UDC 621.391
DOI: 10.15587/1729-4061.2020.216762

PERFORMANCE ANALYSIS OF THE BIOINSPIRED METHOD FOR OPTIMIZING IRREGULAR CODES WITH A LOW DENSITY OF PARITY CHECKS

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This paper reports the principles of building irregular codes with a low density of parity checks. It has been determined that finding irregular finite-length codes with improved characteristics necessitates the optimization of the distributions of powers of the symbol and test vertices of the corresponding Tanner graph. The optimization problem has been stated and the application of a bioinspired approach to solving it has been substantiated. The paper considers the main stages of the bioinspired method to optimize the finite-length irregular codes with a low density of parity checks. It is shown that a given method is based on the combined application of the bioinspired procedure of bats, a special method for building Tanner graphs, and computer simulation.

The reported study aimed to evaluate the effectiveness of the proposed method for optimizing irregular codes when using the selected bioinspired procedure and the predefined model of a communication channel.

Based on the study results, it has been determined that the optimized relatively short irregular codes with a low density of parity checks possess better characteristics compared to existing codes. It is shown that the derived codes do not demonstrate the effect of an "error floor" and ensure an energy win via encoding of about 0.5 dB compared to regular codes depending on the length of the code. It has been determined that the optimization of irregular codes with a low value of the maximum power in the distribution of powers of the symbol vertices of the Tanner graph leads to a decrease in the order of an error coefficient in the region with a high signal/noise ratio.

The application of the optimized irregular codes with a low density of parity checks could improve the efficiency of next-generation wireless telecommunication systems

Keywords: wireless telecommunication systems, irregular codes, optimization, bioinspired search, communication channel

Received date 26.10.2020
Accepted date 30.11.2020
Published date 18.12.2020

1. Introduction

To ensure the predefined reliability of information transfer, telecommunication technologies employ a variety of interference-resistant code structures. A special feature of the next-generation wireless telecommunications systems is the dominant use of codes with a low density of parity checks [1]. The peculiarity of these codes is the sparseness of the verification matrix, which makes it possible to use an iterative decoding method based on trust propagation. The disadvantage of a given method is the presence of a noise threshold effect, above which the probability of proper decoding approaches zero [2].

Codes with a low density of parity checks almost reach the throughput limit for different communication channel models. They also demonstrate better probability rates of iterative decoding errors when increasing a signal/noise ratio (an “error floor” effect), as well as less difficulty in the technical implementation of the codec compared to turbocodes [3].

The graphical representation of this class of codes is based on Tanner graphs. In this case, the verification matrix of some code corresponds to the incident matrix of the corresponding Tanner graph. Depending on the type of a Tanner graph, the regular and irregular codes with a low density of checks for parity are distinguished. In this case, the latter, in general, have better characteristics, which predetermines the expediency of their practical application [3].

To enhance efficiency and improve the characteristics of irregular codes with a low density of parity checks for the predefined conditions for information transfer, it is advisable to optimize their parameters. In this case, different performance criteria can be used, such as a noise threshold value, the computational decoding complexity, encoding speed, etc.

For very long codes, that is, for an asymptotic case, optimization can be implemented using special mathematical tools – the external information exchange diagram [4] and a density evolution procedure [5]. However, finite-length codes have limitations on the use of specific mechanisms.

Thus, it is a relevant task to study the improvement of the effectiveness of finite-length irregular codes with a low density of parity checks by optimizing their parameters.

2. Literature review and problem statement

An approach to building the ensembles of irregular codes with a low density of parity checks based on semi-defined programming is proposed in [6]. To that end, the authors stated appropriate optimization problems, to solve which they used classical optimization methods. Examples of the parameters of the resulting code ensembles with optimized encoding speeds that reach the throughput of the communication erasure channel were given. However, the issues related to the application of a given approach to other models of communication channel and special classes of codes with a low density of parity checks remained unresolved.

To eliminate this problem, study [7] considered the optimization of codes with a low density of parity checks with multiple edges for communication channels with an additive white Gaussian noise (AWGN) and erasure. The authors described a combined approach to the compatible optimization of different parameters for a given code class. Methods of local optimization and differential evolution were used to solve the set optimization problem. In this case, the iterative decoding threshold was determined by using a procedure of density evolution for the selected models of the communication channel.

However, works [6, 7] aim to obtain codes with a low density of parity checks reaching the throughput limit of the selected communication channel models without taking into consideration the computational complexity of decoding. Therefore, to minimize the computational complexity of iterative decoding of long codes with a low density of parity checks, paper [8] devised a methodology for constructing such codes for an arbitrary symmetrical communication channel without memory. A given approach is based on the proposed assessment of the complexity of iterative decoding calculated through the procedure of density evolution and the analysis of the external information exchange diagram for the predefined code. The resulting irregular codes, optimized for decoding complexity, have much better characteristics compared to codes optimized beyond the throughput limit of the communication channel.

However, studies [6–8] do not take into consideration the peculiarities of specific information transfer systems and specific communication channels. In order to eliminate these limitations, paper [9] used the external information exchange diagrams in conjunction with the differential evolution method to optimize relatively long codes with a low density of parity checks in the underwater acoustic communication channel. The study demonstrated that the optimized codes possess better characteristics compared to regular codes with a low density of parity checks and turbo-codes for the selected conditions of information transfer. In addition, paper [10] examined the optimization of codes with a low density of checks for parity of different lengths, used in conjunction with a continuous phase modulation in the construction of a satellite system of digital TV. To that end, the authors of [10] proposed a practical model with global interleaving and stated a corresponding nonlinear optimization problem. To solve the set task, they applied an approach based on an analysis of the external information exchange diagram in conjunction with the latest bionic swarm intelligence procedure. It is shown that the optimized codes produce an additional win from encoding in the channel with AWGN compared to previously obtained codes. In turn, study [11] considered the optimization of finite-length codes with a low density of parity checks to be used in the Internet of Things technology. The proposed approach is based on the computer simulation of the process of transmitting information in a channel with gaussian interference and the use of the simplex descent method to find the optimized codes.

However, studies [6–11] were aimed at optimizing long enough codes, although next-generation wireless telecommunications systems imply the use of relatively short codes. To solve this task, paper [12] proposed a class of spatially-related codes with a low density of parity checks with an uneven structure. To further optimize the parameters of these codes for use in erasure channels and AWGN, the authors applied a procedure of density evolution in conjunction with the method of differential evolution. The optimized codes are shown to exceed regular and irregular codes with a low density of parity checks with a uniform structure for the selected communication channel models in terms of energy intensity. However, these codes have a specific structure that limits their application in practice. Study [13] shows that optimizing short codes with a low density of parity checks for optical communication systems in a free space requires consideration of the characteristics of the communication channel. To that end, it was proposed to jointly use the asymmetric density evolution procedure and various evolutionary optimization procedures used in parallel. As a result, the codes optimized for the asymmetric communication channel with a modulation of the "inclusion-exclusion" type were obtained. However, a given approach is characterized by high computational complexity, which greatly limits the scope of its application. In addition, the use of special mathematical tools in [12, 13] with limitations for optimizing short codes leads to a deterioration in the characteristics of the obtained codes. An option of overcoming these difficulties is to apply the concept of "decoder in a loop" using a genetic algorithm when optimizing short codes [14]. A given approach takes into consideration the characteristics of the communication channel and meets the practical requirements for decoding. It is shown that the obtained codes demonstrate improved characteristics in the communication channels with AWGN and Rayleigh fading compared to existing codes. However, a given approach can only be used for very short codes with a low density of parity checks due to the optimization of the verification matrix in general. Paper [15] also reported a bioinspired approach to optimizing the finite-length irregular codes with a low density of parity checks without the use of specific mathematical tools. To that end, the authors stated an appropriate optimization problem and described the methodology for solving it. The essence of the proposed approach is the joint application of the generalized bioinspired procedures, a method of building Tanner graphs, and the use of computer simulation.

However, paper [15] described only the general idea of a given approach and did not provide information on the characteristics of the reported optimization method for the predefined conditions of information transfer. In particular, an important task is to determine the effectiveness of a given method to optimize the relatively short irregular codes with a low density of parity checks when applying a specific bioinspired procedure. In addition, from a practical point of view, it is advisable to investigate the possibility of using this method in the presence of additive interference in the communication channel. All this allows us to argue that it is appropriate to conduct a study on the assessment of the effectiveness of the bioinspired method of optimizing the finite-length irregular codes with a low density of parity checks.

3. The aim and objectives of the study

The aim of this study was to evaluate the effectiveness of the bioinspired method of optimizing the irregular codes with a low density of parity checks in a communication channel with AWGN.

To accomplish the aim, the following tasks have been set:

– to devise the principles of construction and to determine the parameters of irregular codes with a low density of parity checks;

– to consider the main stages and define special features of the bioinspired method for optimizing irregular codes with a low density of parity checks;

– to evaluate the effectiveness of the bioinspired method for optimizing the irregular codes with a low density of checks on parity exposed to AWGN.

4. The principles of construction and the parameters of irregular codes with a low density of parity checks

In a general case, some irregular code with a low density of parity checks is determined by the distributions of powers of the symbol and test vertices in a Tanner graph:

$$\lambda(x)=\sum_{i=2}^{d_V}\lambda_i x^i, \qquad (1)$$

$$\rho(x)=\sum_{i=2}^{d_P}\rho_i x^i, \qquad (2)$$

where λ_i is the coefficient that determines the share of edges originating from the symbol vertex of the Tanner graph of power i;

ρ_i is the coefficient that determines the share of edges originating from the test vertex of the Tanner graph of power i;

d_V is the maximum power of the symbol vertices of the Tanner graph;

d_P is the maximum power of the test vertices of the Tanner graph.

Thus, (1) and (2) define an ensemble of irregular codes with a low density of parity checks.

Let a code have n symbol vertices in the Tanner graph, then the number of the symbol vertices of power i is

$$N_{V_i}=n\frac{\lambda_i/i}{\sum\limits_{i\geq 2}\lambda_j/j}=n\frac{\lambda_i/i}{\int_0^1\lambda(x)\mathrm{d}x},$$

and the total number of edges originating from all symbol vertices is equal to

$$E=n\sum_{i\geq 2}\frac{\lambda_i/i}{\int_0^1\lambda(x)\mathrm{d}x}=n\frac{1}{\int_0^1\lambda(x)\mathrm{d}x}. \qquad (3)$$

Similarly, suppose the code has m test vertices in a Tanner graph, then the number of the test vertices of power i is

$$N_{P_i}=m\frac{\rho_i/i}{\sum\limits_{i\geq 2}\rho_j/j}=m\frac{\rho_i/i}{\int_0^1\rho(x)\mathrm{d}x},$$

and the total number of edges originating from all test vertices is

$$E=m\sum_{i\geq 2}\frac{\rho_i/i}{\int_0^1\rho(x)\mathrm{d}x}=m\frac{1}{\int_0^1\rho(x)\mathrm{d}x}. \qquad (4)$$

If one equates (3) and (4), one can obtain the following equality:

$$m=n\frac{\int_0^1\rho(x)\mathrm{d}x}{\int_0^1\lambda(x)\mathrm{d}x}.$$

Then, in a general case, the estimated coding speed of a given code is equal to

$$R=\frac{n-m}{m}=1-\frac{\int_0^1\rho(x)\mathrm{d}x}{\int_0^1\lambda(x)\mathrm{d}x}.$$

Paper [5] shows that the effectiveness of irregular codes with a low density of parity checks depends heavily on the pair of the distribution of powers in (1) and (2). Consequently, the search for the irregular codes with a low density of parity checks with improved characteristics is equivalent to finding these distributions of powers.

It should be noted that (1) and (2) determine the ensemble of irregular codes with a low density of parity checks. A Tanner graph for a specific code from a given ensemble can be constructed, for example, using a “progressive edge-growth” (PEG) method [16].

The application of a given method employed the following principles of building irregular codes with a low density of parity checks.

First, we formed the distribution of powers in (2) based on a uniform law for two consistently selected test vertices of the Tanner graph. As a result, the task of searching for irregular codes is reduced to determining only the distribution of powers of the symbol vertices of the Tanner graph (1).

Second, to reduce the computational complexity of finding the distribution of powers (1) close to optimal, it is proposed to use a truncated distribution of powers of the symbol vertices of the Tanner graph. A given distribution is formed by the empirical selection of only a few symbol vertices with the predefined powers. For example, this work uses the powers of 2, 3, d_V and a small number of intermediate powers depending on the code parameters.

Given this, the truncated distribution of powers of the symbol vertices of the Tanner graph, containing l nonzero coefficients, can be represented as follows:

$$\Lambda(x) = \sum_{i=1}^{l} \Lambda_i x^{d_i}, \tag{5}$$

where Λ_i is the coefficient that determines the share of edges originating from the pre-selected symbol vertex of the Tanner graph of power i;

d_i is the pre-selected power of the i-th component of the distribution of powers.

In this case, the following condition must be met for the Λ_i coefficients:

$$\sum_{i=1}^{l} \Lambda_i = 1, \quad 0 < \Lambda_i < 1. \tag{6}$$

Then, considering (6), the search for the distribution of powers of the symbol vertices in (5) can be represented as a search for the elements of Λ_i vector of length l.

In addition, to limit the search area to the dimensionality of l–1, it is advisable to represent the l-th coefficient in (5) as follows

$$\Lambda_l = 1 - \sum_{i=1}^{l-1} \Lambda_i. \tag{7}$$

Thus, the application of the described principles makes it easier to find irregular codes with the predefined coding speed R with improved characteristics.

5. A bioinspired method for optimizing irregular codes with a low density of parity checks

Taking into consideration (5) to (7), the desired distribution of powers of the symbol vertices of the Tanner graph of some irregular code can be represented in the form of a $\bar{\Lambda} = (\Lambda_1, \Lambda_2, \ldots, \Lambda_{l-1})$. vector. To assess the "quality" of a given vector, when constructing a Tanner graph by the PEG method, it is necessary to define the appropriate objective function. In [5], a value of the noise threshold for iterative decoding was selected to be the objective function. To calculate this threshold, the authors used a procedure of density evolution for different distributions of powers of the vertices of the Tanner graph, determined by using the method of differential evolution. However, a given approach is characterized by significant computational complexity while the accuracy of the results decreases for relatively short codes.

To address these drawbacks, paper [15] suggests using the probability of a decoding error (an error factor) as an objective function, calculated from computer simulation based on the Monte Carlo method.

Thus, taking into consideration (5) to (7), a search for the improved irregular codes with a low density of parity checks with the predefined parameters for some model of a communication channel can be formally represented in the form of the following optimization problem:

$$f(\bar{\Lambda}^*) = \min_{\bar{\Lambda} \in \bar{\Lambda}'} f(\bar{\Lambda}), \tag{8}$$

$$f(\bar{\Lambda}) = BER, \tag{9}$$

$$SNR\text{=const}, \; R\text{=const}, \tag{10}$$

$$\bar{\Lambda}' = \left\{ \bar{\Lambda} \;\middle|\; \begin{array}{l} \sum_{i=1}^{l} \Lambda_i = 1 \\ \Lambda_l = 1 - \sum_{i=1}^{l-1} \Lambda_i \\ 0 < \Lambda_i < 1 \end{array} \right\}, \tag{11}$$

where $\bar{\Lambda}^*$ is the global (local) minimum, which corresponds to the "best" vector, consisting of the coefficients of the distribution of powers of symbol vertices;

$\bar{\Lambda}'$ is the set of permissible solutions, which corresponds to a group of vectors that consist of the coefficients of the distribution of powers of symbol vertices;

BER is the probability of a decoding error (an error rate);

SNR is the signal/noise ratio, dB.

It follows from the analysis of function (9) and limitations (10), (11) that the stated minimization problem (8) is the task of nonlinear programming. In this case, determining a global minimum using classical optimization methods is characterized by significant computational complexity. Therefore, to solve it, paper [15] proposed to use the generalized bioinspired optimization procedures that make it possible to find a suboptimal solution with acceptable computational complexity.

Study [17] shows that the bioinspired procedure prompted by the behavior of bats is more effective at solving standard optimization problems than a series of other procedures. Therefore, we shall consider the possibility of using a given bioinspired procedure when solving optimization problem (8).

Consider the main stages of the bioinspired method for optimizing the finite-length irregular codes with a low density of parity checks based on the procedure of bats.

Stage 1. Select the code parameters and the characteristics of a communication channel model.

Step 1. 1. Select the value of coding speed R.

Step 1. 2. Determine the value of the SNR signal/noise ratio, which should be small enough to achieve a predefined probability value for a decoding error over an acceptable simulation time.

Stage 2. The bioinspired optimization of the distribution of powers of the symbol vertices of the Tanner graph for the predefined code parameters.

Step 2. 1. Initialize the population of agents $\bar{\Lambda}_{g,t}$, $g \in [1, NP]$ in the examined search space domain. In this case, the vector $\bar{\Lambda}_{g,t}$ elements are formed in accordance with the uniform distribution with the normalization required to meet condition (6). In the same step, the parameters for a bats' procedure are set – the size of the population *NP*, the initial values of the agents' speed $V_{g,t}$, the frequency of the signals $\omega^{\min}$ and $\omega^{\max}$, the volume of the signal $a_{g,t}$, the frequency of pulse repetition $b_{g,t}$, the initial iteration number $t=1$, the maximum number of iterations *T*.

Step 2. 2. Construct a Tanner graph using the PEG method for each resulting vector $\bar{\Lambda}_{g,t}$ and the distribution of powers of the test vertices $\rho(x)$. The $\rho(x)$ distribution elements are determined according to (2), taking into consideration the selected coding speed *R*. Each Tanner graph obtained in this step fully defines a specific irregular code.

Step 2. 3. Computer simulation of the process of transmitting information over a communication channel with AWGN using each irregular code with a low density of parity checks obtained in step 2. 2. In this case, the number of code words transmitted is not limited. The simulation process is completed when a predetermined error factor value is reached when using an iterative decoding method based on trust propagation.

Step 2. 4. Determine the quality of each agent $\bar{\Lambda}_{g,t}$ based on the calculation of objective function (9).

Step 2. 5. Migrate the agents $\bar{\Lambda}_{g,t}$ based on the following formulae:

$$\omega_{g,t}=\omega^{\min}+(\omega^{\max}-\omega^{\min})\alpha, \tag{12}$$

$$V_{g,t+1}=V_{g,t}+\omega_{g,t}\left(\bar{\Lambda}_{g,t}-\bar{\Lambda}^{*}\right), \tag{13}$$

$$\bar{\Lambda}_{g,t+1}=\bar{\Lambda}_{g,t}+V_{g,t+1}, \tag{14}$$

where α is the vector of length $l-1$ whose elements are valid random numbers that have a uniform distribution in the interval [0, 1].

This step implements the local and global search taking into consideration the value of the generated random value *r*.

If $r>b_{g,t}$, then the local search is implemented by creating new agents according to the following formula:

$$\bar{\Lambda}_{g,t+1}=\bar{\Lambda}_{g,t}+\beta\bar{a}_{g,t},$$

where β is the vector of length $l-1$ whose elements are valid random numbers that have a uniform distribution in the interval [–1, 1].

$\bar{a}_{g,t}$ is the current average value of all agents' loudness in the population.

Consequently, when searching locally, new agents are formed near the best resulting vectors $\bar{\Lambda}_{g,t}$ based on the calculation of objective function (9).

Otherwise, there is a transition to the global search by forming new agents $\bar{\Lambda}_{g,t}$ randomly.

If $r<a_{g,t}$ and $f\left(\bar{\Lambda}_{g,t}\right)<f\left(\bar{\Lambda}^{*}\right)$, the formed vectors $\bar{\Lambda}_{g,t}$ are taken as a new current solution and there is an evolution of the parameters $a_{g,t}$ and $b_{g,t}$ [17].

Step 2. 6. If the number of iterations is $t\le T$, then there is a transition to step 2. 2; otherwise, the best agent $\bar{\Lambda}^{*}$ is determined and the transition to step 3 is performed.

Stage 3. Obtain an ensemble of irregular codes with a low density of parity checks.

At this stage, one saves the found distribution of powers of the symbol vertices $\Lambda(x)$ and the calculated distribution of powers of the test vertices $\rho(x)$ of the Tanner graph for the specified parameters of the code and the communication channel with AWGN.

It should be noted that stage 2 of the proposed method is a principal one. A given stage is based on the combined use of the bioinspired procedure of bats, the PEG method for building a Tanner graph, and computer simulation using the Monte Carlo method.

Thus, the proposed approach to optimizing irregular codes with a low density of parity checks can be regarded to be an adaptation of the principles and procedures proposed in [5], for the case of finite-length codes.

6. The results of analyzing the effectiveness of a bioinspired method for optimizing irregular codes with a low density of parity checks

To evaluate the effectiveness of the bioinspired method for optimizing irregular codes with a low density of parity checks, a computer model of the wireless telecommunication system was developed. A given model takes into consideration the peculiarities of information transfer through a communication channel with AWGN using a given type of codes and an iterative decoding method based on trust propagation The model also makes it possible to change the code parameters, the amount of interference in the communication channel, and compare the optimized codes with existing ones [3, 5].

The simulation that employed the developed computer model used the following settings:

1) coding speed – 1/2;

2) the signal/noise ratio range is 1 to 3 dB;

3) the parameters for the bioinspired optimization method using the procedure of bats [17]; population size, $NP=30$; signal frequency, $\omega^{\min}=0$ and $\omega^{\max}=2$; signal volume, $a=0.8$; the frequency of repeating emitted pulses, $b=0.2$; the maximum number of iterations, $T=150$.

Based on the results of the simulation under the specified conditions, we have determined the distributions of powers of the symbol vertices, close to optimal, which take the following form:

$$\Lambda(x)=0.481x^{2}+0.274x^{3}+$$
$$+0.063x^{4}+0.095x^{5}+0.087x^{15};$$

$$\Lambda(x)=0.375x^{2}+0.231x^{3}+$$
$$+0.097x^{4}+0.036x^{10}+0.163x^{30}+0.098x^{50}.$$

The first distribution was used when constructing irregular codes with a low density of different lengths applying the PEG method – the "short" (504, 252) code and the "long" (1008, 504) code. The second distribution was used only to construct a "short" code. The evaluation of the effectiveness of the derived codes was based on the comparison of their characteristics with the corresponding regular and random irregular codes, whose decoding employed the iterative method based on trust propagation.

The comparison of the characteristics of an irregular (504, 252) code with a low density of parity checks, optimized by using the proposed bioinspired method, and the known regular and random irregular codes with the same parameters is illustrated in Fig. 1.

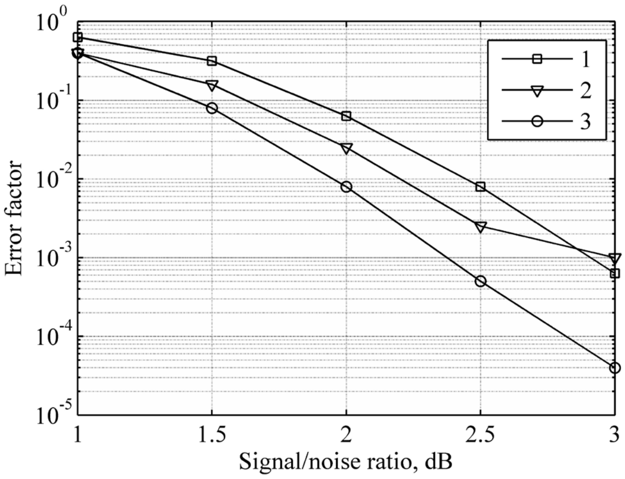

Fig. 1. Dependence of error factor on the signal/noise ratio for (504, 252) codes with a low density of parity checks: 1 — regular code; 2 — random irregular code; 3 – optimized irregular code

It follows from the analysis of Fig. 1 that the developed method makes it possible to obtain an irregular code that ensures an energy gain from coding of about 0.6 dB compared to a regular code at an error factor of 10^{-3}. In this case, the resulting code does not have the effect of an "error floor" as opposed to the reported random irregular code.

In addition, the resulting distribution of powers of the symbol vertices was used to construct an irregular (1008, 504) code with a low density of parity checks, comparing the characteristics of which with other codes is shown in Fig. 2.

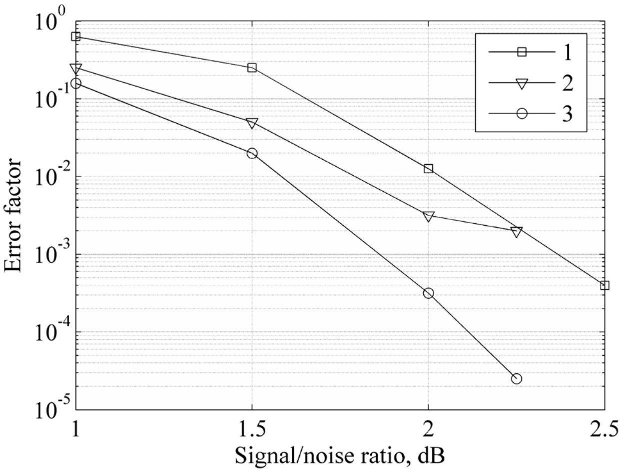

Fig. 2. Dependence of error factor on the ratio of signal/noise for (1008, 504) codes with a low density of parity checks: 1 — regular code; 2 — random irregular code; 3 – optimized irregular code

It follows from the analysis of Fig. 2 that the irregular code with the optimized distribution of symbol vertices ensures an energy gain from the encoding of over 0.5 dB compared to a regular code at an error factor of 10^{-3}. In addition, unlike the reported random irregular code, there is no "error floor" effect, which makes it possible to obtain a much lower error factor in the region of high values of the signal/noise ratio.

Paper [5] shows that long random irregular codes with a low density of parity checks, obtained using the density evolution procedure, almost reach the boundary of a communication channel. The comparison of these codes' characteristics with the obtained irregular (504, 252) codes with a low density of parity checks at different values of the maximum power in the distribution of powers of the symbol vertices is illustrated in Fig. 3.

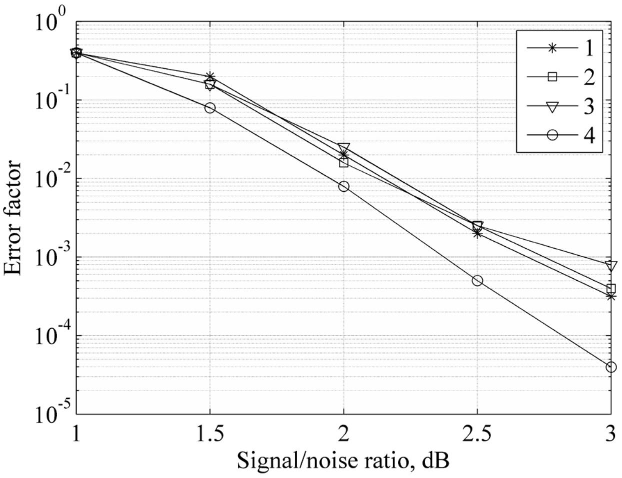

Fig. 3. Dependence of error factor on the signal/noise ratio for the random and optimized irregular (504, 252) codes with a low density of parity checks:
1 — random irregular code (maximum power, 50);
2 — optimized irregular code (maximum power, 50);
3 — random irregular code (maximum power, 15);
4 — optimized irregular code (maximum power, 15)

It follows from the diagrams in Fig. 3 that at a high value of the maximum power in the distribution of powers of the symbol vertices the optimized irregular (504, 252) code demonstrates the effectiveness close to a random irregular code. In this case, the reduction of the maximum power in the distribution of powers of the symbol vertices of the optimized irregular (504, 252) code ensures a much lower error factor in the region of high values of the signal/noise ratio. For example, at a signal/noise ratio of 3 dB, the error factor is less by an order of magnitude.

In this case, the proposed bioinspired method for optimizing irregular codes with a low density of parity checks demonstrates an acceptable computational complexity, which is adjusted by replacing the type and/or parameters of the bioinspired procedure.

7. Discussion of results of analyzing the effectiveness of the bioinspired method for optimizing irregular codes with a low density of parity checks

The optimization methods that are based on special mathematical tools [4, 5] do not make it possible to obtain the finite-length irregular codes with low density parity checks with high design characteristics.

On the other hand, the high computational complexity of the optimization method based on the concept of "decoder in a loop" [14] limits the scope of its application to very short codes. Based on the study results, the proposed optimization method ensures finding longer irregular codes with improved characteristics.

In contrast to most existing methods for optimizing irregular codes [6–10, 12, 13] that employ a special mathematical apparatus, the proposed optimization method is based on the Monte Carlo method and the effective bioinspired procedure. As a result, it becomes possible to simplify taking into consideration the peculiarities of the communication channel, code length, coding speed, and other conditions for information transfer. Owing to this, the optimized irregular codes with a low density of parity checks demonstrate higher energy efficiency compared to regular codes with the same parameters. In addition, the resulting codes do not have an “error floor” effect as opposed to random irregular codes.

Reducing the maximum power in the distribution of powers of the symbol vertices for the optimized irregular code makes it possible to significantly decrease an error factor at high values of the signal/noise ratio compared to existing codes [5].

However, the limitation of the reported method for optimizing irregular codes with a low density of parity checks is the uncertainty when choosing operational parameters for the specified characteristics of a communication channel, in particular, the type of a bioinspired procedure and its parameters. In addition, a given method has constraints on optimizing long irregular codes due to the increased computational complexity.

This study is aimed at improving the next generation of wireless telecommunication systems by ensuring the predefined reliability of information transfer in a communication channel with AWGN. This is achieved by the optimized relatively short irregular codes with a low density of parity checks with improved characteristics.

In further studies, it is planned to carry out a meta-optimization of the operational parameters of the reported bioinspired optimization method for the predefined conditions of information transfer. It is also advisable to analyze the effectiveness of the bioinspired optimization of irregular codes with a low density of parity checks for other models of communication channels.

The results from our research are independent and could be used in promising telecommunication technologies, in particular, in the implementation of advanced wireless telecommunication systems.

8. Conclusions

1. Codes with a low density of parity checks are the main mechanism for ensuring the predefined reliability of information transmission in wireless telecommunication systems of the next generation. The practical need to apply irregular finite-length codes leads to the requirement for optimizing the distributions of powers of the symbol and test vertices of the corresponding Tanner graph for the specified conditions of information transfer. To simplify the search for irregular codes with the assigned parameters with improved characteristics, we have used the truncated distribution of powers of the symbol vertices and the uniform distribution of powers of the test vertices of the Tanner graph.

2. The proposed method for optimizing irregular codes with a low density parity checks is based on the combined application of the bioinspired procedure of bats, the PEG method for building Tanner graphs, and computer simulation based on the Monte Carlo method. To reduce the computational complexity of a given method of optimization, the search for the distribution coefficients is performed only for a few symbol vertices with the predetermined powers. In this case, the distribution of powers of the test vertices of the Tanner graph obeys the uniform law. In addition, the special feature of the proposed approach is the use of an error factor as an objective function in the implementation of the bioinspired search for irregular codes with improved properties.

3. The optimized, relatively short irregular codes with a low density of parity checks demonstrate better characteristics compared to existing codes. In particular, the resulting codes do not have an “error floor” effect, as opposed to random irregular codes with the appropriate parameters. On the other hand, compared to regular codes, the energy win from coding of about 0.5 dB is achieved, depending on the code length. In addition, the optimization of irregular codes with a small value of the maximum power in the distribution of powers of the symbol vertices of the Tanner graph leads to a decrease, by an order of magnitude, in the error factor in the region of a high signal/noise ratio.

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