UDC 621.391 DOI: 10.30748/soi.2020.162.08

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COMPLEX METHODOLOGY OF PARAMETERS MANAGEMENT OF MILITARY RADIO NETWORKS IN THE CONDITIONS OF UNCERTAINTY OF THE RADIOELECTRONIC SITUATION

The experience of the Joint Forces operation (Anti-terrorist operation in Donetsk and Luhansk oblasts) shows that the current order of management of military radio communication systems does not always meet the modern requirements for them. The classic centralized approach to the management of channel and network resources of military radio systems does not quite meet modern requirements, so the authors of this article proposed to take mobile self-organizing networks as a basic principle of construction. The authors propose a comprehensive method of managing the parameters of military radio networks in conditions of uncertainty of the electronic environment, the essence of which is to ensure the maintenance of the specified values of the performance of military radio communication systems at the appropriate level. The article is based on the control principle, which is described in the reference network model of open systems interaction, but with some additions and changes. This approach generally allows for end-to-end management of channel and network resources of military radio systems in a complex electronic environment. In the article, the device of fuzzy logic, the theory of electronic suppression, neural networks, the theory of noise protection, the theory of antennas, noise-resistant coding are used. The proposed complex methodology should be used in the development of software for modules (units) for the assessment of advanced radio communications, based on open architecture interfaces version SCA 2.2, which will: use effective signal-code structures to ensure noise immunity of channels; to ensure efficient use of the radio frequency resource of programmable radio communication means; increase the speed of evaluation of communication channels; reduce the use of computing resources of radio communications with programmable architecture.

Keywords: *radio communication system, intentional interference, radio resource, operating frequency distribution, signal fading, network topology.*

Introduction

Formulation of the problem. The Anti-Terrorist Operation in Donetsk and Luhansk oblasts (Joint Forces operations) showed the imperfection of the existing control and communication system, which is based on radio communication facilities.

The main shortcomings of the existing communication system of the tactical unit of the Armed Forces of Ukraine are [1–20]:

– low mobility of communication nodes of control points;

– low productivity, reliability, intelligence and noise immunity;

– imperfect automation of the processes of establishing, maintaining and maintaining radio communication.

The main technical requirements for the next generation of communication systems are [1–23]:

– integration of all types of traffic (language, data, video, video conferencing);

– full mobility of all subscribers and system elements;

– ensuring a given quality of customer service;

– guaranteed classification of all types of information.

The analysis of possible options for building a network architecture of the tactical management of the world's leading countries [23–56] demonstrated the advantages of using mobile radio networks or MANET (Mobile Ad-hoc Networks) compared to other approaches, which requires improved methods of managing the parameters of such networks.

Thus, the improvement of methods for managing the parameters of military radio networks is an important and relevant scientific and practical task.

Analysis of recent research and publications. A large number of scientific works are devoted to the issues of modeling, evaluation of productivity of general and special purpose radio networks and increase of efficiency of their functioning, among which the works of scientists should be especially noted: Kuvshinov O.V., Slyusar V.I., Vyshnevskiy V.M., Lyakhov A.I., Makarenko S.I., Sova O.Ya., Zhuravskiy Yu.V., Zinchenko A.O., Kreyndelina V.B., G. Bianchi, F. Cali, E. Ziouva, K. Szczypiorski, R. Chatzimisios, R. Oliveira, P. Raptis, A. Zanella, Chuan Heng Fox, K. Ghaboosi, etc.

Among these works, most are devoted to the analysis of the efficiency of general and special-purpose radio networks for maximum load conditions (saturated state of the network) and in assuming the ideal characteristics of the communication channel (absence of noise, interference and other interfering radio signals in the network), but the results, as a rule, are local in areas and conditions of application, have certain advantages and disadvantages.

We will conduct a detailed review of the known scientific results.

In the article [1], the tendency to create integrated hardware platforms by the devices of radio frequency and digital signal processing for joint solution of communication and radar tasks is determined. The analysis of developments in the field of application of the mobile communication system of the GSM standard for the decision of problems of radar control of airspace is carried out. The application of digital charting technology for the detection of air targets using a mobile communication system has been studied. However, this paper does not provide specific mechanisms for managing the parameters of GSM communication networks for airspace monitoring.

In the article [2], the substantiation of ways of efficiency increase of the trunking communication systems of Ukraine is carried out. However, this type of radio is not resistant to electronic suppression.

In the article [3], the way of efficiency increase of use of a radio frequency resource in cognitive radio networks is developed. The most important challenges for quality assurance of cognitive radio networks have been identified, including spectrum sensing, resource allocation management, network oscillation management, delay management and energy consumption management. However, this paper does not consider the impact of the location of electronic warfare on the communication quality in the radio network.

The article [4] proposes a dynamic channel selection algorithm based on a fuzzy inference system (FIS), capable of selecting the most suitable available channel with the desired bandwidth, the minimum required signal-to-noise ratio and the probability of detecting a miss. The proposed algorithm uses different modes of the IEEE 802.22 standard, wireless regional networks (WRAN) at the physical level. The disadvantages of the proposed algorithm include not taking into account the impact of intentional interference.

In the article [5], the development of the controller of access to a radio resource on the basis of a sliding window is carried out. This controller provides a careful balance of spectrum usage between different users of the priority class to avoid network congestion. However, this controller does not allow to take into account the destabilizing factors present in the radio channels, such as intentional interference and fading.

In the article [6], a method of radio frequency spectrum monitoring and network architecture is proposed to regulate the spectrum distribution and control the use of radio frequency spectrum. The proposed software definition of the network architecture provides radio frequency spectrum monitoring with the ability to coordinate the need for communication bandwidth between control workstations and monitoring stations, using software-defined radio devices. However, the proposed approach does not allow measures to be taken to increase the noise immunity of military radio networks.

In the article [7], an algorithm for controlling the parameters of cognitive radio networks is proposed, namely: optimal power, optimal speed and optimal amount of information. This control is based on a genetic algorithm. However, the proposed algorithm takes into account only the mutual interference caused by the mutual influence of users on each other.

In the article [8], a method for determining the location of radio communications depending on the efficiency of electronic suppression is proposed. The proposed method allows to increase the efficiency of radio communication, but to increase the efficiency of radio communication is limited only by determining the optimal location of radio communications.

The article [9] proposes to use clustering algorithms to control the radio resource of radio communications. The proposed algorithm is based on the distribution of radio frequencies between clusters. However, this approach does not allow adaptation to the effects of intentional interference and implement other mechanisms to increase noise immunity.

In the article [10], it is proposed to carry out routing taking into account the impact of intentional interference to improve the efficiency of radio resource use. However, this approach does not allow you to pre-select the operating frequencies on which the transmission of information.

The analysis of works [1–10] allows us to state that they do not allow fully, as well as in conditions of uncertainty of the electronic environment, to:

– select operating frequencies taking into account the impact of intentional interference;

– choose the operating frequencies taking into account the mutual influence of transmitters on each other;

– determine the location of transmitters of radio communications depending on the location of transmitters of electronic warfare;

– determine the network topology depending on the influence of destabilizing factors.

The purpose of the article is to develop a comprehensive methodology for managing the parameters of military radio networks in the conditions of uncertainty of the electronic environment.

Statement of basic materials

In the specified complex technique, it is offered to carry out through hierarchical management of channel and network resources of system of military radio communication of the MANET class with relative observance of hierarchy at each level of the reference network model of interaction of the OSI (open systems interconnection basic reference model) as concepts are specified in the model interactions of open OSI systems are relative.

Therefore, it is proposed to manage the parameters of military radio communication systems on a hybrid principle, centrally with correction at each (set) of network levels.

The essence of the method of hierarchical management of channel and network resources of military radio systems is to ensure the support of the values of indicators of the radio system at a given level.

Under the management of channel and network resources, we will understand the management of network radio resources, topology and routing [27–49].

Radio resource management is the management of frequency, code, time and energy resources between the nodes of the military radio communication system (MRCS), as well as determining the degree of influence of electronic suppression of the enemy.

Topology management consists in operative reconfiguration of MRCS topology and connection of reserve elements (channels, mobile base stations and nodes) in the conditions of a changing situation for the purpose of satisfaction of maintenance of the set quality service.

Routing management is the construction and maintenance of routes, the transfer of information flows at a given topology in order to meet the quality of service flows.

We will formalize the hierarchical management of channel and network resources of military radio communication systems. The military radio control system is a hierarchical structure with vertical connections, which determines the subordination of the tasks to be solved (at the lower level the tasks of the subscriber of the *l*-th level of MRCS are solved, at the upper level - the tasks of managing the *l*-th level of MRCS).

We present this functional structure from the standpoint of graph theory in the form of a tree. In this case, the root of the tree will be placed in accordance with the control subsystem of the second level (I_2, U_2), and the vertices of this tree, which are at a distance of one edge from the root - Q control subsystem of the first level $\left(I_{11},U_{11}\right),...,\left(I_{1q},U_{1q}\right),...,\left(I_{1Q},U_{1Q}\right)$ (Fig. 1). Each subsystem consists of a control unit (identification) I and a control unit U. We consider Q subsystems of zero level, which are located from the root of the tree at a distance of two edges. These subsystems represent interacting processes of the streams exchange of operational and service information P_1, ..., P_q, …, P_Q [27–40].

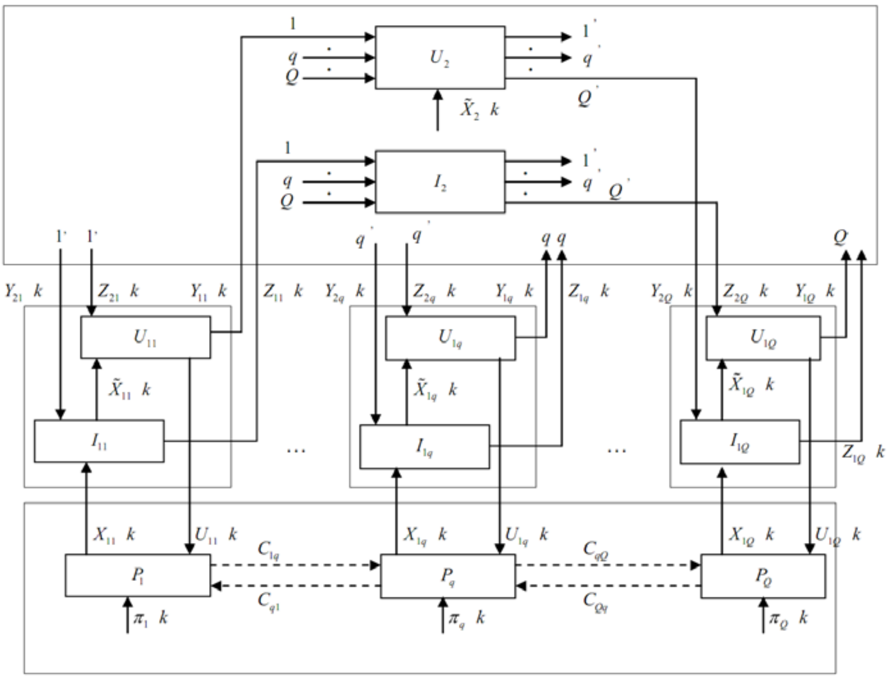

Fig. 1. Hierarchical structure of the management system MRCS

For the q-th control subsystem of the first level $\left(I_{1q}, U_{1q}\right)$, $q=\overline{1,Q}$, we will enter the following notation:

$X_{1q}\left(k\right)$ is the set of vectors, the state of the q-th managed subnet, where $x_{1q}\left(k\right)=\left\{x_{1q}^{a}\left(k\right)\right\}$, $a=\overline{1,a_{1q}}$ with the dimension $a_{1q}\times 1$; $\tilde{X}_{1q}(k)$ is the set of evaluation vectors $\tilde{x}_{1q}(k)=\{\tilde{x}_{1q}^{a}(k)\}$, $a=\overline{1,a_{1q}}$ with the dimension $a_{1q}\times 1$; $U_{1q}(k)$ is the set of control vectors of the q-th managed subnet $u_{1q}(k)=\{u_{1q}^{b}(k)\}$, $b=\overline{1,b_{1q}}$ with the dimension $b_{1q}\times 1$; $Y_{1q}(k)$ is the set of vectors of local variables that are issued to the upper-level control subsystem $y_{1q}(k)=\{y_{1q}^{d}(k)\}$, $d=\overline{1,d_{1q}}$ with the dimension $d_{1q}\times 1$; $Z_{1q}(k)$ is the set of vectors of local output variables $z_{1q}(k)=\{z_{1q}^{d}(k)\}$, $d=\overline{1,d_{1q}}$ with the dimension $d_{1q}\times 1$.

For the second level control subsystem, respectively: $\tilde{X}_2(k)$ is the set of vectors of generalized estimates $\tilde{x}_2(k)=\{\tilde{x}_2^{l}(k)\}$, $l=\overline{1,l_r}$ with the dimension $l_r\times 1=\left(\sum_{q=1}^{Q}a_{1q}\right)\times 1$; $Y_{2q}(k)$ is the set of vectors that are issued to the lower-level control subsystem $y_{2q}(k)=\{y_{2q}^{d}(k)\}$, $d=\overline{1,d_{2q}}$ with the dimension $d_{2q}\times 1$; $Z_{2q}(k)$ is the set of vectors coordinating the output variables issued to the lower level control subsystems $z_{2q}(k)=\{z_{2q}^{d}(k)\}$, $d=\overline{1,d_{2q}}$ with the dimension $d_{2q}\times 1$.

As a result, for the q-th subsystem of zero level P_q, $q=\overline{1,Q}$, we have:

$C_{qp}(k)$ is the set of connection vectors $c_{qp}(k)=\{c_{qp}^{mn}(k)\}$, $m=\overline{1,m_q}$, $n=\overline{1,n_q}$, between the p-th and q-th subsystems ($p,\ q=\overline{1,Q},\ p\neq q$);

$\Pi_q(k)$ is the set of vectors of external influences of $\Pi_q(k)=\{\pi_q^{l}(k)\}$, $l=\overline{1,l_q}$ with the dimension $l_q\times 1$.

To the set of state vector $X(k)=\bigcup_{q=1}^{Q}X_{1q}(k)$ may include vectors of any state variables that affect the quality of communication and efficiency of the operation of the MC. The main ones are:

vector of parameters of information load MC

$$\Lambda(k)=\left\|\Lambda_1(k),\ ...,\ \Lambda_q(k),\ ...,\ \Lambda_Q(k)\right\|^{T};$$

vector of delays in the transmission of information messages

$$H(k)=\left\|H_1(k),\ ...,\ H_q(k),\ ...,\ H_Q(k)\right\|^{T};$$

vector of parameters of electronic environment in the network

$$\aleph(k)=\left\|\aleph_1(k),\ ...,\ \aleph_q(k),\ ...,\ \aleph_Q(k)\right\|^{T};$$

network frequency resources vector

$$\Im(k)=\left\|\Im_1(k),\ ...,\ \Im_q(k),\ ...,\ \Im_Q(k)\right\|^{T};$$

network energy resources vector

$$\Re(k)=\left\|\Re_1(k),\ ...,\ \Re_q(k),\ ...,\ \Re_Q(k)\right\|^{T};$$

network hardware resources vector

$$\mathrm{A}(k)=\left\|\mathrm{A}_1(k),\ ...,\ \mathrm{A}_q(k),\ ...,\ \mathrm{A}_Q(k)\right\|^{T}\ \text{and etc.}$$

Earlier it was noted that the bandwidth of the MRCS network is one of the main indicators characterizing the efficiency of the network as a whole and the quality of service of the transmitted traffic (QoS) in particular. Maximizing the bandwidth of MRCS, by optimizing the parameters of the channel and network levels, will increase the efficiency of MRCS [27–40].

Therefore, the maximum network bandwidth in accordance with expression (1) is chosen in accordance with the optimization criterion.

$$C\to\max_{m,f,w}, \tag{1}$$

where m is the number of RCD in the network; f is the number of available frequencies for transmission in the network; w is the number of available messaging routes.

Bandwidth of C MCRS, at fixed values: the number of stations in the network m, load intensity λ/μ (where λ is the intensity of packets, μ is the packet processing intensity) and packet length L_p, the probability of packet damage by p_f that is characterized by not one but range of values and can be represented as the following functionality (objective function):

$$C=F\left\{m,f,w,L_p,\lambda/\mu,p_f,\kappa\right\}, \tag{2}$$

where κ is the number of modes of radio communication in the network.

$p_f=1-\exp\{-L_p\cdot P_{er}\}$, where P_{er} is the bit error probability.

Bandwidth value C, for different configurations of $f,w,\lambda/\mu,p_f,\kappa,L_p$ and m, is a nonlinear smooth unimodal function without discontinuities. The complex, nonlinear nature of the dependence of the objective function on the parameters $f,w,\lambda/\mu,p_f,\kappa,L_p$ and m does not allow to unambiguously determine the direction of search for the maximum of the objective function.

Obviously, this complex technique should solve the optimization problem, which can be formulated as follows:

$$C = F\left\{m, f, w, \lambda/\mu, L_p, p_f, \kappa\right\} \to \max_{m, f, w, p_f, \kappa} \left| \begin{array}{l} \lambda/\mu = const < \infty, L_p = const, \\ p_f = 0 \div 1,\ m = const. \end{array} \right. \quad (3)$$

For small values of $f, w, \lambda/\mu, p_f, \kappa, L_p$ and *m*, for example, it is possible to use the method of full directed search for all possible values of variable parameters. Otherwise, it is advisable to use an optimizer that implements, for example, a discrete analogue of the Gauss-Zeidel method. The latter method refers to the number of approximate methods and uses information about the unimodal objective function, which can significantly reduce the number of viewed points compared to the method of full search.

The essence of the Gauss-Zeidel method is to equivalently replace the general multiparameter problem of finding the extremum of the optimality criterion, a sequence of one-parameter problems of finding partial extrema. The partial derivative of the optimized functional has the following general form:

$$dI(\vec{x})/dx_i = dI(x_1, ..., x_i, ..., x_n)_{xl \neq i}/dx_i, i, l = 1, ..., I, \quad (4)$$

the optimal value x_i^{opt} can be found from the following general condition:

$$dI(\vec{x})/dx_i = 0, x_i = x_i^{opt}. \quad (5)$$

As it can be seen from the expression (4), the search for optimal values of parameters x_i^{opt} corresponding to the extremum $dI(\vec{x})/dx_i = 0$ can be carried out on the basis of an iterative sequential optimization procedure for each *i*-th parameter at fixed values of the other *l*-th parameters. The convergence of such a procedure to the optimal solution for all optimized variables is guaranteed in the presence of unimodality and differentiability of the objective function.

1. Enter the original data (step 1 in Fig. 2). The parameters of the radio communication system $\Psi = \{\psi_i\}$ are entered, as well as the values of the allowable probability value of the erroneous reception of signals $P_{er\ prob}$ and the minimum required speed of information transmission $v_{i\ prob}$ for each of the elements of MRCS and the allowable load in the network.

2. Assessment of the electronic situation in the network as a whole and for each individual radio direction (action 2 in Fig. 2).

At this stage, the assessment of the electronic situation in some parts of the network – nodes-coordinators for neighboring nodes, and in some radio directions – nodes that transmit information using one of the known methods or using non-standard assessment methodology were developed in [37].

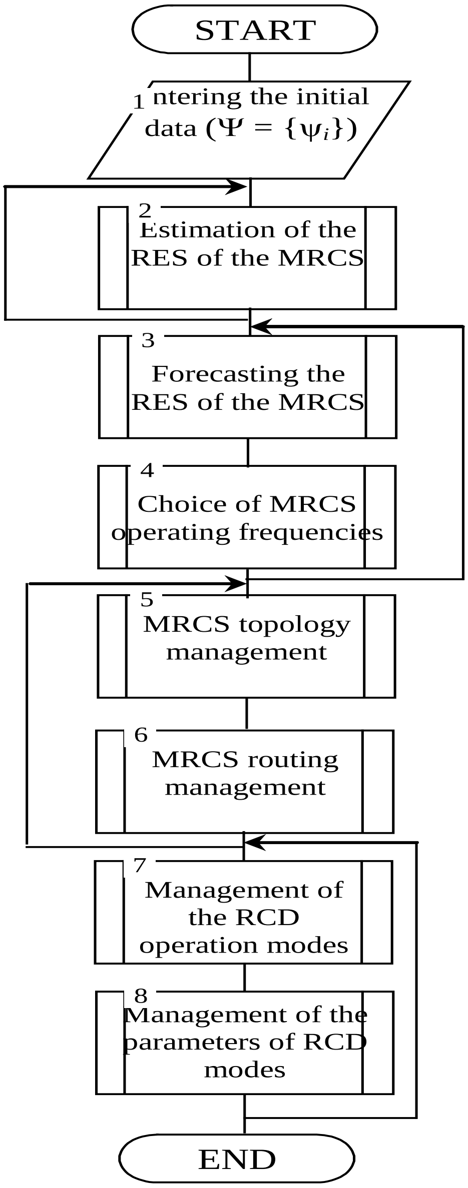

Fig. 2. Algorithm for implementing the method of the MRCS parameters management

3. Forecasting the state of the electronic environment of the radio communication system and for a particular radio direction of the network (action 3 in Fig. 2).

At this stage, the signaling and interference situation is predicted for the network as a whole and for each individual radio direction of the network. This procedure differs from the known ones by the fact that it additionally contains such operations [8–9]:

– recirculation of input data for one reading;

– resampling of the initial process on a logarithmic time scale;

– finding the energy spectrum of the received signal, determining the response;

– finding the entropy of the energy spectrum of the corresponding sample that should be resampled;

– calculation of the maximum value of the entropy responses;

– finding a forecast for the realization of the maximum value of entropy;

– resampling the forecasting result on an exponential time scale.

This procedure has the following sequence of actions [14]:

1. The input data is entered.

2. Time compression of the process, which is predicted to be necessary to ensure the processing of signals in real time performs. At each step, the implementation is updated by one count. Thus, a class of implementations is formed, which differs from each other by shifts by one count. To form a class of discrete samples, each implementation is subjected to the operation of logarithmization and sampling.

Then, find the maximum value of entropy in accordance with the ratio:

$$H(f) = -\int_{-1/2}^{1/2} \ln\left(\frac{X(f)}{\int_{-1/2}^{1/2}\left(X(f)\right)df}\right)df\ ,$$

where $X_n(f) = \dfrac{X(f)}{\int_{-1/2}^{1/2}\left(X(f)\right)df}$ is the normalized energy spectrum of the sample, $X(f) = \sum_{n=-\infty}^{\infty} r_{ss}(n)\exp(-2\pi fn)$, $r_{ss}(n)$ is the correlation function of the process. The use of the proposed procedure allows you to get a more accurate forecast than when using other known procedures.

4. The choice of operating frequencies taking into account the strategy of electronic suppression (step 4 in Fig. 1).

Based on the scientific and methodological apparatus of working frequency selection for military radio communication developed in the works [24; 26], the analysis of the radio frequency resource is carried out, during which the suppressed frequency bands, the strategy of enemy electronic suppression complexes and continuous suppression ellipses are determined.

On the basis of the specified information there is a formation of rational topology of MRCS.

5. Formation of the MRCS topology (action 5 in Fig.1)

The task of network topology management is to ensure the transmission of the maximum number of messages with the required quality (reliability, efficiency, reliability, etc.).

The topology determines the potential of the network to deliver data between interacting nodes [29; 32]. Mobility (failure, packet destruction) of nodes leads to different network topology configurations. Under such conditions, changing the network topology can have a greater effect, as opposed to using routing.

The effective functioning of mobile self-organizing radio networks depends on the structure of its subsystems, as well as on the compliance of these structures with the environmental conditions, first of all, the electronic environment.

The methods of synthesis of rational topology of MR, developed so far, mainly use as initial data a limited number of possible variants of the electronic environment, which are determined, as a rule, on the basis of subjective assessments of decision-makers. The study of the whole solution space in determining the rational topology is usually complicated due to too much required calculations and the impossibility of analytical description of the objective function.

In recent years, methods of artificial intelligence have been developed, which allow to find quasi-optimal solutions in systems whose target functions do not have an analytical description with sufficient speed.

This makes it relevant to conduct research on the application of these methods for the synthesis of rational values of the network topology.

Nowadays, the decision to suppress MRCS receivers by the devices of RES is made on the basis of comparing their coordinates with the suppression zone, in which the interference power in some way exceeds the signal power [31].

This article proposes to solve the inverse problem, namely the location of radio communications in the field, taking into account the optimal location of RES.

We consider a terrestrial USW radio that receives signals against a background of Gaussian noise at a high signal-to-noise ratio. The antennas of the transmitter and receiver MRCS have a pie chart. The coordinates of the RES are known – (x_1, y_1) and transmitter RCS – (x_2, y_2). The terrain in a rectangular coordinate system is given – $H_0(x, y)$. It is necessary to build a suppression zone $\xi(x, y)$ taking into account the terrain, sphericity of the Earth and tropospheric refraction.

In the general case, the suppression zone should be understood as the geometric location of the points for which the energy condition of suppression is fulfilled [31–32]:

$$P_R \ge K_R P_S\ , \tag{6}$$

where P_R is the interference power at the input of the RCS receiver; P_S is the signal power at the input of the RCS receiver; K_R is the suppression factor.

Accordingly, the analytical expression for the suppression zone should be presented as

$$\xi(x,y)=\begin{cases}1, & P_R(x,y)\ge K_R P_S(x,y),\\ 0, & P_R(x,y)<K_R P_S(x,y).\end{cases} \quad (7)$$

To construct the suppression zone of the RES (7) it is necessary to develop partial methods for calculating the signal strength and interference at points with given coordinates. We denote the coordinates of an arbitrary point at which you want to calculate the power of the interference by (x_0, y_0). To take into account the impact of the terrain, you first need to build a route profile – $H_1(R)$, which is an imaginary vertical section of the earth's surface in the direction from the point (x_1, y_1) to the point (x_0, y_0) [33]. The analytical expression from $H_0(x,y)$ for $H_1(R)$ can be got by rotating the coordinate system to the angle at which the direction from the point (x_1, y_1) to the point (x_0, y_0) will coincide with the direction of one of the coordinate axes. In this case, the value of one of the arguments (x or y) is zero, which allows the transition from the function of two arguments $H_0(x,y)$ to the function of one argument $H_1(R)$. The value of the angle θ_1, to which you want to rotate the coordinate system to align the desired direction with the axis Ox, is determined by the expression [5]:

$$\theta_1=\begin{cases}\arccos((x_0-x_1)R_1^{-1}), & y_0>y_1,\\ -\arccos((x_0-x_1)R_1^{-1}), & y_0\le y_1,\end{cases} \quad (8)$$

where R_1 is the distance between the RES tool and the point with coordinates (x_0, y_0).

The distance R_1 is calculated through the coordinates of the corresponding points [35]:

$$R_1=\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}\,. \quad (9)$$

Terrain in the new coordinate system $H_0'(x,y)$, taking into account the transfer of its center to the point of location of the RES, is determined by the expression [35]:

$$\begin{aligned}H_0'(x,y)=H_0(x\cos(\theta_1)-y\sin(\theta_1)+\\ +x_1, x\sin(\theta_1)+y\cos(\theta_1)+y_1).\end{aligned} \quad (10)$$

After equalization in the expression (10) of the argument y to zero and replace the argument x to R, we will obtain an analytical expression for the route profile:

$$H_1(R)=H_0(R\cos(\theta_1)+x_1, R\sin(\theta_1)+y_1)\,. \quad (11)$$

Taking into account the sphericity of the Earth and tropospheric refraction should be done by raising the profile of the route (11) to the appropriate correction $h_1(R)$ [33–34]:

$$h_1(R)=\frac{RR_1}{2R_З}\left(1-\frac{R}{R_1}\right), \quad (12)$$

where $R_З=8{,}5\cdot 10^6\,м$ is the equivalent radius of the Earth taking into account the normal tropospheric refraction.

Route profile taking into account the sphericity of the Earth and tropospheric refraction $\bar{H}_1(R)$ is determined by the expression

$$\bar{H}_1(R)=H_1(R)+h_1(R)\,. \quad (13)$$

The calculation of radio attenuation due to the influence of terrain is performed due to the height of the terrain $\Delta H_1(R)$ along the route profile above the line of sight $Z_1(R)$. In case of excess of relief elements over $Z_1(R)$ of the ΔH_1 parameter is considered negative [31], so

$$\Delta H_1(R)=Z_1(R)-\bar{H}_1(R)\,. \quad б(14)$$

Expression for $Z_1(R)$ is expedient to obtain through the equation a line drawn through two points [31], which are the point of location of the RES and the point (x_0, y_0). As a result, we get

$$\begin{aligned}Z_1(R)=RR_1^{-1}(H_0(x_0,y_0)-\\ -H_0(x_1,y_1))+H_0(x_1,y_1).\end{aligned} \quad (15)$$

Direct consideration of the influence of terrain is carried out by multiplying the signal strength at a point (x_0, y_0) per square of the attenuation factor of radio waves V [31]. This coefficient is a function of the argument u_1, which is determined by ΔH_1 so [31]:

$$u_1(R)=\frac{\Delta H_1(R)\sqrt{2}}{\sqrt{\lambda R(1-RR_1^{-1})}}, \quad (16)$$

where λ is the wavelength.

The dependence $V(u_1)$ in the range of values 0.001 ... 1 has a monotonic character [31]. Its polynomial approximation obtained using the MathCAD software environment has the form

$$\begin{aligned}V(u_1)=0{,}497+1{,}107u_1+0{,}442u_1^2-\\ -0{,}782u_1^3-0{,}855u_1^4-0{,}304u_1^5.\end{aligned} \quad (17)$$

The analysis of expressions (16) and (17) shows that the greatest attenuation of radio waves is not necessarily caused by the highest point of the route profile. A relief element with a lower height that is closer to the RES or point (x_0, y_0) can lead to significantly greater relaxation. Given the complexity and nonlinearity of dependencies $u_1(R)$ and $V(u_1)$, it is necessary to calculate the value of the function $V(u_1(R))$ along the route profile and select its lowest value V_1:

$$V_1=\min_{R\in[0;R_1]}\{V(u_1(R))\}\,. \quad (18)$$

Interference power at a point (x_0, y_0) is obtained from the radiocommunication equation [4]:

$$P_{TR} = \frac{P_{TR} G_{TR} A_E V_1^2}{4\pi R_1^2}, \quad (19)$$

where P_{TR} is the interference transmitter power; G_{TR} is the gain of the RES antenna; A_E is the effective antenna area of the MRCS receiver, m^2.

Calculations of the signal strength of the MRCS transmitter at the point (x_0, y_0) are carried out analogously to expressions (6)–(20) by replacing in the corresponding parameters of the index of one by two, because the source of radio waves is a point (x_2, y_2), as a result of which we will receive such expressions:

$$\theta_2 = \begin{cases} \arccos((x_0 - x_2) R_2^{-1}), & y_0 > y_2, \\ -\arccos((x_0 - x_2) R_2^{-1}), & y_0 \le y_2, \end{cases} \quad (21)$$

$$R_2 = \sqrt{(x_0 - x_2)^2 + (y_0 - y_2)^2}, \quad (22)$$

$$H_2(R) = H_0(R\cos(\theta_2) + x_2, R\sin(\theta_2) + y_2), \quad (23)$$

$$\bar{H}_2(R) = H_2(R) + \frac{RR_2}{2R_3}\left(1 - \frac{R}{R_2}\right), \quad (24)$$

$$\Delta H_2(R) = RR_2^{-1}(H_0(x_0, y_0) - \\ -H_0(x_2, y_2)) + H_0(x_2, y_2) - \bar{H}_2(R), \quad (25)$$

$$u_2(R) = \frac{\Delta H_2(R)\sqrt{2}}{\sqrt{\lambda R(1 - RR_2^{-1})}}, \quad (26)$$

$$V_2 = \min_{R \in [0; R_2]} \{V(u_2(R))\}, \quad (27)$$

$$P_S = \frac{P_{TS} G_{TS} A_E V_2^2}{4\pi R_2^2}, \quad (28)$$

where P_{TS} is the power of the MRCS transmitter; G_{TS} is the gain of the antenna of the MRCS transmitter.

The known method of constructing a suppression zone [31–32] does not take into account that radio communication and, accordingly, radio suppression are possible only within the so-called “radio communication zone”, in which the signal strength exceeds a certain threshold level P_{ther} [33–34]. Radio communication area $\varphi(x, y)$ is expedient to submit in the form of such functional dependence:

$$\varphi(x, y) = \begin{cases} 1, & P_S(x, y) \ge P_{ther}, \\ 0, & P_S(x, y) < P_{ther}. \end{cases} \quad (29)$$

Taking into account (29) the construction of the suppression zone should be carried out by the expression

$$\xi'(x, y) = \begin{cases} 1, & P_{ther} < P_S < P_{TR} K_{TR}^{-1}, \\ 0, & otherwise. \end{cases} \quad (30)$$

Thus, the procedure for constructing the MRCS suppression zone and determining the optimal one taking into account the terrain, the sphericity of the Earth and the tropospheric refraction of radio waves includes:

1. Determining the points at which calculations will be performed (or the step between them).

2. The calculation of interference power for selected points.

2.1. The construction of the route profile $H_1(R)$ (6)–(10).

2.2. The elevation of the route profile due to the sphericity of the Earth and tropospheric refraction (11)–(12).

2.3. The calculation of the obstacle attenuation factor V_1 (13)–(17).

2.4. An interference power calculation (18).

3. The calculation of signal power for selected points.

3.1. Construction of the route profile $H_2(R)$ (19)–(22).

3.2. An elevation of the route profile due to the sphericity of the Earth and tropospheric refraction (23).

3.3. The calculation of the signal attenuation factor V_2 (24)–(27).

3.4. The calculation of signal power (29).

4. The construction of the suppression zone taking into account the radio communication zone (30).

6. Routing management (step 6 in Fig. 2)

In the specified network and the signal-interference situation in the network information transmission routes occurs.

In this procedure, it is proposed to use the results developed in the works [13–19].

7. Selecting the operating mode (step 7 in Fig. 2).

It is proposed to use energy and frequency efficiency of system resources to select the mode of operation of the RCS. These performance indicators are complex and opposite. The boundaries between energy and frequency efficiency do not meet the requirements for changing the mode of operation, so to clarify the rule of choosing the modes of operation of military radio communications, it is proposed to introduce an additional indicator, namely the importance of RES.

The solution of problems that require vector optimization is to convert individual quality criteria into a general criterion, and select the solution of the problem that would meet the best value of the general criterion (maximum or minimum). The convolution of partial quality criteria to the general is carried out using a certain scheme of compromises, which determines the specific principle of optimality.

Thus, there is an urgent scientific problem of multicriteria optimization of the process of selecting modes of operation, taking into account their importance for improving the efficiency of the RCS, which can be written in the form

$$F_{opt} = \max F(\mathrm{Im}, \beta_E, C),$$

where F_{opt} is the optimal working mode, Im is the vector of coefficients of the RES importance.

In the works [14–18], approaches to solve problems of multicriteria and the choice of alternatives in technology, using the mathematical apparatus of utility theory, so to solve this problem it is proposed to use known approaches.

According to [54–56], the importance of RES indicators can be considered as a non-metric utility criterion (NMUC). The main difficulty in solving this problem is to present the NMUC in quantitative form in order to further introduce it into the utility function (UF).

Hybrid modes of operation based on multi-antenna systems are selected as operating modes, namely:

MIMO-OFDM (Multiple-Input Multiple-Output with Orthogonal Frequency Division Multiplexing);

MIMO-UWB (Multiple-Input Multiple-Output with Ulta wideband signal);

MIMO-FHSS (Multiple-Input Multiple-Output with Frequency-Hopping Spread Spectrum)/

To quantify the NMUC, non-metric partial utility criteria (NMPUC) have been identified to characterize the mode of operation. According to [54–56], the main NMPUC are the frequency efficiency of NMUC (β_F);bandwidth, the degree of use of radio frequency resources by the devices of RES (X_{EW}).We present the main NMUC using quantitative characteristics (Tabl. 1).

Table 1

The main NMPUC for the choice of mode of operation of RCS

NMPUC	Quantitative characteristics	Areas of change of input indicators	Indicators that are taken into account while determining the RES importance
β_E	Energy efficiency of the RCD	0,1-0,4	MIMO-OFDM
		0,41-0,79	MIMO-UWB
		0,8-1,0	MIMO-PTOF
C	Bandwidth	0,8-1,0	MIMO-OFDM
		0,41-0,79	MIMO-UWB
		0,1-0,4	MIMO-PTOF
X_{EW}	The degree of use of radio frequency resources by the RES devices	0,1-0,8	Obstacles in the lane part
		0,81-1	Obstructive barriers
k	The importance of information	0,1-0,4	Low
		0,41-0,79	Middle
		0,8-1,0	High

In the general case, the theory of expert evaluation is used to quantify non-metric criteria. The main reason for this is the lack of another general method of converting non-metric criteria into numerical values [14–18].

8. Selection of the signal parameters for the operating mode (step 8 in Fig. 2).

After assessing the impact of intentional interference and signal fading for each of the modes, the choice of rational values of signal parameters, where using mathematical modeling, the initial input of the parameters of the RCD and communication channel, the choice of rational parameter values for each mode, as it is noted in the works [20–21].

If the state of the communication channel corresponds to the parameters that satisfy the type of information transmitted on the communication channel, the packet is transmitted, if not, the packet is transmitted and information about the current state of the communication channel is transmitted to adjust the choice of the RCD mode, which will reduce the time of decision-making on the feasibility of using the operating mode.

The conclusions

In the specified article, the complex technique of parameters management of the military radio networks in the conditions of uncertainty of a radio electronic situation is developed.

The difference between this technique and the known ones is the integrated management of channel and network resources of military radio communication systems.

This technique allows to increase the efficiency of military radio systems operating in a complex electronic environment.

The main advantages of the proposed technique are:

– increasing the efficiency of radio frequency resource use;

– the possibility of RCD operation in the conditions of deficit of the frequency range;

– wide scope of use (radio communication systems for civil and special use);

– the ability to adapt to the signal situation in the channel;

– taking into account the impact of the main types of intentional interference;

– the possibility of providing frequency-territorial planning of the use of radio communications;

– the ability to predict the electronic situation;

– the determination of the optimal location of radio communication devices taking into account the zones of electronic suppression;

– the determination of the optimal route of information transmission taking into account the zones of electronic suppression;

– the determination of the optimal mode of the radio operation to maximize the RCD bandwidth;

The complex technique, which is offered in the work, should be used in the development of software for modules (blocks) for the assessment of promising radio communication devices, based on the open architecture interfaces of SCA version 2.2, which will allow:

– to use effective signal-code constructions to ensure channel noise immunity;

– to ensure efficient use of the radio frequency resource of programmable radio communication devices;

– to increase the evaluation speed of the communication channels;

– to reduce the use of computing resources of radio communications with programmable architecture.

The proposed technique can be implemented in radio communication with a programmable architecture. To do this, you need to adapt the signal processor with additional software for a specific radio communication devices.

Prospects for further research in this area are to develop practical recommendations for the implementation of this technique in the latest radio communication devices.

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Received by Editorial Board 21.08.2020
Signed for Printing 22.09.2020

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КОМПЛЕКСНА МЕТОДИКА УПРАВЛІННЯ ПАРАМЕТРАМИ ВІЙСЬКОВИХ РАДІОМЕРЕЖ В УМОВАХ НЕВИЗНАЧЕНОСТІ РАДІОЕЛЕКТРОННОЇ ОБСТАНОВКИ

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Досвід проведення Операції Об'єднаних Сил (Антитерористичної операції на території Донецької та Луганської областей) свідчить, що існуючий порядок управління системами військового радіозв'язку не задовольняє сучасним вимогам, що висуваються до них. Класичний централізований підхід до управління канальними та мережевими ресурсами систем військового радіозв'язку не відповідає вимогам сучасності, тому авторами зазначеної статті запропоновано в якості базового принципу побудови взяти мобільні самоорганізуючі мережі. Авторами запропоновано комплексну методика управління параметрами військових радіомереж в умовах невизначеності радіоелектронної обстановки, сутність якої полягає в забезпеченні підтримки заданих значень показників функціонування систем військового радіозв'язку на належному рівні. В статті за основу взятий принцип управління, що описаний в еталонній мережевій моделі взаємодії відкритих систем, проте з деякими доповненнями та змінами. Зазначений підхід в цілому дозволяє здійснювати наскрізне управління канальними та мережевими ресурсами систем військового радіозв'язку в складній радіоелектронній обстановці. В зазначеній статті використаний апарат нечіткої логіки, теорії радіоелектронного подавлення, нейронних мереж, теорії завадозахищеності, теорії антен, завадостійкого кодування та інш. Запропоновану в роботі комплексну методику доцільно використовувати при розробці програмного забезпечення для модулів (блоків) оцінки перспективних засобів радіозв'язку, що засновано на інтерфейсах відкритої архітектури версії SCA 2.2, що дозволить: використовувати ефективні сигнально-кодові конструкції для забезпечення завадозахищеності каналів; забезпечити ефективне використання радіочастотного ресурсу програмованих засобів радіозв'язку; підвищити швидкість оцінки каналів зв'язку; зменшити використання обчислювальних ресурсів засобів радіозв'язку з програмованою архітектурою.

Ключові слова: *система радіозв'язку, навмисні завади, радіоресурс, розподіл робочих частот, завмирання сигналу, топологія мережі.*

КОМПЛЕКСНАЯ МЕТОДИКА УПРАВЛЕНИЯ ПАРАМЕТРАМИ ВОЕННЫХ РАДИОСЕТЕЙ В УСЛОВИЯХ НЕОПРЕДЕЛЕННОСТИ РАДИОЭЛЕКТРОННОЙ ОБСТАНОВКИ

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Опыт проведения Операции Объединенных Сил (Антитеррористической операции на территории Донецкой и Луганской областей) свидетельствует, что существующий порядок управления системами военной радиосвязи не удовлетворяет современным требованиям, предъявляемым к ним. Классический централизованный подход к управлению канальными и сетевыми ресурсами систем военной радиосвязи не соответствует требованиям современности, поэтому авторами статьи предложено в качестве базового принципа построения взять мобильные самоорганизующиеся сети. Авторами предложена комплексная методика управления параметрами военных радиосетей в условиях неопределенности радиоэлектронной обстановки, сущность которой заключается в обеспечении поддержания заданных значений показателей функционирования систем военной радиосвязи на должном уровне. В статье за основу взят принцип управления, описанный в эталонной сетевой модели взаимодействия открытых систем, однако с некоторыми дополнениями и изменениями. Указанный подход в целом позволяет осуществлять сквозное управление канальными и сетевыми ресурсами систем военной радиосвязи в сложной радиоэлектронной обстановке. В указанной статье использован аппарат нечеткой логики, теории радиоэлектронного подавления, нейронных сетей, теории помехозащищенности, теории антенн, помехоустойчивого кодирования и др. Предложенную в работе комплексную методику целесообразно использовать при разработке программного обеспечения для модулей (блоков) оценки перспективных средств радиосвязи, основанного на интерфейсах открытой архитектуры версии SCA 2.2, что позволит: использовать эффективные сигнально-кодовые конструкции для обеспечения помехозащищенности каналов; обеспечить эффективное использование радиочастотного ресурса программируемых средств радиосвязи; повысить скорость оценки каналов связи; уменьшить использование вычислительных ресурсов средств радиосвязи с программируемой архитектурой.

Ключевые слова: *система радиосвязи, умышленные помехи, радиоресурс, распределение рабочих частот, замирание сигнала, топология сети.*