Adaptive interference-resistant encoding using Barker-like sequences

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Abstract

Interference resistance is one of the most important characteristics of modern data reception/transmission systems. Improving immunity to fixed baud/reception rates is a pressing issue, for example, in drone control. The studied code sequences allow an increase in the power of the received sequences due to the use of mirror interference-resistant code sequences. The increase in immunity to data transmission is achieved by increasing the length and power of the immunity code sequence used to transmit one message. The advantages of these sequences, such as high immunity to narrowband high-power interference, the possibility of dividing subscribers by code sign, transmission secrecy, high resistance to multipath propagation, and high resolution in navigation measurements will have wide practical use in communication and geolocation systems. An improved method for synthesizing interference-resistant code sequences using ideal ring bundles. An improved method for quickly finding such interference-resistant code sequences that can find and correct errors to the greatest extent depending on the length of the received code sequence. The implemented algorithm for quickly finding such interference-resistant code sequences, which can find and correct errors to the greatest extent depending on the length of the received code sequence. A simulation model of interference-resistant coding using ideal ring bundles has been developed. A software implementation of the simulation model of interference-resistant coding was carried out to find and correct errors in the received interference-resistant code sequences. The proposed interference-resistant code sequences have practical value since the obtained code sequence allows us to find up to 50% and correct up to 25% of distorted symbols from the length of the interference-resistant code sequence quite easily and quickly.

Keywords

Mirror code sequence, ideal ring bundles, non-equidistant code sequence, non-equidistant combinatorial configuration

1. Introduction

The current state of the problem. In connection with the continuous increase in the amount of information transmitted by communication channels, the technologies of interference-resistant coding and decoding of data in real-time are gaining more and more importance. Analysis of active channels shows that the frequency of occurrence of organized threats is much higher than natural threats when transmitting data. Therefore, it is necessary to protect information both from unauthorized access and from its distortion. One of the methods of protection is the encoding of information by using tamper-resistant codes. The interference-resistant coding of information should be understood as a form of transformation that allows finding and correcting a certain number of errors. The increase in immunity to data transmission is achieved by increasing the length of the code sequence used to transmit one message. The use of interference-resistant coding during data transmission leads to an increase in data transmission time. At the same time, the energy consumption for the transmission of one message increases. If the data transmission time is left unchanged, it will expand the signal spectrum by reducing the duration of one symbol and will lead to an increase in the frequency band allocated to one data transmission channel. Systems based on interference-resistant coding are most widely used in relay stations, where the modulated signal is

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demodulated and, if necessary, decoded. As a result, the signal is "cleaned" of noise and interference, and each repeater transmits the signal without the accumulation of noise and interference in the transmission line. Thus, noise and interference are taken into account only between two adjacent repeaters, which is the basis for long-distance data transmission. Transmitting a modulated signal without using interference-resistant coding leads to the accumulation of errors, and distortions and does not ensure the identity of the received signal with the transmitter signal. The urgency of solving the problem. In this regard, the problem of regular synthesis of interference-resistant codes with specified characteristics for wireless communication systems is becoming particularly relevant. Setting the research task. It is necessary to develop an algorithm for quickly finding such interference-resistant code sequences, which can find and correct errors to the greatest extent, depending on the length of the received code sequence. The object of research is interference-resistant code sequences. The subject of research is the method of synthesis of interference-resistant code sequences. The purpose of the work is to improve the method of synthesis and development of a simulation model of interference-resistant coding.

To achieve the set goal, it is necessary to solve the following research tasks:

- to improve the method of synthesis of interference-resistant code sequences using ideal ring bundles;
- to develop a simulation model of interference-resistant coding using ideal ring bundles;
- to carry out a practical implementation of the algorithm for finding and correcting errors of the received interference-resistant code sequences.

The scientific novelty consists in the development of an improved method of synthesis of interference-resistant code sequences.

Practical significance. The proposed interference-resistant code sequences have practical value since the obtained code sequence allows finding up to 50% and correcting up to 25% of distorted symbols from the length of the interference-resistant code sequence.

2. Related Works

The work [1] shows that the basis of the algorithms for the synthesis of interference-resistant code sequences is the principle of redundancy, which makes it possible to find and correct errors due to the peculiarities of the structures of these sequences. As a rule, error-correcting codes are built based on cyclic code sequences, all combinations of which can be obtained by cyclic shifting of one or more code combinations. The idea of building such codes is based on the use of polynomials that are not reduced in the field of binary numbers and are divisible without a remainder only by themselves or by unity.

From the analysis of works [2-4], it can be seen that Bose–Chaudhuri–Hocquenghem codes (BCH codes) are widely used for interference-resistant coding. For their decoding, the Berlekamp algorithm and its main modifications are used, which ensure the correction of all weight errors $W \leq W_0$, where $W_0 + 1 = d_0$. However, the complexity of this algorithm is of the order of $n^2 log_2 n$ operations and requires approximately $(5...20)n$ bits of memory.

Works [5-7] show that the main type of block codes for combating interference are non-binary Reed-Solomon (RS) codes. The length of the set is determined by the output field 2^l, where l defines the length of the set. The decoding of these codes is also based on the Berlekamp algorithm. Despite the efforts of many researchers, the complexity of the operations performed by the decoder remains very high. Thus, when implementing the RS decoder for the code (31, 15), it is necessary to perform approximately 17 operations for each bit of the decoded message, even if some of the operations are performed in parallel, and the multiplication in non-binary fields is performed by tabular methods.

Papers [5-7] consider cascade codes that provide high probability indicators with a fairly high level of interference and moderate decoding complexity. Work [8] shows that the Viterbi algorithm is widely used in data transmission technology using convolutional codes, which have better characteristics compared to block ones. However, the complexity of implementing the Viterbi algorithm grows exponentially with the length of the code. The works [9-11] consider the classes of codes for which the complexity of decoding with the increase in their length does not grow exponentially, but much more slowly, for example, as the square of the length. In works [10, 11], the issue of synthesis of interference-resistant codes using ideal ring bundles is considered. The disadvantage of the existing methods and algorithms for synthesizing interference-resistant codes using ideal ring bundles is the exhaustive coding techniques, which slow down the search for optimized code sequences.

3. Improvement of the method of synthesis of interference-resistant code sequences using ideal ring bundles

The greatest effect of information protection is achieved when all used methods and means are combined into a single integrated information protection mechanism. It should be said here that information protection must be carried out in parallel at three levels: hardware (sketch cards, tokens, cryptographic methods implemented at the software level), software (antivirus software, data archiving, mandatory identification, encryption) and organizational (by essentially, control of compliance with all hardware and software methods of protection in full).

However, most experts are inclined to the opinion of the special place of tamper-resistant coding (implemented by software or hardware) as perhaps the most reliable method, because the information itself is protected here, not access to it. The effectiveness of this approach is explained by the fact that it is not enough for an attacker to get access to information in the form of a sketch card or a password, he also needs to know how the information he needs is encoded.

An interference-resistant code sequence consists of a set of zeros and ones, which are used to convert symbols for further reception-transmission operations. The main features of these fault-tolerant code sequences are improved error detection and correction characteristics. The immunity of the system primarily depends on such code sequences. With the same lengths, the properties of the interference-resistant code sequences may differ. Immunity will depend both on the lengths of these code sequences and on several other characteristics, such as the mutual correlation of the sequences. That is, the selection of the best interference-resistant code sequence is reduced to the algorithm for searching for such code sequences.

Existing methods of converting code sequences do not fully provide an opportunity to improve coding/decoding systems. Therefore, one of the important tasks is the study of effective models for improving the coding/decoding of information according to such indicators as data transfer speed, immunity to code sequences, ease of correction, and error detection. Such models can be non-equidistant code sequences consisting of integers or sequences of numbers defined as their values and the values of all consecutive sums of adjacent elements.

To solve this problem, consider non-equidistant code sequences. By non-equidistant code sequences, we will consider sequences in which allowed code combinations form sequences with different distances between ones and zeros.

These non-equidistant code sequences have some advantages over other interference-tolerant sequences. This is the simplicity of finding and correcting errors on the side of receiving data because the appearance of the symbol "1" and/or the symbol "0" in the form of an obstacle indicates an error since the number of allowed distances has changed.

An error is not found only when the number of false codes is equal to or greater than the code distance. If distorted symbols appear in this non-equidistant code sequence, they will be detected, which contributes to the high immunity of the non-equidistant sequence.

The task of improving the interference -resistant characteristics of non-equidistant code sequences should be solved based on the application of ideal ring bundles (IRB).

We will call an ideal numerical bundles in which the set of all numbers exhausts the values that are proportional to the elements of a natural series with a given number of repetitions for each element of this series. A non-equidistant code sequence is a sequence $K_n = (k_1, k_2, \dots, k_i, \dots, k_n)$ of elements, where all possible adjacent elements in the form of circular sums give the values of all natural numbers 1, 2, ..., $S_n = n^2 - (n-1)$.

Based on the definition, we will construct a table of circular sums of the model of the non-equidistant code sequence K_n (Table 1).

The total number of all ring sums of the weights of elements of a non-equidistant code sequence that have different values:

$$S_n = n^2 - (n-1). \tag{1}$$

At the values $p_j=1$, $q_j=n$, and also at the values $p_j\neq 1$, $q_j=p_j-1$, the ring sums of the weights of the elements of the non-equidistant code sequence are equal to S_n.

The number of ring sums on the sequence of element weights is determined by the following relationship:

$$S_n^* = n(n-1). \tag{2}$$

Consider the construction of an interference-resistant code sequence. As an example, let's take a non-equidistant code sequence built following the weights of the IRB elements of the 8th order of the 4th multiplicity:

1, 1, 1, 2, 2, 1, 3, 4.

Table 1

Allowed ring sums of an interference-resistant non-equidistant code sequence

p_j	q_j							
	1	2		l-1	l		n-1	n
1	k_1	$\sum_{i=1}^{2} k_i$		$\sum_{i=1}^{l-1} k_i$	$\sum_{i=1}^{l} k_i$		$\sum_{i=1}^{n-1} k_i$	$\sum_{i=1}^{n} k_i$
2	$\sum_{i=1}^{n} k_i$	k_2		$\sum_{i=2}^{l-1} k_i$	$\sum_{i=2}^{l} k_i$		$\sum_{i=2}^{n-1} k_i$	$\sum_{i=2}^{n} k_i$
l-1	$\sum_{i=1-1}^{n} k_i + \sum_{i=1}^{1} k_i$	$\sum_{i=1-1}^{n} k_i + \sum_{i=1}^{2} k_i$		k_{l-1}	$\sum_{i=l-1}^{l} k_i$		$\sum_{i=l-1}^{n-1} k_i$	$\sum_{i=l-1}^{n} k_i$
l	$\sum_{i=1}^{n} k_i + \sum_{i=1}^{1} k_i$	$\sum_{i=1}^{n} k_i + \sum_{i=1}^{2} k_i$		$\sum_{i=1}^{n} k_i$	k_l		$\sum_{i=l}^{n-1} k_i$	$\sum_{i=l}^{n} k_i$
n-1	$\sum_{i=n-1}^{n} k_i + \sum_{i=1}^{1} k_i$	$\sum_{i=n-1}^{n} k_i + \sum_{i=1}^{2} k_i$		$\sum_{i=n-1}^{n} k_i + \sum_{i=1}^{l-1} k_i$	$\sum_{i=n-1}^{n} k_i + \sum_{i=1}^{l} k_i$		k_{n-1}	$\sum_{i=n-1}^{n} k_i$
n	$\sum_{i=n}^{n} k_i + \sum_{i=1}^{1} k_i$	$\sum_{i=n}^{n} k_i + \sum_{i=1}^{2} k_i$		$\sum_{i=n}^{n} k_i + \sum_{i=1}^{l-1} k_i$	$\sum_{i=n}^{n} k_i + \sum_{i=1}^{l} k_i$		$\sum_{i=1}^{n} k_i$	k_n

Since these values of the weights of the elements are the numbers of the 8th order of the 4th multiplicity, then each of these numbers of the natural series from 1 to $n(n-1)/r=15$ will be represented in four different ways, and the number of all ways is equal to the number of received numbers.

For a non-equidistant code sequence with n number of knitting elements, our algorithm provides the possibility of coding any numbers from 1 to $S_n=n(n-1)/r+1$.

The code combinations of the non-equidistant code sequence 00000100, 00100000, 01000000, 10000000 represent four ways of encoding the number 1. The number 2 is encoded as follows 00001000, 00010000, 01100000, 11000000. The number 3 is encoded as 00000 010, 00001100, 00110000, 11100000, number 4 – 00000001, 00000110, 00011000, 01110000, etc., number 14 – 10111111, 11111011, 11011111, 01111111, number 15 – 11111111.

Synthesized interference-resistant code sequence based on IRB weights is shown in Table 2. Each numerical combination of the interference-resistant non-equidistant code sequence corresponds to a set of ones and zeros, which is built according to the weights of IRB according to the following rule: 1 is 1, 2 is 10, 3 is 100, 4 is 1000, and so on. The number of different $S_N(S_N-1)/2$ code sequences contain exactly R out of N single symbols in the corresponding digits, which follows from the properties of the IRB. Other $N-R$ symbols of any two non-equidistant code sequences differ from the symbols that are represented in the digits of the same name.

In this way, the minimum code distance of any interference-resistant non-equidistant code sequence constructed with the help of IRB will be determined in the form of the ratio of the order and multiplicity of IRB:

$$d_{min} = 2(n-r). \tag{3}$$

Table 2
Interference-resistant code sequence based on IRB weights order n=8 multiples r=4: 1, 1, 1, 2, 2, 1, 3, 4

1	1	1	1	0	1	0	1	1	0	0	1	0	0	0
0	1	1	1	1	0	1	0	1	1	0	0	1	0	0
0	0	1	1	1	1	0	1	0	1	1	0	0	1	0
0	0	0	1	1	1	1	0	1	0	1	1	0	0	1
1	0	0	0	1	1	1	1	0	1	0	1	1	0	0
0	1	0	0	0	1	1	1	1	0	1	0	1	1	0
0	0	1	0	0	0	1	1	1	1	0	1	0	1	1
1	0	0	1	0	0	0	1	1	1	1	0	1	0	1
1	1	0	0	1	0	0	0	1	1	1	1	0	1	0
0	1	1	0	0	1	0	0	0	1	1	1	1	0	1
1	0	1	1	0	0	1	0	0	0	1	1	1	1	0
0	1	0	1	1	0	0	1	0	0	0	1	1	1	1
1	0	1	0	1	1	0	0	1	0	0	0	1	1	1
1	1	0	1	0	1	1	0	0	1	0	0	0	1	1
1	1	1	0	1	0	1	1	0	0	1	0	0	0	1

To increase the number of allowed combinations of non-equidistant code sequences with the help of IRB, we will build a mirror interference-resistant non-equidistant code sequence with IRB weights, where we change the places of ones and zeros during coding. Code combinations 01111111, 10111111, 11011111, 11111011 correspond to 4 ways of coding number 1. Number 2 corresponds to coding 00111111, 11101111, 11110111.

Number 3 corresponds to 00011111, 110 01111, 11110011, 11111101, number 4 – 10001111, 11100111, 11111001, 11111110, etc., the number 14 is 10000000, 01000000, 00100000, 00000100, the number 15 is 00000000.

The realized mirror interference-resistant non-equidistant code sequence with IRB weights is illustrated in the Table 3.

The number of allowed combinations of the main and mirror interference-resistant code sequences:

$$P = 2S_n^r. \tag{4}$$

The number of errors t1, which are detected using the interference-resistant code sequence, is determined using the minimum code distance d_{min}:

$$t_1 \leq d_{min} - 1. \tag{5}$$

Table 3
Mirror interference-resistant code sequence based on IRB weights order n=8 multiples r=4: 1, 1, 1, 2, 2, 1, 3, 4

0	0	0	0	1	0	1	0	0	1	1	0	1	1	1
1	0	0	0	0	1	0	1	0	0	1	1	0	1	1
1	1	0	0	0	0	1	0	1	0	0	1	1	0	1
1	1	1	0	0	0	0	1	0	1	0	0	1	1	0
0	1	1	1	0	0	0	0	1	0	1	0	0	1	1
1	0	1	1	1	0	0	0	0	1	0	1	0	0	1
1	1	0	1	1	1	0	0	0	0	1	0	1	0	0
0	1	1	0	1	1	1	0	0	0	0	1	0	1	0
0	0	1	1	0	1	1	1	0	0	0	0	1	0	1
1	0	0	1	1	0	1	1	1	0	0	0	0	1	0
0	1	0	0	1	1	0	1	1	1	0	0	0	0	1
1	0	1	0	0	1	1	0	1	1	1	0	0	0	0
0	1	0	1	0	0	1	1	0	1	1	1	0	0	0
0	0	1	0	1	0	0	1	1	0	1	1	1	0	0
0	0	0	1	0	1	0	0	1	1	0	1	1	1	0

The number of errors t2 that are corrected using the fault-tolerant code sequence is determined by the number of errors detected t1:

$$t_2 \leq (t_1 - 1)/2. \tag{6}$$

Let's define the dependence that determines the number of errors that can be detected by t1 interference-resistant code sequence:

$$t_1 \leq 2(n - r) - 1. \tag{7}$$

Let's define the dependence that determines the number of errors that can be corrected by t2 interference-resistant code sequence:

$$t_2 \leq n - r - 1. \tag{8}$$

We define the minimum code distance for an interference-resistant code sequence as

$$d_{1,2} = S_n - 2(n - r). \tag{9}$$

Let's find dependencies to determine the number of errors that can be detected using a fault-tolerant code sequence:

$$t_1 \leq 2(n-r)-1, if\ S_n \geq 4(n-r)\,, \tag{10}$$

$$t_1 \leq S_n - 2(n-r)-1, if\ S_n < 4(n-r). \tag{11}$$

Let's find the dependencies to determine the number of errors that can be corrected using a fault-tolerant code sequence:

$$t_2 \leq n-r-1, if\ S_n \geq 4(n-r), \tag{12}$$

$$t_2 \leq \frac{S_n-2(n-r+1)}{2}, if\ S_n < 4(n-r). \tag{13}$$

Let's find the optimal relationship between the values of the parameters *n* and *r* from the point of view of the best corrective ability of the interference-resistant code sequence. The immunity of this code sequence increases with the increase in the value of the difference $l = n - r$.

The largest value of l will be provided:

$$S_n = 2n. \tag{14}$$

Let us give the relationship between the parameters n and r, when the interference-resistant code sequence maximally detects and corrects the largest number of errors:

$$L = \begin{cases} n/2,\ n\ - even\ number \\ (n-1)/2,\ n\ - odd\ number. \end{cases} \tag{15}$$

The fault-tolerant code sequences obtained based on ideal ring bundles can find up to $n-1$ and correct up to $n/2-1$ errors for even values of n, and find up to n and correct up to $(n-1)/2$ errors for odd values of n provided that the number of allowed combinations of interference-resistant code sequences based on knitting is theoretically doubled due to the introduction of mirror interference-resistant code sequences.

Let us compare it with the most well-known error-correcting codes Bose-Chaudhuri-Hocquenghem (BCH), which detect and correct the maximum number of errors. The calculation of the relationship between the amount of *i* information and the number of *k* correction symbols in a code combination of length *n*, capable of correcting at least *s* errors, is based on the following expressions:

$$n = i + k; \tag{16}$$

$$2k \geq n+1; \tag{17}$$

$$2k \leq 2n/(n+1)\,; \tag{18}$$

$$S = end\,(d-1)/2, \tag{19}$$

where *d* is the minimum code distance.

To conduct a comparative analysis of BCH codes and test codes, we will use the following relationships:

$$N = 2n-1; \tag{20}$$

$$t = 2n-3; \tag{21}$$

$$P = 2n+1; \tag{22}$$

$$N^* = 2n+1; \tag{23}$$

$$t^* = (N^*-3)/4\,; \tag{24}$$

$$P^* = 2(N^* + 1), \tag{25}$$

where: N and N* are the lengths of code sequences; t and t* are the number of errors to be corrected; P and P* are the powers of the BCH and IRB code sequences, respectively.

Formulas (20)–(22) correspond to the ratio of the BCH code parameters [3], and (23)–(25) correspond to the parameters of the IRB code that provide maximum immunity to the length of the code sequence [4]. Analysis of the results of comparing these codes based on formulas (20)–(25) shows that for a fixed length of code sequences, the maximum achievable noise immunity of IRB codes is not inferior to BCH codes of the same sequence length. A certain advantage of the BCH code is the ability to provide an increase in power (22), but at the expense of loss of immunity to interference. Unlike BCH codes, the synthesis of IRB codes with a high level of noise immunity does not require complex calculations, and the length of code sequences is determined by a linear dependence (23), which makes it possible to construct code sequences with a high level of noise immunity.

4. The simulation model of interference-resistant coding

The algorithm of the simulation model of interference-resistant coding with the help of non-equidistant combinatorial configurations, which are clustered on the basis of the concept of the ideal ring knitting and the representation of the number that we code in ASCII format and the implemented method of coding using the ideal ring knitting. The algorithm of the simulation model of interference-resistant coding includes the following stages:

- entering data of the code parameters and choosing the ideal ring bundles;
- selection of a code combination using an ideal ring bundle;
- generation of a tamper-proof code of the selected number.

The block diagram of the algorithm for developing a simulation model of interference-resistant coding using non-equidistant combinatorial configurations consists of the following blocks:

- block "Choosing code parameters by IRB" - we choose the ideal ring bundles based on the values of the code parameters;
- block "Input of information for tamper-resistant coding" - input of the desired parameters of the tamper-proof code with IRB restrictions;
- block "If the power of the code is greater than the sum of the IRB" - the sum of the elements of the IRB is compared with the entered value. If the entered value is greater than the sum of the IRB elements, it is necessary to re-enter the number to select another IRB;
- "Calculation of code positions according to the selected IRB" block - there are corresponding positions in the IRB and corresponding sums of elements that correspond to the selected number;
- block "Construction of the table of the interference-resistant code according to the positions of the IRB" - a table of the found combinations of the IRB is generated;
- block "Generation of code combinations according to IRB values" - a table of code combinations is generated, where each IRB element corresponds to its own unique code;
- block "Construction of a code combination according to the indices in the code table" - the result of the generated interference-resistant code is formed due to the connection of two codes of four bits each;
- block "Cycle Arch. Received code combination" – processing cycle of the received combination. Replacement of groups "0" and "1" with appropriate groups when finding and correcting errors.
- block "Output of the resulting code combination" - record the results of interference-resistant coding in a file.

As an example, let's consider the calculation of the corrective capacity of interference-resistant codes built using IRB with parameters: 1) $N = 6, R = 1$; 2) $N = 15, R = 7$; 3) $N = 16, R = 8$. Since the sum of IRB Sn=31, the length of the code combinations and the power of the code in all these three cases are the same. The maximum number of errors to be detected or corrected during the implementation of the first of the defined codes is 9 and 4. In each of the other two cases, the IRB allows you to generate code that can detect up to 15 and correct up to 7 errors. Thus, the last two results are much better than the previous one. So, in general, any IRB can be used to build a jamresistant code. However, it is most expedient to use the codes formed by means of IKV, the parameters of which are connected by relation (15). A simulation model of fault-tolerant coding using non-equidistant combinatorial configurations is developed in the Delphi programming language [12]. The developed simulation model works flawlessly using a wide range of Windows operating systems. For the synthesis of non-equidistant interference-resistant code sequences based on IRB, a diagram of software components has been developed, which is presented in the form of interference-resistant sequence coding modules, random interference generation modules, and interference-resistant sequence decoding modules (Fig. 1).

As can be seen from the diagram of the sequence of actions of the data encoding process, the first action is the user's selection of a file and the opening of the file reading stream. Next comes the command to encode the file. While there is no end of the file, we read the data block. Next, we randomly generate obstacles and record them in the output file stream. Then we close the streams.

Let us present the diagram of the sequence of actions for the file decoding process, which is shown in Fig. 2. We will start the data decoding process with the file opening command. After that, send the command to decode the file. Encoded data from the file will be read in blocks until the end of the file. Next, the coder checks for errors. If errors are found, the coder corrects them. The next action is to decode the block data and write it to a file.

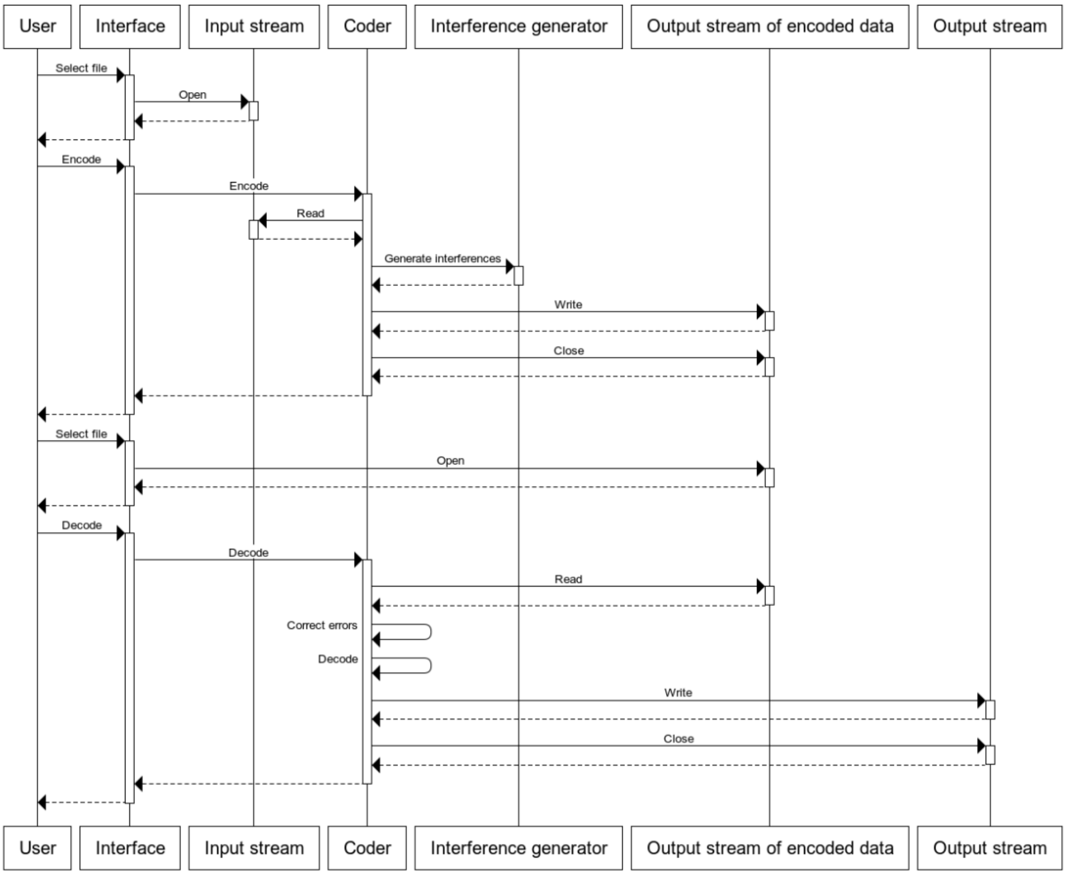


Figure 1: The sequence diagram of the data encoding process.

After the decoding is completed, we display statistical information about the result of decoding actions.

The program sequence diagrams show the operation process of the jamming-tolerant coding software product using non-equidistant jamming-tolerant code sequences and illustrate the possibilities of finding and correcting random jamming.

The simulation model of interference-resistant coding using non-equidistant combinatorial configurations has the following features:

- the input data will be the parameters of an interference-resistant non-equidistant code sequence of order *N* with multiplicity *R*;
- provides coding and decoding with finding and correcting errors in the number of up to t_2.

The program has an easy-to-use and intuitive interface. The main elements of the window form (Fig. 3):

- the input data (IRB parameters of order N with multiplicity R);
- the number of errors to be corrected (no more than the number specified in the Info window);
- the button with the inscription <OpenFile>, allows you to select the necessary file for encoding, creating random interference generation and decoding with the possibility of error correction.

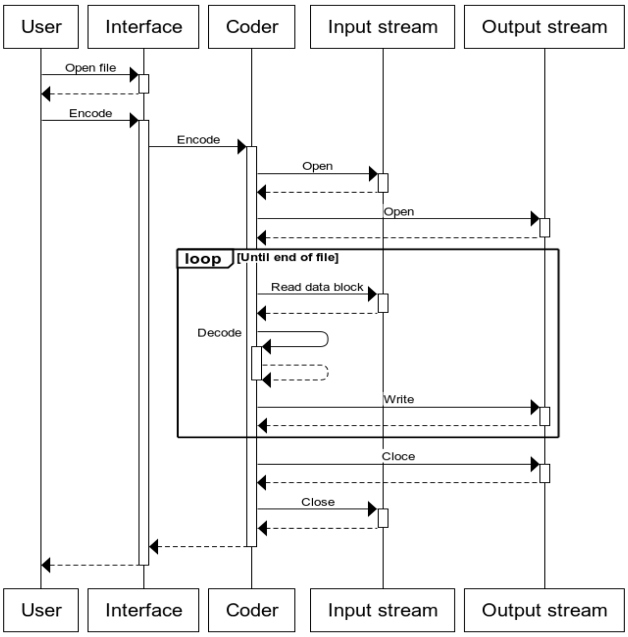
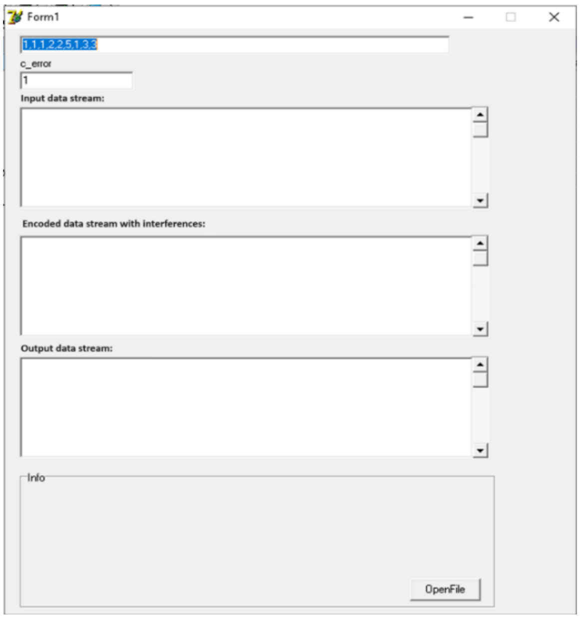


Figure 2: The sequence diagram of the data decoding process.



1,1,1,2,2,5,1,3,3

c_error

1

Input data stream:

Encoded data stream with interferences:

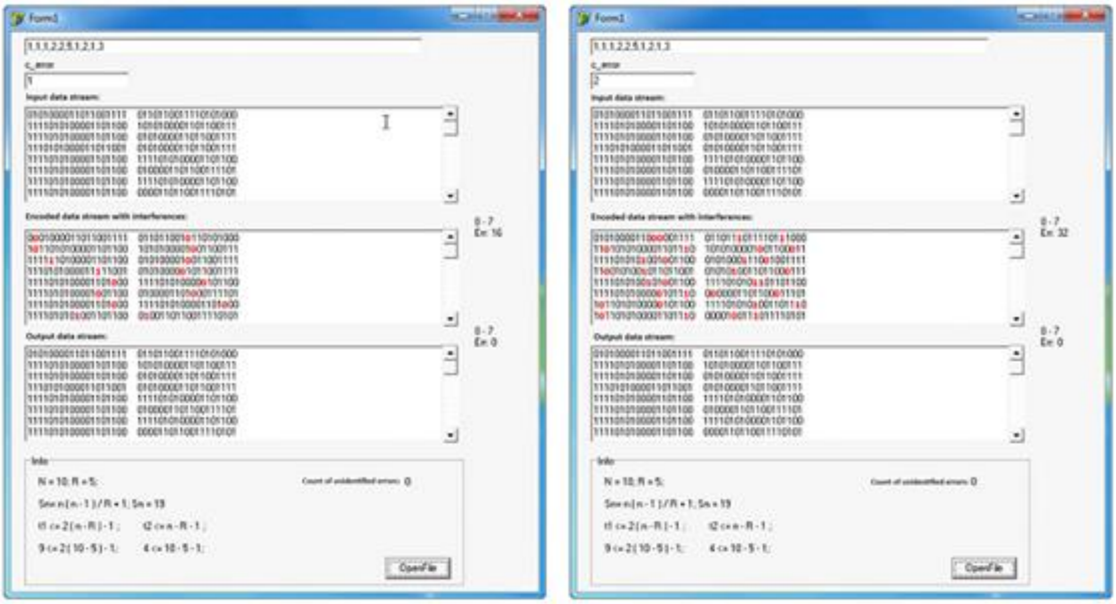
Output data stream:

Info

Figure 3: Basic elements on the form of the encoding/decoding window with the possibility of correction with the help of IRB.

5. Results

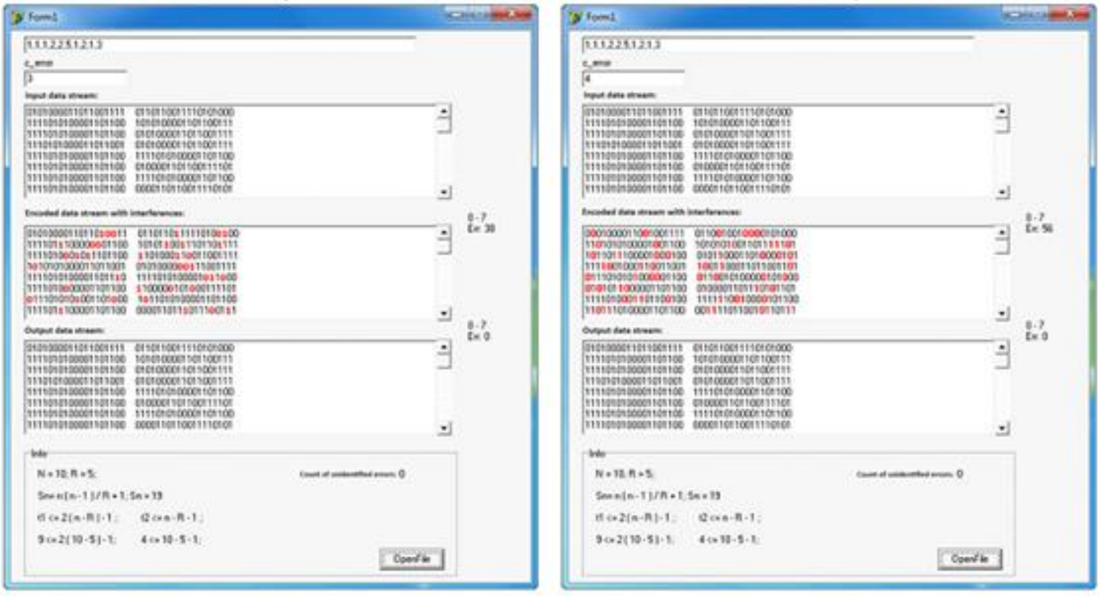
The results of the coding and decoding with the finding and correction of all errors in the number from one to two using interference-resistant non-equidistant code sequences are shown in Figure 4a and Figure 4b.



a) b)

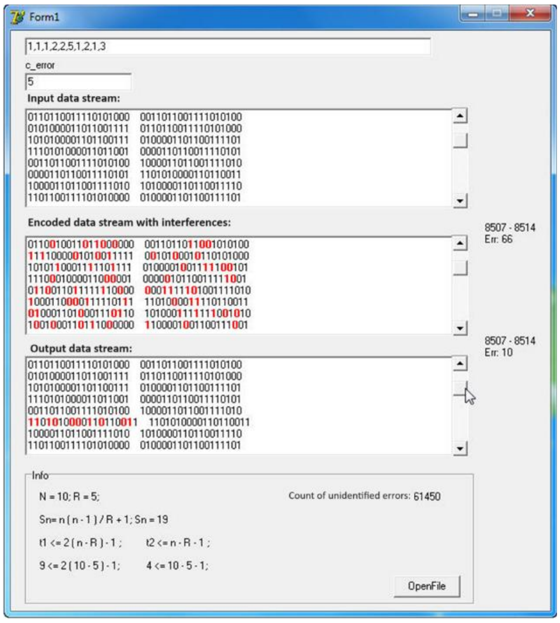
Figure 4: Conducting coding, interference generation, and decoding operations with correction of all single (a) and double (b) errors.

The following results of the coding and decoding with the finding and correction of all errors in the number from three to four using interference-resistant non-equidistant code sequences are shown in Figure 5a and Figure 5b. The results of the coding and decoding with the finding and correction of not all five-fold errors using interference-resistant non-equidistant code sequences are shown in Figure 6.



a) b)

Figure 5: Conducting coding, interference generation, and decoding operations with correction of all triple (a) and quadruple (b) errors.



```
1,1,1,2,2,5,1,2,1,3
```

```
5
```

Input data stream:

```
0110110011110101000   0011011001111010100
0101000011011001111   0110110011110101000
1010100001101100111   0100001101100111101
1110101000011011001   0000110110011110101
0011011001111010100   1000011011001111010
0000110110011110101   1101010000110110011
1000011011001111010   1010000110110011110
1101100111101010000   0100001101100111101
```

Encoded data stream with interferences:

```
0110010011011000000   0011011011001010100
1111000001010011111   0010100010110101000
1010110001111101111   0100001001111100101
1110001000011000001   0000010110011111001
0110011011111110000   0001111101001111010
1000110000111110111   1101000011110110011
0100011010001110110   1010001111111001010
1001000110111000000   1100001001100111001
```

```
8507 - 8514
Err: 66
```

Output data stream:

```
0110110011110101000   0011011001111010100
0101000011011001111   0110110011110101000
1010100001101100111   0100001101100111101
1110101000011011001   0000110110011110101
0011011001111010100   1000011011001111010
1101010000110110011   1101010000110110011
1000011011001111010   1010000110110011110
1101100111101010000   0100001101100111101
```

```
8507 - 8514
Err: 10
```

```
N = 10; R = 5;                    Count of unidentified errors: 61450
Sn= n ( n - 1 ) / R + 1; Sn = 19
t1 <= 2 ( n - R ) - 1 ;      t2 <= n - R - 1 ;
9 <= 2 ( 10 - 5 ) - 1;       4 <= 10 - 5 - 1;
```

Figure 6: Conducting encoding, jamming, and decoding operations correcting not all quintuple errors.

Analyzing the given experimental data obtained using the developed model, we see that finding and correcting all errors is presented in Figure 4 and Figure 5. There is a fairly significant number of errors found in Figure 6, but not corrected, which fully corresponds to the theory of non-equidistant interference-resistant code sequences.

6. Conclusion

It is shown that to eliminate interference during the transmission of code sequences over wireless communication channels, it is advisable to use interference-resistant coding. The method of synthesizing interference-resistant code sequences was improved, which, due to the use of ideal ring bundles, ensured an increase in the interference resistance of the obtained sequences, finding up to 50% and correcting up to 25% of distorted symbols from the length of the interference-resistant code sequence. A simulation model of interference-resistant coding using non-equidistant combinatorial configurations was developed in the Delphi programming language, which is focused on low computing power and works without errors using a wide range of Windows operating systems. It is shown that the use of ideal ring bundles for the synthesis of interference-resistant code sequences significantly simplifies the synthesis process and ensures its implementation in real-time. It was determined that the perspective of further research is the reduction of redundancy, which can be achieved by using mirror non-equidistant interference-resistant code sequences.

References

[1] I. Tsmots, V. Rabyk, O. Riznyk, Y. Kynash, Method of Synthesis and Practical Realization of Quasi-Barker Codes, in: 2019 IEEE 14th International Conference on Computer Sciences and Information Technologies (CSIT), Lviv, Ukraine, 2019, pp. 76-79. doi: 10.1109/STC-CSIT.2019.8929882.

[2] J. Ahmad, A. Akula, R. Mulaveesala and H. K. Sardana, Barker-Coded Thermal Wave Imaging for Non-Destructive Testing and Evaluation of Steel Material, IEEE Sensors Journal, vol. 19, no. 2, 2019, pp. 735-742. doi: 10.1109/JSEN.2018.2877726.

[3] J. Fu, G. Ning, Barker coded excitation using pseudo chirp carrier with pulse compression filter for ultrasound imaging, in: BIBE 2018; International Conference on Biological Information and Biomedical Engineering, Shanghai, China, 2018, pp. 1-5.

[4] M. Wang, S. Cong and S. Zhang, Pseudo Chirp-Barker-Golay coded excitation in ultrasound imaging, in: 2018 Chinese Control And Decision Conference (CCDC), Shenyang, 2018, pp. 4035-4039. doi: 10.1109/CCDC.2018.8407824.

[5] O. Riznyk, O. Povshuk, Y. Kynash, I. Yurchak, Composing method of anti-interference codes based on non-equidistant structures, in: 2017 XIIIth International Conference on Perspective Technologies and Methods in MEMS Design (MEMSTECH), Lviv, 2017, pp. 15-17.

[6] O. Riznyk, O. Povshuk, Y. Noga, Y. Kynash, Transformation of Information Based on Noisy Codes, in: 2018 IEEE Second International Conference on Data Stream Mining & Processing (DSMP), Lviv, 2018, pp. 162-165. doi: 10.1109/DSMP.2018.8478509.

[7] O. Riznyk, Y. Kynash, O. Povshuk and Y. Noga, The Method of Encoding Information in the Images Using Numerical Line Bundles, in: 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT), Lviv, 2018, pp. 80-83. doi: 10.1109/STC-CSIT.2018.8526751.

[8] R. Oleg, K. Yurii, P. Oleksandr and B. Bohdan, Information technologies of optimization of structures of the systems are on the basis of combinatorics methods, in: 2017 12th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT), Lviv, 2017, pp. 232-235. doi:10.1109/STC-CSIT.2017.8098776.

[9] S. Wang and P. He, Research on Low Intercepting Radar Waveform Based on LFM and Barker Code Composite Modulation, in: 2018 International Conference on Sensor Networks and Signal Processing (SNSP), Xi'an, China, 2018, pp. 297-301. doi: 10.1109/SNSP.2018.00064.

[10] S. Xia, Z. Li, C. Jiang, S. Wang and K. Wang, Application of Pulse Compression Technology in Electromagnetic Ultrasonic Thickness Measurement, in: 2018 IEEE Far East NDT New Technology & Application Forum (FENDT), Xiamen, China, 2018, pp. 37-41. doi: 10.1109/FENDT.2018.8681975.

[11] V. Banket and S. Manakov, Composite Walsh-Barker Sequences, in: 2018 9th International Conference on Ultrawideband and Ultrashort Impulse Signals (UWBUSIS), Odessa, 2018, pp. 343-347. doi: 10.1109/UWBUSIS.2018.8520220.

[12] Embarcadero/Products/Delphi. Native Apps For Any Device From One Codebase With Delphi! 2001. URL: https://www.embarcadero.com/products/Delphi, last accessed 2024/09/05.