Досліджено технології побудови мобільних мереж 5 G, які повинні забезпечити умови створення ультращільних мереж для отримання високоякісних послуг. Зроблена формалізована постановка задачі синтезу оптимального сигналу за умовами відносної інваріантності до адитивної перешкоди. Розроблено метод оптимізації параметрів сигналу за середньоквадратичним критерієм. Запропоновано рішення задачі оптимізації методами нелінійного програмування. Показано, що рішення цього завдання дозволяє знайти сигнал із заданими параметрами, інваріантний до детермінованих перешкод.

Розроблено метод оптимізації параметрів сигналу за рівномірним критерієм. Метод базується на визначенні сукупності коефіцієнтів розкладання сигналу, при яких максимум модуля вихідного сигналу демодулятора, взятий за всіма значеннями випадкового параметра, мінімальний. Запропоновано рішення задачі методами лінійного програмування. Використання методу дає можливість підвищити завадостійкість в системі передачі даних та збільшити швидкість передачі інформації в каналі зв'язку.

Проведено синтез оптимального сигналу по відношенню до адитивної перешкоди. Даний сигнал дозволяє забезпечити в системі максимально можливу завадостійкість. Розглянуто діскретнорізницеве перетворення, що має універсальну властивість інваріантності щодо широкого класу перешкод.

Показано, що досягнення абсолютної або відносної інваріантності та доцільність застосування одного з перерахованих методів залежить від характеристик перешкоди, ступеня апріорної визначеності, а також можливості організації зворотного каналу зв'язку. Результати моделювання показали, що запропоновані в статті методи формування інваріантного сигналу дозволяють підвищити стійкість системи в каналі зв'язку на 5–7 дБ. Впровадження розроблених методів дасть можливість збільшити швидкість переданої інформації на 30 % за умови забезпечення заданої достовірності передачі даних. Забезпечення інваріантності системи передачі інформації дозволить створити ультращільні мережі п'ятого покоління

Ключові слова: стійкість мереж, адитивна перешкода, оптимальний сигнал, квазідетермінована перешкода

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DEVELOPMENT OF METHODS TO IMPROVE NOISE IMMUNITY IN THE FIFTH-GENERATION MOBILE NETWORKS BASED ON MULTIPOSITION SIGNALS

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1. Introduction

In modern networks, increasing attention during information transfer is paid to the construction of information systems, capable of providing for the assigned probability of information transmission at a change in conditions along a communication channel. These conditions are typically caused by various influences and interferences.

The systems under consideration differ from each other by their purpose, the principle of construction, and have one common property – insensitivity to various interferences. This raises the need to ensure the insensitivity to interferences in modern mobile 5 G networks.

5 G mobile network technologies will create the conditions for higher throughput compared to 4 G technologies. This will ensure greater affordability of broadband mobile communication, this will make it possible to organize super reliable scalable communication systems between devices, to provide for a lower delay, to save battery power, etc. All the specified factors will favorably affect the development of technology for the Internet of Things.

In order to ensure a data transfer rate along a radio channel of 1 Gbps, each subscriber will require upgrading not only the base stations, mobile devices of subscribers, but also the methods for generating and processing multi-position signals. When implementing an information transfer rate close to the throughput of a communication channel, it is required to enable the invariance of the system to various kinds of interferences specific to communication channels.

Recently, the concept of invariance has been increasingly used in engineering science to define the property of robustness, the information transmission systems insensitivity to random change in their parameters, to various interfering influences. Invariance is understood as a capability of the system of automated control to resist interfering effects. The role of the invariant belongs to the magnitude of controlling influence along one of the coordinates. The proof can be found in papers [1, 2]. If control along one of the coordinates is not dependent on the interfering impact, the system of automated regulation is then referred to as invariant. In the automated control systems, the interfering influences and controlling signals are spatially separated. This makes it possible to measure the interfering influence and to use all sorts of compensation methods for the implementation of invariance. In information transmission systems, a useful signal and an interference act at the same point and, typically, could not be completely separated, otherwise there would be no problem related to eliminating the noise at all. In information transmission systems, there is always a mixture of signal and interference. Consequently, for information transmission systems it is impossible or difficult to apply compensatory methods for noise suppression. Therefore, the problem of invariance is solved by the method for forming a multi-position signal. The proposed methods make it possible to increase the rate of information transmission by two times (assuming the invariance of the critical indicator of noise immunity   an error probability). Thus, when implementing a 5 G technology, the crucial scientific task is to form a signal that would provide for the maximum system noise immunity to the action of interferences.

Given the above, under modern conditions for the development of technologies for communication networks, it is a relevant task to undertake a research aimed at the development of methods for synthesis of the optimal signal under conditions for relative invariance to an additive interference.

2. Literature review and problem statement

The main task when introducing 5 G is to ensure that the information transfer rate is close to the channel's throughput capacity. In this case, a signal formation must be carried out in such a way that while providing for the assigned noise immunity, the multiplicity of modulation increases with, accordingly, an increase in the rate of information transfer.

Paper [3] shows that the development of 5 G networks will focus on the construction of ultradense networks (UDN) of wireless access with a heterogeneous structure of cells with a radius not exceeding 50 m based on the new kinds of signal-code radio channel structures. These structures will exceed by an order of magnitude the spectral efficiency compared to 4 G networks and enable data transfer at rates above 10 Gbit/s. However, the paper does not provide calculations that determine the noise immunity of the proposed systems. Therefore, given such information transmission rates, an error probability will greatly exceed permissible values.

Study [4] demonstrated that an increase in the spectral efficiency in 5 G networks could be achieved by applying the non-orthogonal methods of access (NOMA) and the non-orthogonal signals (for example, FTN, F-OFDM-signals, and others). However, the study did not provide calculations related to the power of channel-to-channel interferences, characteristic of OFDM signals.

Paper [5] describes the 5 G networks infrastructure, which will be based on cloud technologies with a software-defined network. In this case, the main routing method is packet switching. An important quality criterion of network operation within this method is the percentage of lost packets due to errors at information transmission. Thus, an error probability indicator is essential to the development of mobile communication networks, and, consequently, for providing high quality services. However, the paper does not give methods to reduce the likelihood of an error, which would make it possible to render services in real time with the predefined quality.

Paper [6] describes techniques to form signals that enable, when increasing the rate of information transfer, the improvement of system parameters compared to the 4 G technology. The methods reported do not provide for the assigned reliability of information transmission.

Study [7] suggested methods for forming a multidimensional signal, which could not provide for the modulation with different multiplicity. Paper [8] proposes methods for effective distribution of dynamic resources in OFDMA systems employing the Packet Firefly algorithm. However, the quality of information communication channels does not make it possible to effectively apply this algorithm, as the percentage of lost packets would exceed the permissible value.

Study [9] suggested an algorithm for optimal reception using a coherent reception method. It was determined that in this case the probability of an error is significantly reduced. However, it is necessary to know the phase of the received signal that is often impossible in the transmission of information along modern radio channels.

Paper [10] considers LTE networks based on the M2M services. It shows the need for a machine-to-machine exchange with a rate of transmitted information close to the channels' throughput capacity. However, the paper does not describe any techniques for OFDM signal formation at the transmitting device and, accordingly, at the receiving device.

Thus, the above publications propose various methods for signal formation at transmission, methods for optimal reception, which could make it possible to reduce the probability of error, to increase the rate of information transfer. However, in all these studies, noise immunity is enabled based on the compensation for interferences characteristic of a radio channel. As regards the achievement of rates for information transmission close to the channel's throughput, the techniques to improve noise immunity are ineffective, because interferences in modern access networks are described by the stochastic laws of distribution. For this reason, the proposed methods do not provide for the required speed at the stage of radio access because the interferences, specific for these sections of the network, reduce by an order of magnitude the noise immunity, and, accordingly, the rate of information transfer.

In such circumstances, taking into consideration the additive character of an interference, it is the crucial task to form a signal structure resistant to interference for different criteria. The existence of various conflicting factors describing the distribution medium, as well as varied energy characteristics of the signal, necessitates solving the optimization problem whose desired variables are its parameters.

3. The aim and objectives of the study

The aim of this study is to examine a possibility to synthesize an invariant system of information transfer, against a specific class of interferences, which is the most effective 5 G mobile network infrastructure.

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

– to formalize the problem of synthesis of optimal signal for the conditions of relative invariance against an additive interference;

– to construct a method for the optimization of signal parameters based on the mean square criterion and equitable criterion;

– to assess noise immunity of the invariant information transfer system against an additive interference.

4. Formalization of the problem of synthesis of the optimal signal for the conditions of relative invariance against an additive interference

One of the methods to synthesize systems with constant parameters invariant to an additive interference is the method for finding the optimal signal. In accordance with this method, demodulation operator $\Phi_{\text{opt}N}$ is chosen as optimal relative to interference N while the relative invariance to interference Ξ (if it is possible) is achieved by choosing a signal S, which minimizes, based on different criteria, the effect of interference action at the output from demodulator. We shall consider the synthesis of an optimal signal in more detail. We remind that we examine systems of discrete information transfer with constant parameters, and, therefore, they could be invariant (absolutely or relatively) only in relation to the quasi-deterministic interferences.

A quasi-deterministic interference could be recorded in the form of a deterministic function of time with random parameters α, β, γ and others [11]:

$$\xi = \xi(t, \alpha, \beta, \gamma, \ldots). \quad (1)$$

In the simplest case, which will be considered below, there is a single random parameter:

$$\xi = \xi(\alpha, t). \quad (2)$$

For the condition of relative invariance, in order to find an optimal signal, it is necessary to minimize the magnitude $\Phi_{\text{opt}N}(S, \xi)$. Thus, it is appropriate to synthesize an optimal signal based on two criteria: a mean square criterion and a uniform criterion.

4. 1. Construction of optimization methods based on a mean square criterion and a uniform criterion

If one applies a mean square minimization criterion, the problem is then stated as follows:

$$J[S(t)] = \int_{\alpha_1}^{\alpha_2} \left\{ \Phi_{opt\,N}[S(t), \xi(\alpha, t)] \right\}^2 \mathrm{d}\alpha \to \min_{S(t)},$$

where (α_1, α_2) is the region of change in parameter α. The optimal demodulation algorithm along a gaussian channel is the algorithm of coherent reception:

$$\Phi_{opt\,N}[S(t), \xi(\alpha, t)] = \int_0^T S(t)\xi(\alpha, t)\mathrm{d}t.$$

Let us use the representation of an interference and a signal in the form of expanded orthonormal functions $\varphi_i(t)$:

$$S(t) = \sum_{i=n_1}^{n_2} a_i \phi_i(t); \quad (3)$$

$$\xi(\alpha, t) = \sum_{i=n_1}^{n_2} b_i(\alpha)\phi_i(t). \quad (4)$$

Then

$$\Phi_{opt\,N}[\{a_i\}, \alpha] = \sum_{i=n_1}^{n_2} a_i b_i(\alpha)$$

and the problem of mean square minimization is written in the form

$$J[\{a_i\}] = \int_{\alpha_1}^{\alpha_2} \left[\sum_{i=n_1}^{n_2} a_i b_i(\alpha) \right]^2 \mathrm{d}a =$$

$$= \sum_{i=n_1}^{n_2} a_i^2 \int_{\alpha_1}^{\alpha_2} b_i^2(\alpha)\mathrm{d}\alpha + \sum_{j,i=n_1}^{n_2} a_i a_j \int_{\alpha_1 \atop i \neq j}^{\alpha_2} b_i(\alpha) b_j(\alpha)\mathrm{d}\alpha.$$

Denote:

$$c_i = \int_{\alpha_1}^{\alpha_2} b_i^2(\alpha)\mathrm{d}\alpha = \int_{\alpha_1}^{\alpha_2} \left[\int_0^T \xi(\alpha, t)\phi_i(t)dt \right]^2 \mathrm{d}\alpha; \quad (5)$$

$$c_{ij} = \int_{\alpha_1}^{\alpha_2} b_i(\alpha) b_j(\alpha)\mathrm{d}\alpha =$$

$$= \int_{\alpha_1}^{\alpha_2} \left[\int_0^T \xi(\alpha, t)\phi_i(t)\mathrm{d}t \int_0^T \xi(\alpha, t)\phi_j(t)\mathrm{d}t \right] \mathrm{d}\alpha. \quad (6)$$

Coefficients c_i and c_{ij} could be calculated in advance if a quasi-deterministic interference is assigned in form (2).

Thus, taking into consideration the natural constraint for signal's energy, we obtain:

$$J[\{a_i\}] = \sum_{i=n_1}^{n_2} c_i a_i^2 + \sum_{i=n_1}^{n_2} \sum_{j=n_1 \atop i \neq j}^{n_2} c_{ij} a_i a_j \to \min_{\{a_i\}}; \quad (7)$$

$$\sum_{i=n_1}^{n_2} a_i^2 = A. \quad (8)$$

That is, it is necessary to find such a totality of coefficients α_i, which satisfy condition (8), at which sum (7) reaches a minimum.

A given problem, stated as (7), (8), belongs to a class of nonlinear programming tasks. One of the methods to solve it is to reduce it to a certain system of equations. We shall perform appropriate transformations. Renumber, to simplify the record, indexes in variables and coefficients of function J: numbering from n_1 to n_2 is replaced with numbering from 1 to K, where $K=n_2-n_1+1$. Then:

$$J\left[\{a_i\}\right]=\sum_{i=1}^{K} c_i a_i^2+\sum_{i=1}^{K}\sum_{\substack{j=1\\ i\neq j}}^{K} c_{ij} a_i a_j; \tag{9}$$

$$\sum_{i=1}^{K} a_i^2 = A. \tag{10}$$

Find partial derivatives from function (9) for all variables:

$$\frac{\partial J}{\partial a_1}=2c_1 a_1+2\sum_{j\neq 1} c_{1j} a_j;$$
$$\frac{\partial J}{\partial a_2}=2c_2 a_2+2\sum_{j\neq 2} c_{2j} a_j;$$
$$\dots\dots\dots\dots\dots\dots$$
$$\frac{\partial J}{\partial a_1}=2c_K a_K+2\sum_{j\neq K} c_{Kj} a_j.$$

By equating partial derivatives to zero, we obtain the following system of linear equations:

$$\left.\begin{array}{l} c_1 a_1+\sum\limits_{j\neq 1} c_{1j} a_j=0;\\ c_2 a_2+\sum\limits_{j\neq 2} c_{2j} a_j=0;\\ \dots\dots\dots\dots\dots\dots\\ c_K a_K+\sum\limits_{j\neq K} c_{Kj} a_j=0. \end{array}\right\} \tag{11}$$

It has non-zero solutions only if the determinant of system D is equal to zero:

$$D=\begin{vmatrix} c_1 & c_{12} & c_{13} & \cdots & c_{1K}\\ c_2 & c_{21} & c_{23} & \cdots & c_{2K}\\ \cdots & \cdots & \cdots & \cdots & \cdots\\ c_K & c_{K1} & c_{K2} & \cdots & c_{K(K-1)} \end{vmatrix}=0.$$

The result of solving a system of linear equations (11) is the point of extremum for function (9). If this extremum is the minimum, the problem could be considered solved.

Note that limiting condition (10) in this case is irrelevant. Indeed, let the totality a_1^*, a_2^*, a_K^* is some non-zero solution to system (11), so that

$$\sum_{i=1}^{K}\left(a_i^*\right)^2=B\neq A.$$

Denote $A/B=r^2$. It is obvious that $ra_1^*, ra_2^*, \dots, ra_K^*$ is also the solution to system (11), however, this solution satisfies condition (10), since

$$\sum_{i=1}^{K}(ra_i^*)^2=r^2\sum_{i=1}^{K}(a_i^*)^2=r^2 B=A.$$

Thus, a solution to the problem on synthesis of signal $\{\alpha_i\}$ is any non-zero solution to system (10), provided the corresponding extremum is a minimum.

Existence of a solution to system (11) is a necessary, but not sufficient, condition for determining a minimum of function (9). First, the obtained solution to the system could produce a maximum rather than a minimum, and, second, the resulting minimum could appear local. In order to finally solve the problem, it is required to apply sufficient conditions for the existence of an extremum in the function of many variables. In addition, it is necessary to perform a direct substitution of all derived solutions in expression (9), and to determine the minimum that provides for the smallest value for magnitude J.

Note that the number of terms in the sums of expression (9) and, therefore, the order in which it is necessary to solve a system of linear equations (10), is equal to the base of the desired signal $K=2\Delta f\cdot T$, where Δf is the signal spectrum width. The number of coefficients in equations, subject to calculation from formulae (5) and (6), is equal to the square of the signal's base. In order to achieve relative invariance of the system against a quasi-deterministic interference, it is required to use a fairly complex signal with a base of at least several dozens. Solving an appropriate system of equations is possible only by using numerical methods employing computational equipment.

Thus, when solving a given problem, we run into a typical contradiction: the more complex the optimal signal, the better the conditions of invariance are met, but the harder it is to search for it through modern computational methods. This contradiction is sometimes impossible to overcome.

In a given method of optimal signal synthesis, it was assumed that the parameter of interference α is distributed evenly in the interval (α_1, α_2), because not a single value for α was favored. If we consider a general case, then α has certain arbitrary distribution. Denote the corresponding density of probability $W(\alpha)$. Then, it is required to minimize the functional

$$J\left[S(t)\right]=\int_{\alpha_1}^{\alpha_2}\left\{\Phi_{\text{optN}}\left[S(t),\xi(\alpha,t)\right]\right\}^2 W(\alpha)\mathrm{d}\alpha.$$

If one represents the desired signal in the form of decomposition of (3), (4), we obtain:

$$J=\int_{\alpha_1}^{\alpha_2}\left[\sum_{i=1}^{K} a_i b_i(\alpha)\right]^2 W(\alpha)\mathrm{d}\alpha=$$
$$=\sum_{i=1}^{K} a_i^2\int_{\alpha_1}^{\alpha_2} b_i^2(\alpha)W(\alpha)\mathrm{d}a+$$
$$+\sum_{i=1}^{K}\sum_{j=1}^{K} a_i a_j\int_{\alpha_1}^{\alpha_2} b_i(\alpha)b_i(\alpha)W(\alpha)\mathrm{d}\alpha.$$

Introduce designations:

$$c_i^*=\int_{\alpha_1}^{\alpha_2} b_i^2(\alpha)W(\alpha)\mathrm{d}\alpha,$$

$$c_{ij}^*=\int_{\alpha_1}^{\alpha_2} b_i(\alpha)b_i(\alpha)W(\alpha)\mathrm{d}\alpha$$

Then we obtain:

$$J=\sum_{i=1}^{K} c_i^* a_i^2+\sum_{i=1}^{K}\sum_{\substack{j=1\\ i\neq j}}^{K} c_{ij}^* a_i a_j\to\min_{\{a_i\}}.$$

Thus, taking into consideration the distribution of the random parameter of interference α, the problem is reduced to minimizing the function similar to (9), which differs from it only by coefficients.

The considered method for finding an optimal signal is not the only one. Since the problem is reduced to finding an extremum in the function of many variables, it could be solved by using different methods for extremum search.

For the case of an optimization method based on a uniform criterion, the problem of optimal signal synthesis takes the form:

$$\max_{\alpha}\left|\Phi_{opt\,N}\left[S(t),\xi(\alpha,t)\right]\right|\to\min_{S(t)}, \qquad (12)$$

where $S(t)$ is the desired signal, and $\xi(\alpha, t)$ is the quasi-deterministic interference with a single random parameter; it changes in the interval (α_1, α_2).

By using, as above, the decomposition of a signal and an interference (3) and (4), we obtain from equality (12)

$$\max_{\alpha_1\le\alpha\le\alpha_2}\left|\sum_{i=n_1}^{n_2} a_i b_i(\alpha)\right|\to\min_{\{a_i\}}. \qquad (13)$$

Thus, the problem is reduced to finding vector $\{\alpha_i\}$ with components that satisfy the condition

$$\sum_{i=n_1}^{n_2} a_i^2 = A, \qquad (14)$$

such that a maximum of the output signal demodulator module, taken for all values of random parameter α, is minimal. Problem (13) could be solved by the method of linear programming, replacing condition (14) with any linear equivalent.

We shall perform transformations that reduce a given problem to the standard form of a linear programming program. We introduce a variable x, which satisfies condition

$$x\ge\left|\sum_{i=n_1}^{n_2} a_i b_i(\alpha)\right|.$$

Because x cannot exceed the magnitude $\left|\sum a_i b_i(\alpha)\right|$, the minimum value for x is obvious to be equal to the maximum of this magnitude. That is,

$$\min x=\max\left|\sum a_i b_i(\alpha)\right|,$$

and a maximum is taken for variable α at fixed α_i.

Then problem (13) could be replaced with an equivalent in the form:

$$\text{find } \min x, \qquad (15)$$

$$x\ge\left|\sum_{i=n_1}^{n_2} a_i b_i(\alpha)\right|. \qquad (16)$$

A given problem is stated as follows: it is required to find the totality of decomposition coefficients of signals $\{\alpha_i\}$, such that variable x, not less than $\left|\sum a_i b_i(\alpha)\right|$, accepts the minimally possible value at a change in α in the interval (α_1, α_2).

In order to reduce problem (15), (16) to the form of a linear programming problem, it is required to eliminate the operation for finding an absolute value for the function, and to replace the function from variable α with a totality of numbers.

To this end, it is necessary to replace inequality (16) with two:

$$x\ge\sum_{i=n_1}^{n_2} a_i b_i(\alpha),\quad x\le-\sum_{i=n_1}^{n_2} a_i b_i(\alpha).$$

Then, one should replace each of the last inequalities with a system of inequalities, to count functions $b_i(\alpha)$ at points $\alpha_1, \alpha_2,..., \alpha_j,..., \alpha_n$, uniformly distributed in the interval (α_1, α_2). We obtain:

$$\text{find } \min x, \qquad (17)$$

$$x\ge\sum_{i=n_1}^{n_2} a_i b_i(a_j); \qquad (18)$$

$$x\le-\sum_{i=n_1}^{n_2} a_i b_i(a_j), \qquad (19)$$

$$i=n_1, n_1+1, ..., n_2;\quad j=1,2,...,n. \qquad (20)$$

The dimensionality of the obtained linear programming problem is defined by the number of terms in the decomposition of desired signal $K=n_2-n_1+1$ and the number of inequalities in the system of constraints (18), (19), which should equal $2n$. When synthesizing a signal of medium complexity, the magnitudes K and $2n$ are of the order of a few dozen.

Complexity of solving the problems (17) to (20) is defined, however, by that when ignoring constraint (14) one could only obtain a trivial solution of zero. Therefore, it is necessary to introduce a certain linear constraint that has the same meaning as (14). The specific form of this constraint depends on the physical content of the problem being solved and on the form of coordinate functions. If, for example, one knows the signs of the desired coefficients, then condition (14) could be replaced with a linear constraint

$$\sum_{i=n_1}^{n_2} a_i \,sign\, a_i = C.$$

In some cases, all coefficients in line with the problem's statement are positive, then the simple additional constraints are applied:

$$\left.\begin{array}{l}\sum_{i=n_1}^{n_2} a_i = C,\\ a_i\ge 0.\end{array}\right\}$$

As an example, we shall state a problem on synthesis of the optimal signal for a quasi-deterministic interference, assigned in the form of a harmonic oscillation at random frequency $\xi(\varepsilon, t)=\sin\alpha t$. Let the interference frequency be varied from 300 to 1,300 Hz so that the parameter α has boundaries from 2π·300 to 2π·1,300 rad/s and the duration of the signal's element is equal to $T=2\cdot10^{-2}$ s. The chosen basis for the space of a signal and an interference is the totality of orthonormal harmonic functions:

$$\phi_i(t)=\frac{\sqrt{2}}{\sqrt{T}}\sin\frac{2\pi}{T}it. \qquad (21)$$

If the signal and the interference have components with frequencies only from 300 to 1,300 Hz, then the basis of decomposition is formed by functions $S(t)$, $\xi(\alpha, t)$ with indices from i=6 up to i=26, so that the signal and the interference are represented in the form:

$$S(t)=\sum_{i=6}^{26}\alpha_i\phi_i(t);\quad \xi(\alpha,t)=\sum_{i=6}^{26}b_i(\alpha)\phi_i(t),$$

where α_i are the desired signal decomposition coefficients;

$$b_i(\alpha)=\sqrt{\frac{2}{T}}\int_0^T \sin\alpha t\sin\frac{2\pi i}{T}tdt=$$

$$-(-1)^i\sqrt{\frac{T}{2}}\frac{i\sin\frac{\alpha T}{2}}{(\alpha T)^2-(2\pi i)^2}. \quad (22)$$

Function $|b_i(\alpha)|$ is shown in Fig. 1.

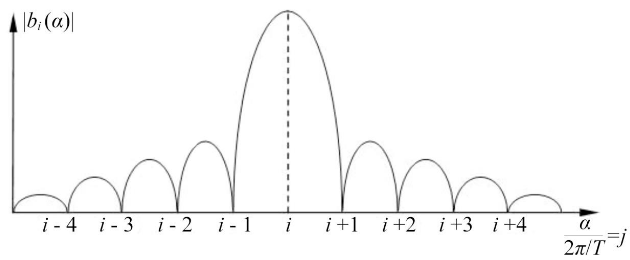

Fig. 1. Dependence of the concentrated interference decomposition coefficient on its frequency

The most characteristic along the x axis are the points that correspond to the maxima and zeros of function $b_i(\alpha)|$. These points are selected as counts along variable α. It is obvious that the corresponding values for parameter α are determined (within the assigned change) from expression:

$$\alpha_j=\frac{2\pi}{T}(3+0.5j). \quad (23)$$

By substituting (23) in (22), we obtain:

$$b_i(\alpha_j)=(-1)^i K\frac{i\sin\pi(3+0.5j)}{(3+0.5j)^2-i^2},$$

$$K=\frac{\sqrt{T}}{4\sqrt{2}\pi^2};\quad j=6,7,8,...,46.$$

Thus, the problem of linear programming in a given example takes the form:

$$\left.\begin{array}{l}\min x,\\ x\geq\sum_{i=6}^{26}a_i b_i(\alpha_i),\\ x\geq-\sum_{i=6}^{26}a_i b_i(\alpha_i),\\ j=6,7,8,...,46.\end{array}\right\} \quad (24)$$

The constraints for the stated problem include 82 inequalities, each of which contains the sum, consisting of 21 terms.

The optimal signals, resulting from the application of the above-considered techniques, could hardly be realized or could prove inapplicable for other reasons, for example, due to a large peak factor. In this case, it is required to find a signal close, based on the defined criteria, to the resulting optimal signal, which would be suitable for practical application. For example, if a relay form of the signal is assigned, at which it could accept only two values, 1 and −1, then such a signal $S_{\text{rel opt}}(t)$ is determined from the optimal signal $S_{\text{opt}}(t)$ based on rule $S_{\text{rel opt}}(t)$=sign($S_{\text{opt}}(t)$). Such a relay signal is the closest to signal $S_{\text{opt}}(t)$ within the class of relay signals with a mean square criterion. That is, the following equality holds:

$$\int_0^T[S_{opt}(t)-signS_{opt}]^2\mathrm{d}t=\min_{S_{rel}}.$$

Thus, the constructed method for optimizing a signal based on a uniform criterion makes it possible to synthesize the signal that is invariant to an additive interference. That would provide an opportunity to improve noise immunity in a data transfer system and to increase the rate of information transmission along a communication channel.

4. 2. A discrete-difference transform applied to the synthesis of signal modulation invariant methods

When considering the general principles to synthesize systems with constant parameters, invariant to a non-additive interference, we noted the need for finding a signal modulation method that would be invariant to a given interference. The problem is reduced to choosing, as an information parameter, of a signal or one of its defining parameters, which are not subject to the effect of this interference, or some transformation of the defining parameters, subject to the interference effect.

Here we consider a discrete-difference transformation that has a universal property of invariance relative to a wide class of non-additive interferences. A discrete-difference transform of time function time $\Theta(t)$ implies the computation of differences between the counts of this function at discrete time moments $t_n=t_0+n\Delta t$, (n=1, 2,...). A difference for function $\Theta(t)$ of the first order, or, as they say, the first difference at time t_n, is equal to:

$$\Delta_n^1\theta=\theta(t_n)-\theta(t_{n-1}).$$

The difference of the second order (the second difference) at time t_n is equal to:

$$\Delta_n^2\theta=\Delta_n^1\theta-\Delta_{n-1}^1\theta=[\theta(t_n)-\theta(t_{n-1})]-$$
$$-[\theta(t_{n-1})-\theta(t_{n-2})]=\theta(t_n)-2\theta(t_{n-2}).$$

In general, a difference of the k-th order (the k-th difference) of function $\Theta(t)$ at time t_n is determined via difference of the (k–1)-th order from formula

$$\Delta_n^k\theta=\Delta_n^{k-1}\theta-\Delta_{n-1}^{k-1}\theta.$$

Hereafter, the two following remarkable properties of a discrete-difference transform are important:

– it is linear, that is

$$\Delta^k(\theta_1-\theta_2)=\Delta^k\theta_1+\Delta^k\theta_2;$$

– if function $\Theta(t)$ is differentiated k times, and its k-th derivative is identically equal to zero, then the difference of function of the k-th order is also idetically equal to zero, that is

$$\Delta^k\theta \equiv 0, \qquad (25)$$

if

$$\frac{d^k\theta(t)}{dt^k} \equiv 0.$$

These properties in the discrete-difference transform make it possible to find the modulation methods, invariant to certain kinds of interferences. We show such a possibility in the general form. Let some j-th parameter λ_j of the signal, taking into consideration the impact of interference ξ, be represented as:

$$\lambda_{j\xi}(t) = F_j(\xi, \lambda_j) = \lambda_j(t) + \xi_j(t), \qquad (26)$$

where $\lambda_j(t)$ is the random sequence of values for parameter λ_j, reflecting the transmitted message; $\xi_j(t)$ is the parameter λ_j fluctuation under the influence of interference ξ. Compose a difference of the k-th order for function (26):

$$\Delta_n^k\lambda_{j\xi}(t) = \Delta_n^k\lambda_j(t) + \Delta_n^k\xi_j(t).$$

If all implementations of the impact of interference $\xi_j(t)$ on parameter λ_j such that

$$\frac{d^k\xi_j(t)}{dt^k} = 0, \qquad (27)$$

then, considering (25) $\Delta_n^k\xi_j(t) = 0,$ and, therefore,

$$\Delta_n^k\lambda_j\xi(t) = \Delta_n^k\lambda_j(t).$$

That is $\Delta_n^k\lambda_j(t) = \mathrm{in\,var}\,\xi.$

Thus, if the result of the impact of an interference on a certain defining signal parameter satisfies condition (27), then the difference of the k-th order of this parameter is completely invariant to a given interference. By assigning information to the k-th difference of the defining parameter λ_j, we obtain the desired signal modulation method, which is invariant to interference ξ.

Practical application of the discrete-difference transformation is as follows. The transmitted information modulates the k-th difference in the selected defining parameter $\Delta^k\lambda_j$. The resulting sequence of k-th differences $\Delta_1^k\lambda_j, \Delta_2^k\lambda_j, ..., \Delta_n^k\lambda_j$ allows us to build a sequence of $(k-1)$-th differences:

$$\left.\begin{aligned} &\Delta_1^{k-1}\lambda_j = \Delta_0^{k-1}\lambda_j + \Delta_1^k\lambda_j,\\ &\Delta_0^{k-1}\lambda_j = \Delta_1^{k-1}\lambda_j + \Delta_2^k\lambda_j,\\ &\ldots\ldots\ldots\ldots\\ &\Delta_n^{k-1}\lambda_j = \Delta_{n-1}^{k-1}\lambda_j + \Delta_n^k\lambda_j,\end{aligned}\right\} \qquad (28)$$

where $\Delta_0^{k-1}\lambda_j$ is the arbitrary initial value for the $(k-1)$-th difference. In turn, the resulting sequence of the $(k-1)$-th differences makes it possible to build a sequence of the $(k-2)$-th differences:

$$\left.\begin{aligned} &\Delta_1^{k-2}\lambda_j = \Delta_0^{k-2}\lambda_j + \Delta_1^{k-1}\lambda_j = \Delta_0^{k-2}\lambda_j + \Delta_0^{k-1}\lambda_j + \Delta_1^k\lambda_j,\\ &\Delta_2^{k-2}\lambda_j = \Delta_1^{k-2}\lambda_j + \Delta_2^{k-1}\lambda_j,\\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\ &\Delta_n^{k-1}\lambda_j = \Delta_{n-1}^{k-1}\lambda_j + \Delta_n^k\lambda_j,\end{aligned}\right\} \qquad (29)$$

where $\Delta_0^{k-1}\lambda_j$ is the arbitrary initial value for the $(k-2)$-th difference.

By continuing to build the sequences of lower order differences, we obtain as a result the sequence of values defining λ_j: $\lambda_{j1}, \lambda_{j2}, ..., \lambda_{jn}, ...$. These values define the relevant sending of signal $S(t, \lambda_{j1})$, $S(t, \lambda_{j2})$,..., $S(t, \lambda_{jn})$,..., transmitted over a communication channel.

At the receiving side, following the demodulation of a signal, one determines the value for parameter λ_j: $\lambda_{j1}, \lambda_{j2}, ..., \lambda_{jn}, ...$, and executes a backward, relative to the transmitter, sequence of operations: the first differences are computed:

$$\left.\begin{aligned} &\Delta_2^1\lambda_j = \lambda_{j2} - \lambda_{j1},\\ &\Delta_3^1\lambda_j = \lambda_{j3} - \lambda_{j2},\\ &\ldots\ldots\ldots\\ &\Delta_n^1\lambda_j = \lambda_{jn} - \lambda_{j(n-1)},\end{aligned}\right\} \qquad (30)$$

then – the second differences:

$$\left.\begin{aligned} &\Delta_3^2\lambda_j = \Delta_3^1\lambda_j - \Delta_2^1\lambda_j,\\ &\ldots\ldots\ldots\ldots\\ &\Delta_n^2\lambda_j = \Delta_n^1\lambda_j - \Delta_{n-1}^1\lambda_j,\end{aligned}\right\} \qquad (31)$$

and so on to the k-th differences:

$$\left.\begin{aligned} &\Delta_{k+1}^k\lambda_j = \Delta_{k+1}^{k-1}\lambda_j - \Delta_k^{k-1}\lambda_j,\\ &\ldots\ldots\ldots\ldots\\ &\Delta_n^k\lambda_j = \Delta_n^{k-1}\lambda_j - \Delta_{n-1}^{k-1}\lambda_j.\end{aligned}\right\} \qquad (32)$$

Formulae (32) show that the first received information symbol is the $(k+1)$-th transmitted symbol. This is because when using, as an informational parameter, the k-th difference in some defining parameter, the formation of each informational symbol involves (k+1) signal packets and, therefore, to calculate the first value for the k-th difference in parameter λ_j, it is necessary to have k consecutive values for this parameter. Thus, the first k symbols serve as an "anchor" to calculate the subsequent symbols and they are "lost" in a transmission process. The loss of the first k symbols is the price to pay for the benefits of a discrete-difference transformation [12].

It is possible to achieve an absolute invariance in the system that employs a discrete difference transform if condition (27) is precisely satisfied, which, in turn, is possible if one could represent in the form of an exponential polynomial of k-th degree with random, but constant in the interval $k+1$, packets coefficients $\xi_j(t) = \alpha_1 t + \alpha_2 t^2 + ... + \alpha_k t^k$.

Under an arbitrary law of influence from interference $\xi_j(t)$, a discrete difference transform could only provide a relative invariance only. In this case, the following condition must be met:

$$\left|\Delta^k\xi_j(t)\right| << \left|\Delta^k\lambda_j\right|. \qquad (33)$$

It should be noted that for interferences that slowly change over time, it is almost always possible to find the order of difference, at which the relative condition of invariance (33) is satisfied, since the differences in the counts of functions that change slowly tend to descend in proportion to an increase in their order.

As an example, consider the function:

$$\xi(t) = \sin\frac{2\pi}{T}t. \tag{34}$$

None of the derivatives from this function is identically equal to zero. However, if interval τ between its counts is much less than the period T ($\tau << T$), then the differences in function counts are significantly less than its maximum value, equal to unity. Moreover, with an increase in the order of difference, their magnitude decreases rapidly.

Thus, a discrete difference transform is the theoretical basis for relative signal modulation methods [13]. Mobile networks have widely employed the systems with a phase-difference modulation (PDM) using the first differences in signal parameters (system with PDM-1). Implementation of systems that use the second-order differences (systems with PDM-2) is under way.

5. Results of studying noise immunity in the systems with invariant modulation methods

Of the greatest practical interest is the process to enable the noise immunity at autocorrelation demodulators, since only they provide for a perfect invariance to the frequency of the signal. A probability of error at autocorrelation reception method is a function of two parameters: the ratio of signal's energy to the spectral density of interference power $|E/N_0|$ and a signal base $\Delta f{\cdot}T$. At small bases, the calculation of noise immunity in an autocorrelation demodulator of systems with PDM-2 is associated with a series of mathematical problems, which have not yet been fully resolved. Of practical interest is therefore the bottom estimate of the probability of an error at autocorrelation reception, which is asymptotically equal to it, under condition $\Delta f{\cdot}T \rightarrow 1$.

Indeed, at $\Delta f{\cdot}T=1$, the autocorrelation receiver degenerates into an optimal non-coherent one, because narrowing a channel's bandwidth to magnitude $\Delta f=1/T$ is tantamount to enabling a coherent filter at the input to an autocorrelator [5]. Therefore, in order to calculate noise immunity within actual systems with PDM-2, one could use expressions at which magnitude $\Delta f{\cdot}T$ is of order 1–2.

Charts to illustrate comparative noise immunity in systems with PDM-2 at small signal bases are shown in Fig. 2.

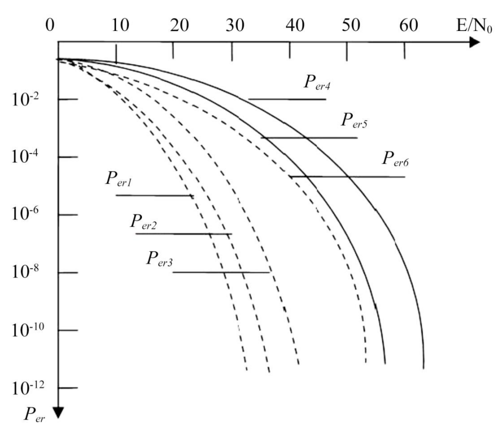

Fig. 2. Comparative evaluation of noise immunity in the system with PDM-2 at small signal base: $|P_{er}|$ is the probability of error, $|E/N_0|$ is the ratio of signal's energy to the spectral density of an interference power

The curve $|P_{er5}|$ characterizes noise immunity relative to the interference invariant to the signal frequency in the system with PDM-2 with base $\Delta f{\cdot}T$, close to unity. The curve $|P_{er4}|$, built based on results from paper [5], characterizes noise immunity of the system with a frequency modulation (FM) when using the so-called narrowband reception on the envelope, which provides for the system's invariance to changes in frequency within the range of bandwidth of frequency filters. Other curves (dotted) in Fig. 2. refer to systems that are non-invariant to the signal's frequency: they are shown for comparison.

The curve $|P_{er1}|$ is the error probability at a coherent signal reception in a perfect system with FM, characterizes the limit of noise immunity at element-wise reception in binary systems. The curve $|P_{er2}|$ corresponds to the potential noise immunity of the system with PDM-2 (coherent reception). The curve $|P_{er3}|$ corresponds to the potential noise immunity of the system with PDM-2 (non-coherent reception). The curve $|P_{er6}|$ | describes the noise immunity of optimal non-coherent signal reception with FM.

As one can see, the noise immunity of PDM-2 at small signal bases is close to the FM noise immunity at optimal non-coherent reception and a specific frequency of the signal.

The calculation of noise immunity at autocorrelation reception of signals with PDM-2 for large bases could be simplified. This is possible because in this case it is possible, with accuracy sufficient for practice, to approximate the probability density of a random variable at the output from demodulator via normal law. Similar analysis into autocorrelation reception of signals with PDM-1 reveals that at $\Delta f{\cdot}T \geq 10$ the results of accurate calculation and the calculation using the approximation via normal law are almost identical.

Approximate expressions for the probability of error at the autocorrelation reception of signals with PDM-2 with a large base take the form:

$$p_{avt} \approx F\left[\frac{E/N_0}{\sqrt{2}\sqrt{\left(1+\dfrac{\Delta fT}{2E/N_0}\right)\left(1+\dfrac{\Delta fT}{2E/N_0}+E/N_0\right)}}\right],$$

$$p_{avt} \approx 1/2\exp\left[-\frac{E/N_0}{4(1+\Delta fT/2E/N_0)}\right].$$

By comparing with the expression for the probability of error at the autocorrelation reception of signals with PDM-1

$$p_{avt}(PDM-1) \approx F\left[\frac{\sqrt{E/N_0}}{\sqrt{1+\dfrac{\Delta fT}{2E/N_0}}}\right],$$

one could conclude that at known signal frequency a system with PDM-2 is approximately two-times less than the system with PDM-1 in terms of power.

Fig. 3 shows curves of noise immunity for systems PDM-2 with a different base $\Delta f{\cdot}T>>1$. For those same values for the base, we present the curves of noise immunity for a system with FM when using the so-called "broadband reception with integration after detector" [5], calculated from formula:

$$p(\mathrm{FM})=F\left[\frac{\sqrt{E/N_0}}{\sqrt{2(1+\frac{\Delta fT}{E/N_0})}}\right].$$

Dependence chart $1/2\exp(-E/N_0/4)$, which defines the lower boundary of noise immunity for the autocorrelation demodulators PDM-2 at $\Delta f{\cdot}T>>1$, is shown in Fig. 3. When the conditions $2E/N_0>>\Delta f{\cdot}T$ and $\Delta f{\cdot}T>>1$ are satisfied, this dependence could be used to quite accurately determine the noise immunity of system [14].

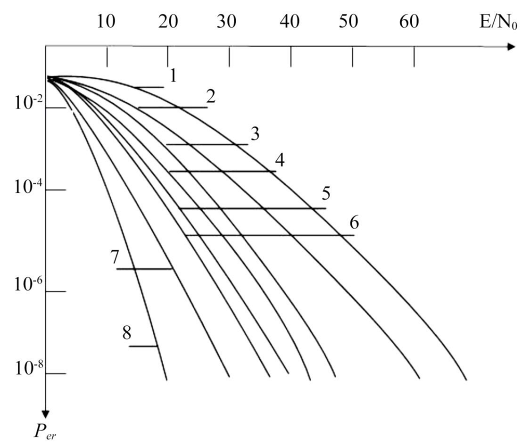

Fig. 3. Comparative evaluation of noise immunity in the system with PDM-2 with a large signal base: 1 – FM, $\Delta f{\cdot}T=100$; 2 – PDM-2, $\Delta f{\cdot}T=100$; 3 – FM, $\Delta f{\cdot}T=30$; 4 – PDM-2, $\Delta f{\cdot}T=30$; 5 – FM, $\Delta f{\cdot}T=10$; 6 – PDM-2, $\Delta f{\cdot}T=10$; 7 – $P_{er}=0.5exp(-E/N_0/4)$, 8 – PDM-2, $\Delta f{\cdot}T=1$

Studying the noise immunity of system with PDM-2 under the action of Gaussian white noise leads to the following conclusions:

– systems with PDM-2 have the highest rate among systems with constant parameters that are invariant to changes in the signal frequency;

– autocorrelation demodulators PDM-2 are slightly inferior, in terms of noise immunity, to the optimal non-coherent demodulators of signals with FM, which operate in a certain range of signal frequencies.

Experimental studies and modeling, conducted for the conditions of a shortwave radio channel at large carrier frequency instability fluctuations, have shown such results. A system with PDM-2 under such conditions has significant advantages compared to the systems that were used earlier in similar circumstances.

6. Discussion of results of studying noise immunity in the fifth-generation mobile networks, based on multi-position signals

Introduction of 5 G networks requires the construction of ultradense networks with information transfer rates of 1 Gbit/s and higher, with a minimum delay and at the assigned accuracy. However, as is well known, increasing the rate of information transmission is possible based on two techniques. The first is based on reducing the length of a packet at a consistent flow of information. The second technique is to increase the number of subcarrier frequencies at parallel transmission of information, that is, the implementation of the OFDM principle, which underlies 4 G and 5 G mobile networks.

An important prerequisite is to provide for the assigned reliability of information transfer despite changes in the conditions along a communication channel, caused by various influences and interferences. That is, such systems must possess the property of invariance to different interferences.

Taking into consideration the additive character of an interference, which could not be compensated by using an adaptive corrector, in order to synthesize the structure of an invariant signal, the best method would be to optimize it based on a mean square criterion or a uniform criterion. When employing both criteria, the approach is based on the possibility to represent an interference and a signal in the form of decompositions for orthonormal functions. Solving the problem is reduced to finding the totality of coefficients that satisfy the conditions for maximum separation of the signal and the interference. The difference in criteria is in the technique for obtaining a result at which, for the case of a mean square criterion, there is a need to solve the problem of nonlinear programming, and for the case of a uniform criterion, the problem could be solved by linear methods.

The advantage of a given approach in practice is the lack of need to use an adaptive corrector because, instead, the adaptive signal structure is used. Thus, the noise immunity of the system increases by 5–7 dB compared to others, which makes it possible to increase the rate of information transmitted at the assigned reliability by 30 %. In this case, the rate of information transfer approaches a channel's throughput, which is required for the networks of the 4–5 generations.

The main advantage of the proposed approach is that we selected, as an information parameter, the signal that is not sensitive to the effect of known interference. In the same way, one could select a certain transformation of the defining parameters subject to the action of an interference. The most universal in this regard is the discrete difference transform of time function, which implies the calculation of differences in the counts of this function at fixed points in time.

Compared to increasing the spectral density through the use of non-orthogonal methods of access (NOMA) and the non-orthogonal signals (FTN, F-OFDM) [4], which increase the power of a channel-to-channel interference, in the proposed approach the specified characteristics remain minimal.

In addition, in contrast to methods proposed in [7], there is a possibility to form the multidimensional signals, which could provide for the modulation of different multiplicity. Another resolved task is the efficient allocation of dynamic resources, similar to OFDMA systems [8] with sufficient quality in the information transmission channels.

Application of the discrete-difference transformation makes it possible to find modulation methods that are invariant to certain types of interference, which, unlike the approach in [9], reduces the probability of error.

At the same time, it should be noted that the possibilities to apply the method are limited by the need for *a priori* knowledge of the structure and distribution law of interferences. If the result of interference influence on some defining parameter of the signal meets certain conditions, the temporal difference in the parameter is absolutely invariant to a given interference. Only in this case one could synthesize the signal that is adaptive to an additive interference.

Otherwise, application of the suggested methods would be ineffective and the only possible option could be the use of adaptive correctors. In addition, the signals, derived as a result of solving the optimization problem, could prove to be technically difficult to implement. That will require searching for the signal with a quasi-optimal structure, which would not warrant the effect, obtained theoretically, to separate it from an interference.

Further advancement of the theory is to study the processes that form the signal- code structures of a signal simultaneously with a noise-resistant code that would correct error packets. In addition, it is interesting to consider a possibility for applying the method to the class of spatiotemporal signals.

The basic problems related to improving the data transfer rate will address the increasing multiplicity of modulation, which is limited by a channel's throughput capacity, or the application of new methods for interference filtering.

7. Conclusions

1. It is possible to improve noise immunity in the fifth-generation networks by optimizing parameters of the signal. If an additive interference is a quasi-deterministic one, of if a nonadditive interference leads to distortion of non-power parameters of the signal, the invariance in the characteristics of noise immunity could be achieved within a class of systems with constant parameters. Underlying such an approach is the use of appropriate methods of modulation and demodulation. In this case, a general task on the optimal signal synthesis could be resolved by applying one of the criteria: a mean square criterion or a uniform criterion. Solving this problem would improve the network noise immunity and increase customer service density at base stations.

2. Underlying the optimization method based on a mean square criterion is the approach according to which a useful signal and an interference represent an additive convolution along orthonormal surfaces. An interference is evenly distributed in a certain interval and the only constraint for the problem is the energy limit for the signal. An optimization problem could be reduced to the class of nonlinear programming tasks. Because the attainment of relative invariance of the system to a quasi-deterministic interference requires the use of a quite complex signal with a wide spectrum, then solving the respective system of equations is possible only by applying numerical methods. Solving this problem makes it possible to find a signal with the assigned parameters, which is resistant against a certain class of interferences.

Solving the optimization problem based on a uniform criterion implies determining the totality of signal decomposition coefficients, at which a maximum of the module of output signal from a demodulator, derived for all values of a random parameter, is minimal. After replacing signal parameters with the linear equivalents based on a totality of numbers, the problem is solved by methods of linear programming. The proposed method of signal optimization based on a uniform criterion makes it possible to synthesize the signal that is invariant to an additive interference. That will provide an opportunity to improve noise immunity in a data transmission system and to increase the rate of information transmission along a communication channel.

3. The possibility of achieving an absolute or a relative invariance and the feasibility of application of one of the above methods depend on the characteristics of an interference, the extent of their *a priori* certainty, as well as the feasibility to build a reverse communication channel. Simulation results show that the methods, proposed in this paper, for forming a signal invariant to interference could improve noise immunity of the system along a communication channel by 5–7 dB. That makes it possible to increase the rate of transmitted information by 30 % provided the assigned reliability is ensured. Enabling the invariance of an information transfer system provides an opportunity to construct ultradense networks of the fifth generation.

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Запропоновано математичні моделі просторової оцінки потужності сигналу на вході приймача для сімейства стандартів 802.11х для діапазону 5 ГГц. Моделі отримані на основі експериментальних досліджень розподілу сигналу для кутового та центрального розміщення точки доступу.

Особливістю даних моделей є оцінка основного енергетичного параметра в реальному часі та врахування максимально-можливої кількісті факторів впливу. Також для даних моделей було визначено допустимі межі, що мають мінімальний вплив на ефективну швидкість передачі інформації.

Було встановлено, для стандарту 802.11 у частотному діапазоні 5 ГГц, існують досить значні флуктуації сигналу. В залежності від заповнення приміщення різнорідними об'єктами рівень флуктуацій може становити δ=±4..8 дбм, при наявності системи MIMO. Найбільша концентрація енергії випромінювання спостерігається безпосередньо біля передавальних антен на відстані до двох метрів, що в подальшому затухає на 10…20 дбм.

Встановлено, що наявність технології MIMO вносить певну неоднорідність у просторовий розподіл. При цьому існують зони із меншим рівнем сигналу та зони-смуги із вищим за рахунок існування декількох антен. Ефективність такої системи є максимальною у площині розміщення антен.

До переваг отриманих моделей оцінки просторового розподілу сигналу можна віднести: оцінка рівня сигналу у просторі для будь-якого приміщення; врахування флуктуацій основного енергетичного параметра та параметрів середовища передачі; врахування параметрів приміщення та заповнення простору об'єктами. Такі моделі є найбільш ефективними для застосування у методах діагностики та контролю безпровідних мереж та каналів сімейства стандартів 802.11х

Ключові слова: безпровідний канал, стандарт 802.11, розподіл сигналу, потужність сигналу, частотний діапазон 5 ГГц

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CONSTRUCTION OF MATHEMATICAL MODELS FOR THE ESTIMATION OF SIGNAL STRENGTH AT THE INPUT TO THE 802.11 STANDARD RECEIVER IN A 5 GHZ BAND

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1. Introduction

Given the relative ease in constructing high-speed access channels to modern telecommunication and info-communication services, networks from the 802.11x family of standards have become very popular [1]. In addition, such networks are actively used in the concept of the Internet of Things [2] as a technology of the channel and physical levels of information transfer.

Networks from the 802.11x family of standards are characterized by constant development in the direction of improving the main quality criterion – the effective rate of information transfer. This criterion depends on energy parameters of a wireless channel and on the large number of destabilizing factors. The main energy parameter that determines a signal quality is the level of signal strength at the input to a receiving device [3]. The main destabilizing factors include the widespread deployment of wireless networks. That leads to overloading the frequency resources, which significantly impairs the transmitting characteristics of wireless channels. It can be observed using as an example the range of 2.4 GHz in densely populated areas.

In order to unload the frequency resource, other ranges are employed: 5 GHz, and 60 GHz in future. Each such range has differences in the mechanism of wave propagation and is less common at present. However, in order to derive more reliable models for the estimation of a signal's energy parameters, an independent research is needed for each such range. Therefore, it is a relevant task to investigate a 5 GHz range that provides for a possibility to obtain more channels with a high throughput. It would be also appropriate to construct an effective mathematical model for the estimation of signal strength in the space of premises, taking into consideration all the destabilizing factors.