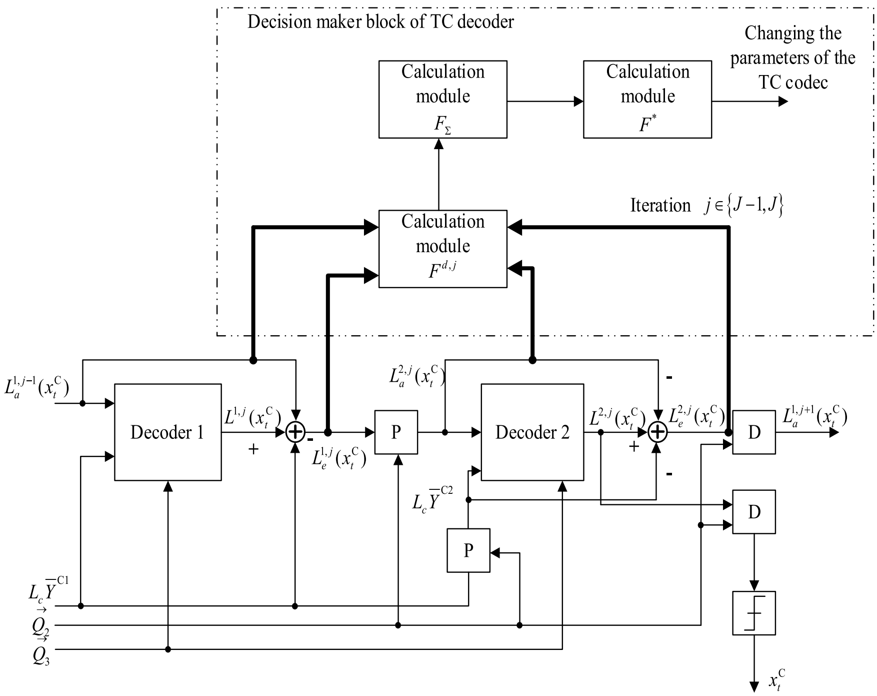

Fig. 2 Block diagram of the modified iterative TC decoder

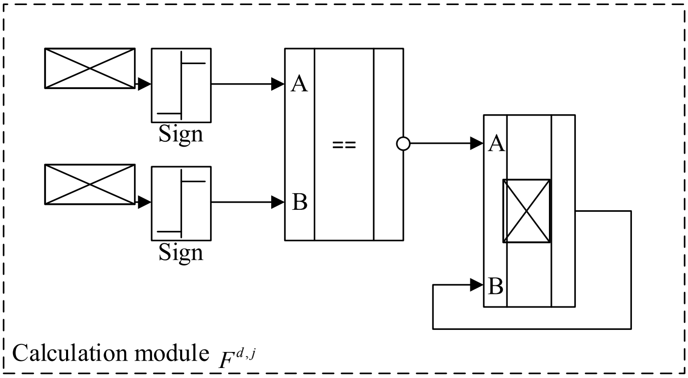

Fig. 3 Block diagram of the module for calculating the number of changes in the sign of a posteriori-a priori LLR $F^{d,j}$

The input of calculation module $F^{d,j}$ receives a priori LLR $L_a^{d,j}\left(x_t^C\right)$ and a posteriori LLR $L_e^{d,j}\left(x_t^C\right)$. Then their signs are determined and if they are not equal, then the value of $F^{d,j}$ is incremented:

$$F^{d,j} = F^{d,j} + 1, \quad \text{if } \operatorname{sign}\left(L_a^{d,j}\left(x_t^C\right)\right) \neq \operatorname{sign}\left(L_e^{d,j}\left(x_t^C\right)\right), t \in \overline{1, N}, \tag{2}$$

where N is a number of bits in a block.

The more often the values of $F^{d,j}$, the more often incorrectly decoded bits appear, which leads to a deterioration in the reliability of information reception.

The total indicator of the number of changes in the sign of a posteriori-a priori LLR for all decoding iterations F_Σ is determined:

$$F_\Sigma = \sum_{j=1}^{I} \sum_{d=1}^{2} F^{d,j}. \tag{3}$$

If the transmission channel does not affect the transmitted information, then the value of the number of changes in the sign of the a posteriori-a priori LLR will be minimal and equal to the number of transmitted information bits:

$$F_{\min} = N \tag{4}$$

If the transmission channel affects the transmitted information in such a way that normal decoding becomes impossible, then the maximum value of the number of changes in the sign of a posteriori-a priori LLR will be equal to:

$$F_{\max} = \frac{N(2I + 1)}{2}. \tag{5}$$

In practice, for a qualitative assessment, it is better to use the normalized value of the number of changes in the sign of a posteriori-a priori LLR:

$$F^{*} = \frac{F_{\Sigma} - N}{N(I - 0.5)}. \tag{6}$$

The values of F^{*} are used to select the parameters of the turbo code codec.

The algorithm for implementing the method of multilevel parametric adaptation is presented below.

Step 1. Formation of the set of values of systematic information bits X^{C} of size $1 \times N$, produced by the turbo code encoder:

$$X^{C} = \left\{x_{1}^{C}, x_{2}^{C}, \ldots, x_{N}^{C}\right\}, \tag{7}$$

where N is the length of the input.

Step 2. The initial parameters of the data transmission system are set: polynomial generator (1.7/5), Log-Map decoding algorithm, TC coding rate $R = 1/2$, regular interleaver (deinterleaver), the number of bits in the transmitted (received) block $N = 1000$.

Step 3. Formation of the set of a priori values of the about the transmitted data bits at the 2nd decoder of the jth iteration

$$LA = \left[\, L_{a}^{2,j}\left(x_{1}^{C}\right)\; L_{a}^{2,j}\left(x_{2}^{C}\right)\; \ldots\; L_{a}^{2,j}\left(x_{N}^{C}\right) \right]. \tag{8}$$

Step 4. Formation of the set of a posteriori values of the LLR about the transmitted bits

$$LE = \left[\, L_{e}^{2,j}\left(x_{1}^{C}\right)\; L_{e}^{2,j}\left(x_{2}^{C}\right)\; \ldots\; L_{e}^{2,j}\left(x_{N}^{C}\right) \right]. \tag{9}$$

Step 5. Cycle execution: if $\operatorname{sign}\left(L_{a}^{d,j}\left(x_{t}^{C}\right)\right) \neq \operatorname{sign}\left(L_{e}^{d,j}\left(x_{t}^{C}\right)\right)$, then $F^{d,j} = F^{d,j} + 1$, $F_{\Sigma} = \sum_{j=1}^{I} \sum_{d=1}^{2} F^{d,j}$, $F^{*} = \frac{F_{\Sigma} - N}{N(I - 0.5)}$, $t \in \overline{1, N}$ for all bits of a block of length N, decoders d, $d \in \overline{1, 2}$, decoding iterations j, $j \in \overline{1, I}$.

Step 6. Calculation of the average normalized number of changes in the sign of a posteriori-a priori LLR based on the results of receiving K data blocks:

$$\tilde{F}^{*} = \frac{\sum_{i \in 1}^{K} F_{i}^{*}}{K}. \tag{10}$$

Step 7. Depending on the value of the average normalized number of changes in the sign of the a posteriori-a priori LLR, the parameters of the turbo code codec will change. If the calculated value is less than the specified value, then it is considered that the data transmission system meets the conditions and the parameters do not change. If it is greater, then depending on the value, the parameters of the turbo

Table 1 Interleaver types depending on the average normalized number of sign changes of a posteriori-a priori LLR

$\tilde{F}^*$	Interleaver types
[0.25–0.3]	Regular
(0.3–0.35]	Pseudo-random
(0.35–0.4]	S-random

Table 2 Values of the encoder polynomials depending on the average normalized number of changes in the sign of a posteriori-a priori LLR

$\tilde{F}^*$	Polynomial
[0.0–0.05]	(1, 17/15)
(0.05–0.1]	(1, 35/23)
(0.1–0.15]	(1, 75/53)
(0.15–0.2]	(1, 171/133)
(0.2–0.25]	(1, 371/247)

code codec change.

$$\begin{cases} \tilde{F}^* > 0.4, I = I + 1 \\ 0.25 < \tilde{F}^* \le 0.4, P \Leftrightarrow \\ \tilde{F}^* \le 0.25, RSCE Polynomial \uparrow \end{cases} \tag{11}$$

If value $\tilde{F}^* > 0.4$, then the number of decoding iterations is increased by 1. When $0.25 < \tilde{F}^* \le 0.4$ is within these limits, the interleaver type is changed in accordance with Table 1. When $\tilde{F}^* \le 0.25$, then the encoder polynomial is changed in accordance with Table 2.

Table 2 shows the values of the encoder polynomials depending on the average normalized number of changes in the sign of the posterior-a priori LLR for the coding rate TC $R = 1/2$.

5 Analysis of the Results

Evaluation of the characteristics of the information transmission reliability using the proposed method of structural adaptation of the encoder and decoder of the turbo code was carried out using the method of simulation. To compare the proposed results, the fourth generation 4G LTE-Advanced mobile communication standard was chosen as an analogue. The simulation was carried out in the Visual Studio 2019 environment. The simulation results were obtained based on the reliability $\alpha = 0.95$, $t_\alpha = 0.95$ (the argument of the Laplace function), relative accuracy $d = 0.1$.

A turbo code similar to the 4G LTE-Advanced standard was used with two component encoders, a Log-Map decoding algorithm, a regular interleaver (deinterleaver), the number of bits in the transmitted (received) block $N = 1000$. The coding rate

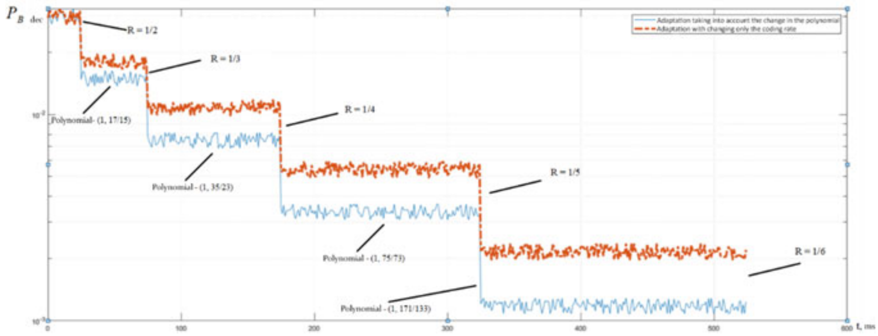

Fig. 4 Simulation results with an additional encoder polynomial change

changed from $R = 1/2$ to $R = 1/6$. The signal-to-noise ratio was chosen to be 0.4 dB. The average value of the decoding bit error probability $P_{B\ dec\_\ pre} = 10^{-3}$ is selected as the preset value of the information reliability.

In Fig. 4 is shown a graph obtained by means of simulation modeling, depending on $P_{B\ dec}$ on the operating time of the TC codec in milliseconds when changing only the coding rate from $R = 1/2$ to $R = 1/6$ and a graph with changing the coding rate and additionally encoder polynomial.

The analysis of the simulation results shows an increase in the reliability of information transfer with an additional change in the TC polynomial, while the number of errors decreased by 0.2–0.7 times.

In Fig. 5 is shown a graph of the dependence of $P_{B\ dec}$ on the operating time of the TC codec in milliseconds when only the coding rate is changed from $R = 1/2$ to $R = 1/6$ and a graph with the proposed parametric adaptation algorithm (the coding rate, the number of iterations and the interleaver are changed).

The analysis of the simulation results shows an increase in the reliability of information transfer using the proposed algorithm of multilevel parametric adaptation,

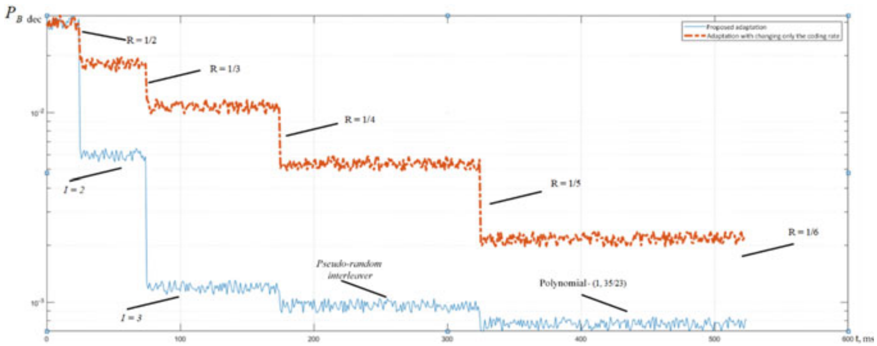

Fig. 5 Results of modeling the proposed method of multilevel parametric adaptation

while the number of errors has decreased by 2–3.3 times. This indicator is achieved by adding additional decoding iterations in the adaptation process, using more complex RSCE polynomials and changing the interleaving method.

6 Conclusions

1. The article proposes a method for multilevel parametric adaptation of the turbo code codec in wireless data transmission systems depending on the values of the normalized number of changes in the sign of a posteriori-a priori LLR about the transmitted data bits of the TC decoder.
2. The results of simulation showed that the application of the method of multilevel parametric adaptation of the turbo code codec reduces the number of errors by 2–3.3 times, and also makes it possible to increase the reliability of information transmission in comparison with the known results, for example, the fourth generation 4G LTE-Advanced mobile communication.

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