Інформаційна безпека

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METHOD OF FORMING THE SIGNAL CODE CONSTRUCTIONS FOR INFORMATION TRANSMISSION IN HIDDEN INFORMATION TELECOMMUNICATION NETWORKS

The paper proposes a method for the formation of signal-code structures using orthogonal chaotic signals obtained by modified mapping based on the Chebyshev polynomial and the Gram-Schmidt orthogonalization procedure. The proposed method allows to increase the speed of information transmission in the data exchange paths of the hidden information telecommunication networks and not to apply additional methods of destruction of the phase portrait of the chaotic signal to increase its structural secrecy.

Keywords: *signal-construction, signal constellation, analytical chaotic implementation, reliability, Pearson correlation coefficient, Gram-Schmidt orthogonalization, noiseless coding.*

Introduction

Recently, the problem of building secure information telecommunication networks of special purpose, which must meet the high requirements for ensuring the reliability and speed of the transfer of information, is becoming more and more actual [9–12].

A promising direction of the development of such systems is the construction of information telecommunication networks in which chaotic signals are combined with noiseless codings for the information transmission and in which the modulation / encoding (demodulation / decoding) procedure is carried out jointly (signal-code construction SCC. Rational construction of such SCC allows combining the advantages of noiseless coding and selected types of signals and implementing relatively simple decoding algorithms.

The purpose of this work is to construct a method for the formation of signal-code constructions with the use of chaotic signals and noiseless coding for promising hidden information telecommunication networks.

Main part

Advantages of using chaotic signals as information carriers are given in the works [1–2; 6; 8]. In particular, their quasiorotogonal properties allow to organize the code division of chaotic implementations in a group signalBut the task of designing signal constellations and signal – code constructions, using chaotic signals, is not sufficiently investigated.

The traditional approach to the transmission of chaotic signals involves the formation of two chaotic implementations $x_1(t)$ - "0", $x_2(t)$ - "1" for the sequential transfer of bit streams. The property of the quasiorthogonality of chaotic signals allows to make a transition from sequential transmission to parallel transmission.

This allows to reduce the transmission time of the message in m times.

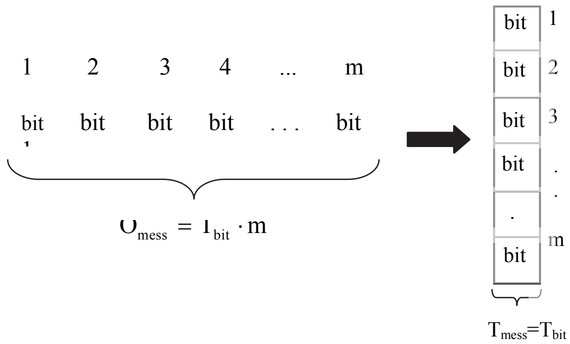


Fig. 1. Transition from sequential to parallel bit transmission

To do this, in this case $T_{bit} = T_{mass.}$, each bit is transmitted by a separate implementation of the chaotic process, orthogonal to one from the set m. Thanks to the parallel transmission, all bits are received at the same time, therefore it is impossible to distinguish the order of their follow-up. To eliminate this disadvantage, it is proposed to generate separate chaotic sequences specific to "0" and "1" in the corresponding position in the message. The initial value x_{i_j} of the formation of the chaotic implementations (fig. 2) is a code that uniquely indicates the direct value of the bit ("0" or "1") and simultaneously indicates the "location" of each bit in the sequence (its serial number).

The informational message, formed in this way, is a superposition of chaotic implementations, duration T_{bit}:

$$S(t) = \sum_{i=1}^{m} x_i(t) . \qquad (1)$$

For example, to transmit a message, that in binary form has a code 10010 , it is necessary to generate chaotic sequences with the following initial values $x_{1_1}, x_{0_2}, x_{0_3}, x_{1_4}, x_{0_5}$, in such orde.

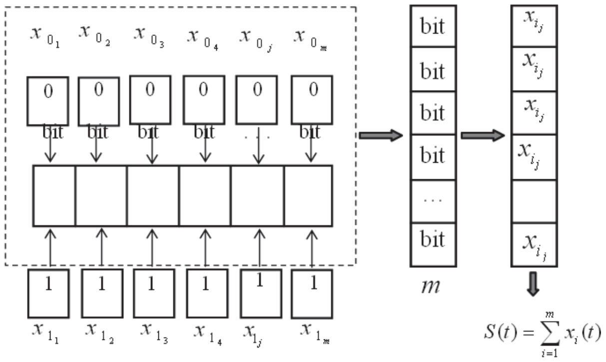


Fig. 2. Coding scheme of bit sequence using the initial values of chaotic implementations

The rule for selecting the initial values for generating chaotic implementations is presented in tabl. 1

Table 1

Bit	Initial values x_{i_j} (code) to generate chaotic implementations in accordance with the order of following binary symbols						
	1	2	3	4	5	….	m
"0"	x_{01}	x_{02}	x_{0_3}	x_{0_4}	x_{0_5}	x_{0_j}	x_{0_m}
"1"	x_{11}	x_{12}	x_{1_3}	x_{1_4}	x_{1_5}	x_{1_j}	x_{1_m}

where x_{i_j} – the initial value; i – the value of binary symbol ("0" or "1"); j – serial number in sequence.

The set of messages to be translated is encoded using a binary code $N = 2^m$, where m – the number of binary bits in the message.

For the construction of multichannel data exchange paths in information telecommunication networks that use shared spatial, frequency and time resources, it is important to choose the ensemble of signals to be used as a carrier of information. Generally, signals should be linearly independent. Under the conditions of active impedance, the choice of orthogonal signals is preferable. Only in this case the signal energy is used to the fullest extent.

The most striking example of practically orthogonal signals is the set of implementations of quasi-white noise in a limited frequency band. Due to their special properties, namely, a similar autocorrelation function, a uniform spectrum in a limited frequency band, at the output of the correlator, which coincides with the "sign" of the signal, there is an acute peak of voltage. It facilitates the task of signal separation and deciding in the process of demodulation. Choosing the noise-like signals as bearers allows you to form an ensemble of signals with the above properties.

On the receiving side, to make decision about value of the bit in each of the positions received message is checking two hypotheses: H_{0_j} – the presence of "0" and H_{1_j} – the presence of "1" on the position in the message. The presence in the message of other $m-1$ bits leads to errors in making a decision in the general case of non-orthogonality of chaotic implementations.

To separate each of the m signals on the receiving side, you need to have m decision devices (fig. 3).

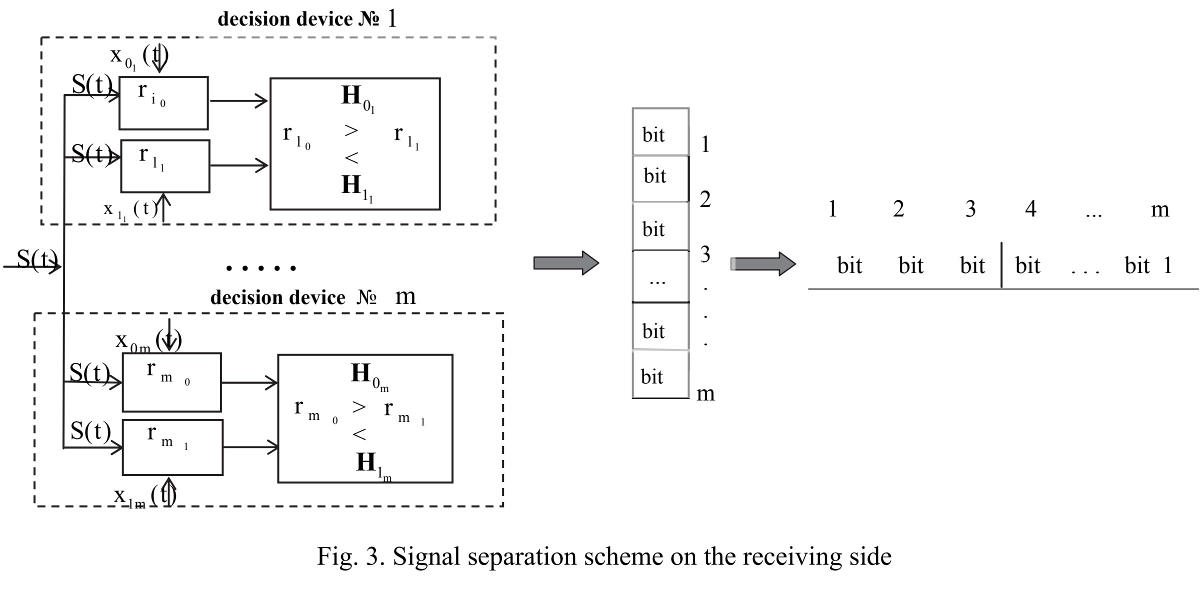


Fig. 3. Signal separation scheme on the receiving side

The decision is made by calculating the Pearson correlation coefficient between the implementation from the receiver input S(t) (1) and each of the standard chaotic implementations with the code x_{0_j} and x_{1_j} for the m-s decision device. The Pearson correlation criterion is a statistical parametric method for determining the degree of correlation between two variables. The condition for applying the specified coefficient is the normal law of distribution of the comparable values. So for the decision device № 1 (fig. 3), such standards are chaotic implementations with initial values x_{0_1} and x_{1_1} :

$$r_{m_0} = \frac{\sum (s-\bar{s})\cdot(x1-\bar{x1})}{\sqrt{\sum (s-\bar{s})^2 \cdot \sum (x1-\bar{x1})^2}} ; \qquad (2)$$

$$r_{m_1} = \frac{\sum (s-\bar{s})\cdot(x2-\bar{x2})}{\sqrt{\sum (s-\bar{s})^2 \cdot \sum (x2-\bar{x2})^2}} , \qquad (3)$$

where r_{m_0}, r_{m_1} – Pearson correlation coefficients, for "0" та "1" for m-s decision device, sample of standard chaotic implementations for "0" та "1" m-s decision device; $\bar{s}, \bar{x1}, \bar{x2}$ – average sample values. The obtained correlation coefficients are compared with each other. Depending on which value the coefficient is greater, the hypothesis H_{0_j} is accepted – the presence of "0" on the j-s position or H_{1_j} – the presence of "1" on the j-s position. As a result of the selected hypotheses, we obtain a parallel sequence of bits of the received message in the m outputs of the decision devices.

In the work mathematical modeling of the data transmission system using the proposed method was carried out. As a carrier, chaotic sequences generated by a discrete mapping based on the modified Chebyshev mapping [4] were used:

$$x_{n+1} = \alpha \cdot (4x_n^{\,3} - 3x_n) , \qquad (4)$$

where α – control parameter.

The choice of mapping (4) is due to the fact that among all the most well-known one-dimensional discrete chaotic mappings, a modified mapping based on the Chebyshev polynomial allows us to obtain an ensemble of realizations with the most uniform power spectrum and good orthogonal properties [4]. This is important for the construction of hidden information telecommunication networks.

It should be noted that the general disadvantage of chaotic signals obtained with any kind of mappings is their lack of structural secrecy. The reason for this is structured phase portraits or attractors that are images of chaotic signals in the pseudophase space. Traditional methods for determining energy and structural secrecy usually do not use the specific properties of attractors. At present, a nonparametric method [7] is developed, which allows to determine the presence or absence of any ordering and regularities between points of the attractor on the phase portrait. Methods for breaking the structure of the attractor of chaotic signals and bringing it closer to the attractor of the white noise are known [2; 5; 7].

In [5] the method of formation of analytical chaotic sequence, presented in the form of oscillatory process, is proposed. For this, from the original chaotic sequence,

$$\{x_0, x_1, x_2, \ldots x_{N-1}\} ,$$

a complex sequence is obtained,

$$\{x_0 + jx_{\perp 0}, x_1 + jx_{\perp 1}, x_2 + jx_{\perp 3}, \ldots x_{N-1} + jx_{\perp N-1}\}$$

the imaginary part of which is the Hilbert transform of the original chaotic sequence $\{x_0, x_1, x_2, \ldots x_{N-1}\}$.

The amplitude and phase of a complex sequence is calculated according to the following expressions:

$$A_n = \left|\dot{A}_n\right| = \sqrt{x_n^{\,2} + x_{\perp n}^{\,2}} ; \qquad (5)$$

$$\psi_n = \left|\dot{\psi}_n\right| = \arctan\left(\frac{x_n}{x_{\perp n}}\right). \qquad (6)$$

After transferring the complex amplitude and phase to a harmonic carrier, an analytic chaotic sequence is obtained:

$$s_n = A_n \cos(\psi_n + \omega n) . \qquad (7)$$

An important aspect is the correct choice of frequencies, the values of which should not take values in the small frequency domain $\omega \neq 2\pi n$, $(n = 0,1,\ldots)$, since in this case the attractor takes the form close to the attractor of the initial sequence.

In fig. 4 for comparison, the image of a phase portrait of modified mapping based on the Chebyshev polynomial and its same phase portrait using the method of formation of analytical chaotic sequence [5] for the destruction of the signal attractor is given. The transmission of messages in a parallel way allows us to provide the structural secrecy of the chaotic signals that are used for transmission.

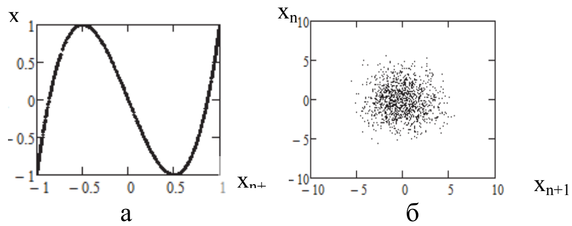
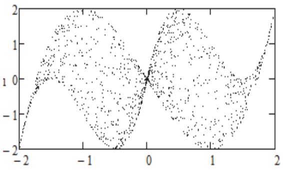
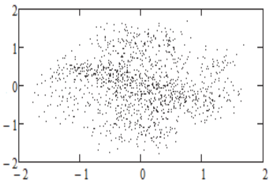
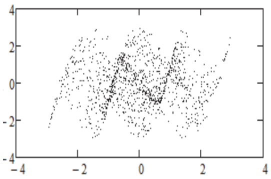
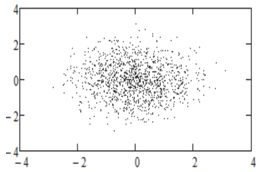
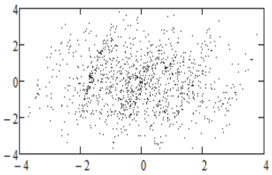
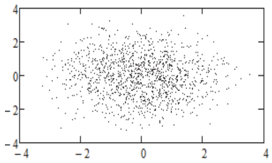
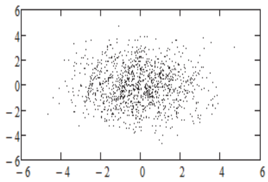
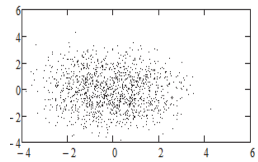
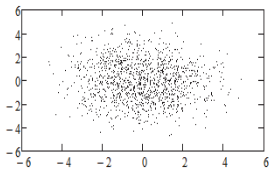
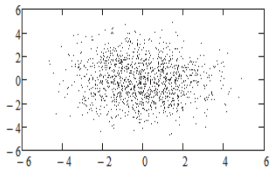
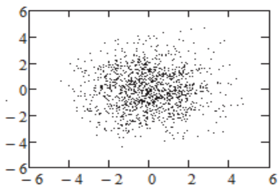
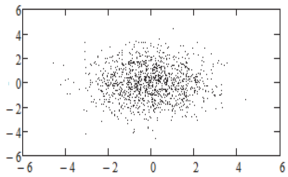
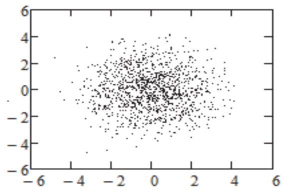
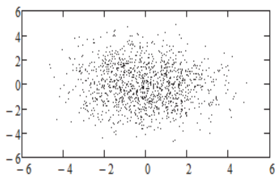


Fig. 4. A phase portrait of a chaotic sequence of modified mappings based on the Chebyshev polynomial before (a) and after (b) the application of the method of forming an analytic chaotic sequence

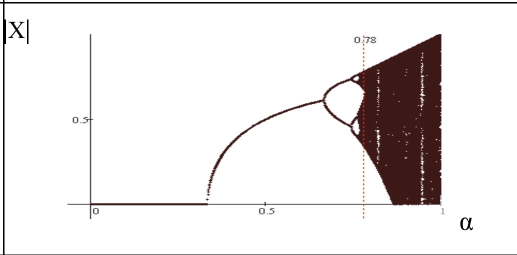
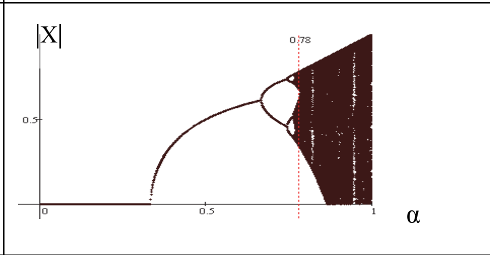
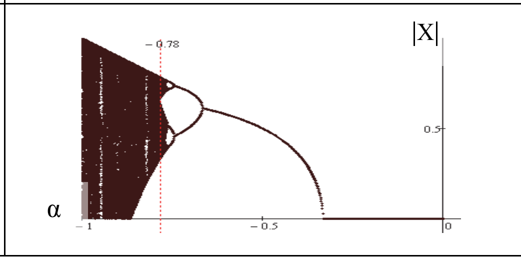
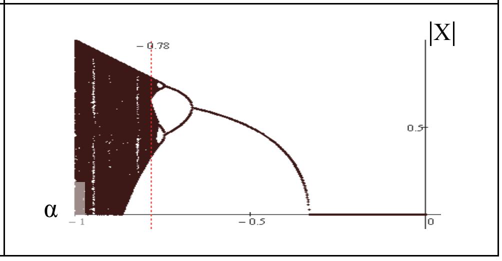
A group chaotic signal, represented by a sum of 5 or more chaotic signals, has a phase portrait similar to a white noise portrait. Nonparametric methods (BDS-statistics) [7] do not determine the ordering and regularities between the points of the attractor of such a signal. Table 2 shows the image of the group chaotic signal (GCS) attracted by the modified mapping and the analytical chaotic group signal (AHGS), depending on the number of implementations that make it. It is seen that an increase in the number of chaotic implementations in a group signal brings its phase portrait closer to the portrait of an analytic chaotic signal, which has a visual similarity to the phase portrait of white noise [5].

Table 2

	Image of the GHS attractor BDS test value	Image of the GHAS attractor BDS test value
$S(t)=\sum_{i=1}^{2} x_i(t)$	 BDS = 27	 BDS = 8
$S(t)=\sum_{i=1}^{3} x_i(t)$	 BDS = 1,16	 BDS = 1,31
$S(t)=\sum_{i=1}^{4} x_i(t)$	 BDS = 1,158	 BDS = 1,043
$S(t)=\sum_{i=1}^{5} x_i(t)$	 BDS = 0,51	 BDS = 0,92
$S(t)=\sum_{i=1}^{6} x_i(t)$	 BDS = 2,78	 BDS = 1,85
$S(t)=\sum_{i=1}^{7} x_i(t)$	 BDS = 1,496	 BDS = 3,187
$S(t)=\sum_{i=1}^{8} x_i(t)$	 BDS = 1.226	 BDS = 1.471

It is seen that an increase in the number of chaotic implementations in a group signal brings its phase portrait closer to the portrait of an analytic chaotic signal, which has a visual similarity to the phase portrait of white noise [5]. This indicates the possibility of increasing the structural secrecy of the group analytic signal in comparison with a separate chaotic implementation without the use of an analytic chaotic signal.

Table 3

	$-1<x<0$	$0<x<1$
$0<\alpha<1$		
$-1<\alpha<0$		

Confirmation of increased structural secrecy is the value of BDS-statistics [7], which tends to decrease with the increase of the components of the group chaotic signal. Table 3 shows the form of bifurcation diagrams for modified mappings based on the Chebyshev polynomial for the initial value $x_0 = 0,7$ with variations of the control parameter $-1<\alpha<1$ The table 3 shows that chaotic mode is observed at

$$-1<\alpha<-0,78\,; \qquad (5)$$

$$0,78<\alpha<1\,. \qquad (6)$$

It should be noted that this form of bifurcation diagrams for other values of initial values $-1<x_0<1$ is retained. The specific values of the control parameter and the initial values for generating chaotic implementations are conveniently graphically represented as the points of the signal constellation (fig. 5), where the axis of the abscissa denotes x_0, the axis of the ordinate denotes α. Each point of a chaotic signal constellation corresponds to one bit of transmitted information. The group chaotic signal, in length m bits, corresponds to a code combination of m points of a chaotic signal constellation, in accordance with Table 1 of the initial conditions. To encode any m-bit message you need 2m chaotic implementations.

As noted above, the time of the parallel transmission of such a m-bit message will be equal to the duration of the one bit transmission – T_{bit}. This allows you to increase the speed of data transmitted at m times. The minimum difference (distance) between the values, selected on the axes (fig. 5), can be any small, which will ensure good inter-correlation properties of the received chaotic implementations. In the general case, the location of the signal constellation points may be non-equilibrium. The limitation to select a control parameter α is Sharkovsky's windows in bifurcation diagrams (Table 3).

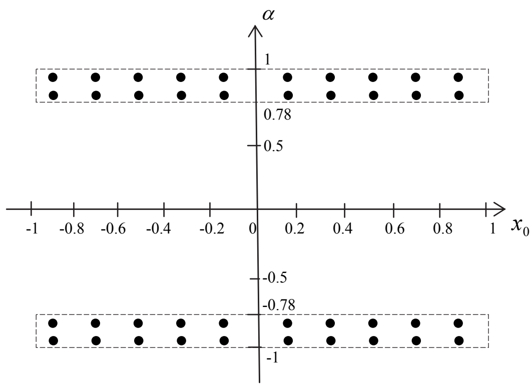


Fig. 5. Chaotic signal constellation

In the work, the simulation of the transmission of 8-bit data blocks (which can correspond to a message from one correspondent or one-bit messages from 8 correspondents) was carried out. In this case, to encode any 8-bit message, according to Table 1, 16 initial values will be needed to get chaotic implementations.

Table 4 shows the initial values of chaotic implementations that were used in modeling to encode the order of following bits in a message.

Table 4

біт	Initial values (code) for the formation of chaotic implementations in accordance with the order of binary symbols							
	1	2	3	4	5	6	7	8
"0"	0,04	0,08	0,12	0,16	0,2	0,24	0,28	0,32
"1"	0,36	0,4	0,44	0,48	0,52	0,56	0,6	0,64

Figure 6 shows the dependence of the bit error probability on the signal / noise ratio for the parallel transmission of messages using analytical chaotic implementations obtained by a modified mapping of Chebyshev and consisting of K =50, 100, 150 discrete signal samples.

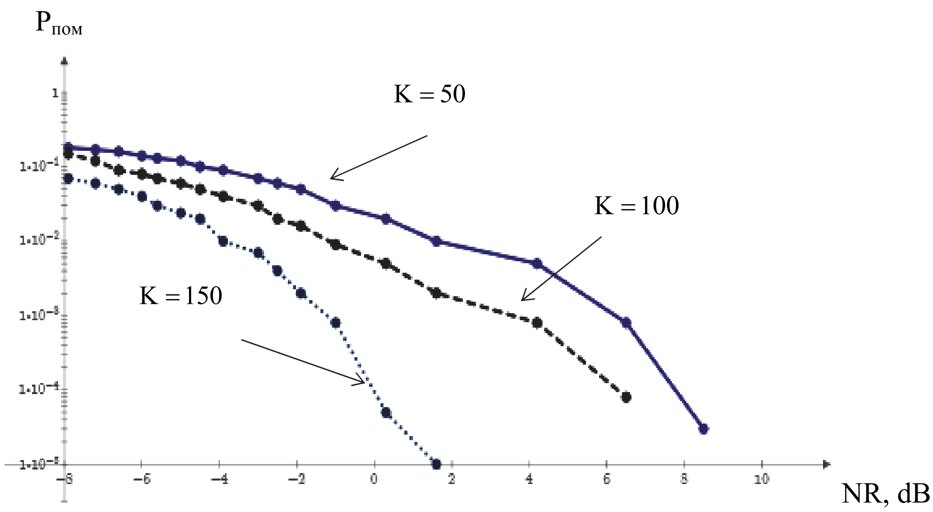


Fig. 6. The dependence of the bit error probability on the signal-to-noise ratio in parallel transmission of messages at K = 50,100,150 discrete samples of analytic chaotic implementations

The graph shows that an increase in the number of samples from 50 to 150 for analytic chaotic implementations contained in a group signal yields a signal-to-noise gain of about 6 dB. In this work an estimation of the orthogonal properties of analytic chaotic realizations, obtained with the help of the Modified mapping based on the Chebyshev polynomial, (4) was carried out. Figure 7 shows a table for calculating the angles between all possible pairs of 16 chaotic implementations vectors that were used during modeling:

0	100	92	82	87	96	93	78	94	88	97	85
0	0	97	102	84	82	83	88	88	91	96	101
0	0	0	92	90	88	95	97	96	89	79	82
0	0	0	0	89	88	87	90	89	93	86	92
0	0	0	0	0	92	83	88	92	84	91	97
0	0	0	0	0	0	82	83	91	91	89	97
0	0	0	0	0	0	0	80	100	84	93	91
0	0	0	0	0	0	0	0	85	97	94	91
0	0	0	0	0	0	0	0	0	97	89	101
0	0	0	0	0	0	0	0	0	0	102	82
0	0	0	0	0	0	0	0	0	0	0	85

Fig. 7. A table for calculating the angles between all possible pairs from 16 chaotic implementations vectors, that were used during modeling

In order to increase the reliability of receiving messages, an orthogonalization of analytical chaotic implementations that were part of a group signal was carried out. In this case, the scalar product between all the pairs of signals, and therefore their mutual energy will be zero For these purposes, the Gram-Schmidt orthogonalization procedure [3] was carried outFigure 8 shows a table for calculation the angles between all possible pairs from 16 chaotic implementations vectors after orthogonalization:

0	90	90	90	90	90	90	90	90	90	90
0	0	90	90	90	90	90	90	90	90	90
0	0	0	90	90	90	90	90	90	90	90
0	0	0	0	90	90	90	90	90	90	90
0	0	0	0	0	90	90	90	90	90	90
0	0	0	0	0	0	90	90	90	90	90
0	0	0	0	0	0	0	90	90	90	90
0	0	0	0	0	0	0	0	90	90	90
0	0	0	0	0	0	0	0	0	90	90
0	0	0	0	0	0	0	0	0	0	90

Fig. 8. A table for calculating the angles between all possible pairs from 16 chaotic implementations vectors, that were used in modeling after orthogonalization

The results of numerical simulation of data transmission using orthogonal analytic chaotic implementations are presented below. Fig. 9 shows the dependence of the bit error probability on the signal-to-noise ratio in the case of parallel transmission of signals for orthogonal analytic chaotic implementations based on the Modified Chebyshev mapping at K = 50, 100, 150 discrete samples.

The graph shows that the use of orthogonal analytical chaotic implementations in data transmission provides a gain of about 1,5–2 dB compared with the use of such implementations without an orthogonalization procedure. The reliability of receiving messages in the general case is not sufficient and is determined by the type of data transmission channel and the kind of noise in it.

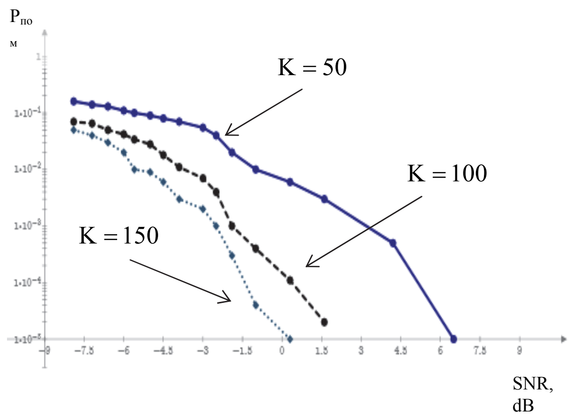


Fig. 9. Bit error probability for parallel transmission of messages at K = 50,100,150 discrete samples of orthogonal analytic chaotic implementations

The use of noiseless coding is one of the most effective ways to increase the reliability of receiving messages and reduces the likelihood of errors to some acceptable level.

To do this, it is proposed to add bits of control digits to the parallel bit packet. Additional orthogonal chaotic implementations are formed for their transmission (fig. 10). The choice of noiseless code depends on several factors: the type of errors in the data transmission channel, the permissible speed of transmission, the required reliability of reception, and so on.

For example, block codes are well corrected for errors that occur rarely but with large packages. Rolling codes are effective in a white noise channel. They are well corrected for frequent and minor errors, but do not work well with bug packages.

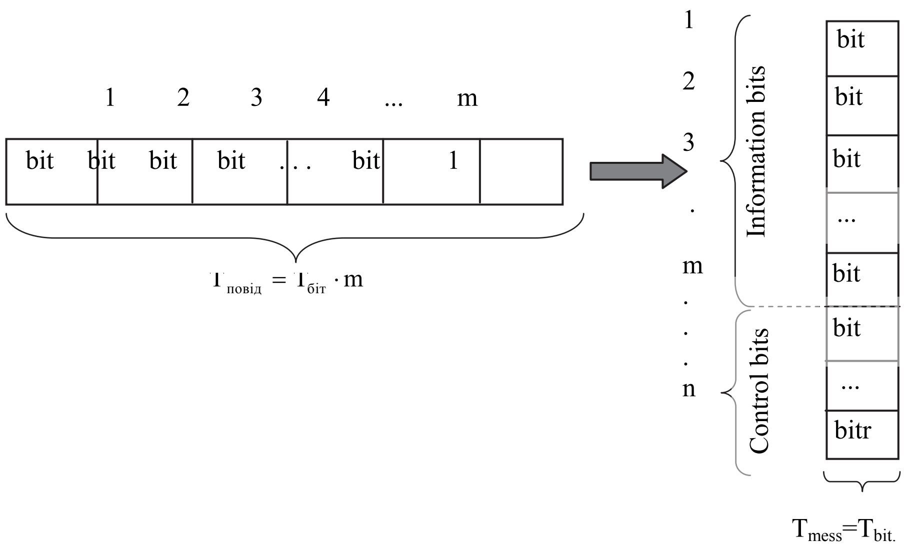


Fig. 10. Application of control digits for the organization of noiseless coding for parallel transmission of messages

Conclusions

The application of the proposed method for the formation of chaotic signal-code constructs can increase the transmission rate of information in proportion to the number of bits constituting a message.

Applying the Gram-Schmidt orthogonalization procedure can increase the reliability of receiving messages and provide a gain of about 1,5–2 dB with $P_{er} = 10^{-5}$, compared with the use of chaotic implementations without an orthogonalization procedure. In order to increase the structural secrecy of the formed group chaotic signal, which consists of more than 5 chaotic implementations, it is impractical to apply the methods of destroying the phase portrait, since the phase portrait of such a signal looks like a phase portrait of white noise. The rejection of these methods will simplify algorithms for processing the group chaotic signal.

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МЕТОД ФОРМУВАННЯ ХАОТИЧНИХ СИГНАЛЬНО-КОДОВИХ КОНСТРУКЦІЙ ДЛЯ ПЕРЕДАЧІ ІНФОРМАЦІЇ В ЗАХИЩЕНИХ ІНФОРМАЦІЙНИХ ТЕЛЕКОМУНІКАЦІЙНИХ МЕРЕЖАХ

К.С. Васюта, І.В. Захарченко, І.А. Нікіфоров

В роботі запропоновано метод формування сигнально-кодових конструкцій з використанням ортогональних хаотичних сигналів, отриманих за допомого модифікованого відображення на основі поліному Чебишева та процедури ортогоналізації Грама-Шмідта. Запропонований метод дозволяє підвищити швидкість передачі інформації у трактах обміну даними прихованих інформаційних телекомунікаційних мереж та не застосовувати додаткові методи руйнування фазового портрету хаотичного сигналу для підвищення його структурної скритності.

Ключові слова: *сигнально-кодова конструкція, сигнальне сузір'я, аналітична хаотична послідовність, достовірність, коефіцієнт кореляції Пірсона, ортогоналізація Грама-Шмідта, завадостійке кодування.*

МЕТОД ФОРМИРОВАНИЯ ХАОТИЧЕСКИХ СИГНАЛЬНО-КОДОВЫХ КОНСТРУКЦИЙ ДЛЯ ПЕРЕДАЧИ ИНФОРМАЦИИ В ЗАЩИЩЕННЫХ ИНФОРМАЦИОНЫХ ТЕЛЕКОМУНИКАЦИОННЫХ СЕТЯХ

К.С. Васюта, І.В. Захарченко, І.А. Никифоров

В роботе предложен метод формирования сигнально-кодовых конструкций з использованием ортогональных хаотических сигналов, полученных с помощью модифицированного отображения на основе полинома Чебышева и процедуры ортогонализации Грамма-Шмидта. Предложенный метод позволяет повысить скорость передачи информации в трактах обмена данными скрытых информационных телекоммуникационных сетей и не применять дополнительные методы разрушения фазового портрета хаотического сигнала для повышения его структурной скрытности.

Ключевые слова: *сигнально-кодовая конструкция, сигнальное созвездие, аналитическая хаотическая последовательность, достоверность, коэффициент корреляции Пирсона, ортогонализация Грамма-Шмидта, помехоустойчивое кодирование.*