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# DEVELOPMENT OF A METHOD OF ADAPTIVE CONTROL OF MILITARY RADIO NETWORK PARAMETERS

*A method of adaptive control of military radio network parameters has been developed. This method allows predicting suppressed frequencies by electronic warfare devices, determining the topology of the military radio network. Also, this method allows determining rational routes of information transmission and operating mode of radio communications. Forecasting of the electronic environment is characterized by recirculation of input data for one count, resampling on a logarithmic time scale, finding a forecast for the maximum value of entropy and resampling the forecast on the exponential time scale. The developed method allows choosing a rational network topology. The choice of topology of the military radio communication system is based on the method of ant multi-colony system. The main idea of the new option of ant colony optimization is that instead of one colony of the traditional ant algorithm several colonies are used that work together in a common search space. However, this procedure additionally takes into account the type of a priori uncertainty and the evaporation coefficient of the pheromone level. The proposed method allows choosing a rational route for information transmission. The proposed procedure is based on an improved DSR algorithm. This method uses several operating modes of radio communications, namely the technology of multi-antenna systems with noise-like signals, with pseudo-random adjustment of the operating frequency and with orthogonal frequency multiplexing. The developed method provides a gain of 10–16 % compared to conventional management approaches*

*Keywords: radio communication system, intentional interference, radio resource, signal fading, network topology, routing*

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## 1. Introduction

Currently, a single global information space is being built among the elements of management systems for various purposes. The main difference of this architecture is the use of high-level systems based on the principles of building the Internet.

For this purpose, the transition is made from various types of independently functioning subsystems to integrated communication and data transmission systems (IC DTS) that provide transmission and "seamless" connection. "Seamless" means the exclusion of manual operations while connecting subscribers and exchanging data among disparate communication systems. This, in turn, requires the use of multifunctional radios, which allow through control of the parameters of military radio communication systems.

The versatility of radio stations is realized through the use of a wide class of signals, coding methods and measures to increase noise immunity, modes of information transmission, algorithms for choosing a rational topology and route of information transmission [1, 2].

The approximate relationship between the parameters and control variables by levels of the open systems interconnection model is given in Table 1.

Table 1

Approximate relationship between parameters and control variables by OSI (Open Systems Interconnection) model levels

| OSI level | Control objects | Basic optimization parameters | Controlling influence of the node |
|---|---|---|---|
| Physical | Radio channel within radio connectivity with neighboring nodes | Bandwidth, transmission time in the channel, battery power consumption, transmission power, antenna pattern, etc. | Transmission power (direction), type of modulation, type of correction code, parameters, etc. |
| Channel | Radio channels within radio communication with neighboring nodes | Bandwidth and transmission time in the channel, battery power consumption, amount of service information, etc. | Channel level exchange algorithms: deterministic, random, hybrid; sizes of packages and receipts |
| Network | One or more transmission routes | Amount of service information, route parameters (time of construction and existence, quantity, capacity, delivery time, battery power consumption, etc.) | Network layer exchange algorithms: tabular, probe, hybrid, wave asymmetric, hierarchical, etc. Topology control algorithms |
| Transport | Information direction of communication | Bandwidth, time and variation of its transmission in the direction | Queue management algorithms. Overload window size, timeout time, etc. |
| Applied | Node, neighboring nodes, network area, entire network | Bandwidth, time and variation of transmission time, battery power consumption, transmission security | Algorithms (protocols) of information exchange of application level, coordination and intellectualization on OSI levels |

From the analysis of Table 1, it can be concluded that in order to effectively control the parameters of military radio networks, this should be done at several levels of the OSI model.

The problem of compatibility of radio communication devices (RCD) of different standards and ranges is currently being implemented for the tactical management of the armed forces of the world's leading countries through the use of software-defined radio (SDR) and software-defined networking (SDN).

The ability of communication devices to change their basic technical characteristics through reprogramming allows you to manage channel and network resources.

A key feature of modern military operations (combat operations) is the conditions of a priori uncertainty about the state of the electronic environment. This happens because of the dynamic change of network topology due to the movement of radio communications, physical destruction of radio communications, changes in the underlying surface and electronic suppression.

Given the above, there is an urgent scientific task of developing methods for managing channel and network resources of military radio networks in conditions of uncertainty of the electronic environment.

## 2. Literature review and problem statement

In [3], the tendency to create integrated hardware platforms by radio frequency and digital signal processing devices for the joint solution of communication and radar tasks is determined. However, this paper does not provide specific mechanisms for controlling the parameters of GSM communication networks for airspace monitoring.

In [4], the substantiation of ways to increase the efficiency of trunking communication systems of Ukraine is carried out. However, this type of radio communication is not resistant to electronic suppression.

In [5], the methods of increasing the efficiency of radio frequency resource use in cognitive radio networks were developed. However, this paper does not consider the impact of the location of electronic warfare on the quality of communication in the radio network.

The paper [6] proposes a dynamic channel selection algorithm based on a fuzzy inference system (FIS), capable of selecting the most available channel with the desired bandwidth, the minimum required signal-to-noise ratio and the probability of detecting a miss. The disadvantages of the proposed algorithm include not taking into account the impact of intentional interference.

The paper [7] proposes the development of the controller of access to a radio resource on the basis of a sliding window. However, this controller does not allow taking into account destabilizing factors present in radio channels, such as intentional interference and fading.

In [8], a method for monitoring the radio frequency spectrum and network architecture is proposed to regulate the spectrum distribution and control the use of the radio frequency spectrum. However, the proposed approach does not allow taking into account measures to increase the noise immunity of military radio networks.

The paper [9] proposes an algorithm for controlling the parameters of cognitive radio networks, 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.

The paper [10] proposes a method for determining the location of radio communication devices depending on the effectiveness of electronic suppression. The proposed method allows increasing the efficiency of radio communication, but this is limited only by determining the optimal location of radio communications.

The paper [11] proposes to use clustering algorithms to control the radio resource of radio communications. The proposed algorithm is based on the distribution of radio frequencies among clusters. However, this approach does not allow adapting to the effects of intentional interference and implementing other mechanisms to increase noise immunity.

The paper [12] proposes to use artificial intelligence in problems of increasing the efficiency of cognitive radio networks. However, this research is intended only for general training (adaptation) of cognitive radio networks without specifying the factors that affect its effectiveness.

The paper [13] proposes adaptive algorithms for adjusting the threshold values of radio communication system parameters. The specified research allows allocating a useful signal against noise, adapting to a signal situation. However, this research does not allow complex control of the parameters of special-purpose radio systems.

Given the fact that the management of channel and network resources requires the processing of different units of measurement and origin of input data, it is proposed to analyze the algorithms for processing different types of data.

In [14], the development of generalized metrics in the problem of analysis of multidimensional data with different characteristics is carried out. The essence of the proposed metric is that this metric allows you to build algorithms for clustering, classification and association based on it, using classical processing methods. However, this metric does not allow effective functioning in conditions of shortage of computing resources.

The paper [15] considers the problem of information processing from heterogeneous technical monitoring devices. As a possible solution to the problem, the application of a generalized method of information processing based on the method of clustering of territorially combined information sources of monitoring and the use of a frame model of the knowledge base of the monitoring objects identification is proposed. The clustering method is formed on the basis of the hierarchical Lance-Williams agglomerative procedure using the Ward metric. The frame model of the knowledge base is built using the tools of object-oriented modeling. The disadvantages of the proposed generalized methodology include not taking into account the relative importance of the events that occur and the inability to work in a shortage of computing resources. Also, the disadvantages of this method include the inability to redistribute computing resources among the elements to increase the efficiency of information processing.

The papers [2, 16] exemplify an approach to the processing of various types of data on the state of the communication channel. The essence of the proposed approach is an assessment of the state of the communication channel and three different indicators. This approach requires complete information about the state of the channel and accumulates evaluation errors during operation.

The analysis of the works [2–16] allows us to state that the existing scientific achievements do not allow for a through management of channel and network resources of military radio networks, but only separate control influences at a separate level of the open systems interconnection model. All this does not allow using available radio resources of military radio networks effectively and counteracting comprehensively destabilizing factors that affect the efficiency of military radio networks.

Therefore, in order to increase the efficiency of military radio networks, it is necessary to conduct comprehensive control of the parameters of military radio networks at the channel and network levels of the open systems interconnection model. This can be achieved by developing appropriate control procedures that will allow:

1) at the channel level of the OSI model:

– selecting operating frequencies taking into account the impact of intentional interference and the projected strategy of electronic warfare;

– determining the rational operating mode of radio communication facilities;

2) at the network level of the OSI model:

– choosing the topology of the military radio communication system;

– choosing a rational route for the transmission of information among the elements of the military radio system;

– determining the location of transmitters of radio communication devices depending on the location of electronic warfare transmitters;

– complex management of channel and network resources at each level of the open networks interconnection model.

## 3. The aim and objectives of the study

The aim of the study is to develop a method for adaptive control of military radio network parameters, which would allow control at the channel and network levels of the open networks interconnection model.

To achieve the aim, the following objectives were set:

– to set the task of managing channel and network resources of military radio communication systems on the maximum bandwidth;

– to develop an algorithm for adaptive control of military radio network parameters.

## 4. Statement of the problem of management of channel and network resources on the maximum bandwidth

It is proposed to carry out a through management of channel and network system resources with relative observance of hierarchy at each level of the reference network open systems interconnection OSI model (open systems interconnection basic reference model).

By management of channel and network resources we mean management of the network radio resource, topology, routing and operating mode of radio communication devices [3–5].

Radio resource management is the management of frequency, code, time and energy resources among nodes of military radio communication systems, as well as determining the degree of influence of electronic suppression of the enemy.

Topology management is the operational reconfiguration of the topology of military radio communication systems and the connection of backup elements (channels, mobile base stations and nodes) in a changing situation in order to meet the maintenance of a given quality of service.

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

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 in accordance with the control subsystem of the second level ($I_2, U_2$), and the tops of this tree, located at a distance of one edge from the root – $Q$ first-level control subsystem ($I_{11}, U_{11}$), ..., ($I_{1q}, U_{1q}$), ..., ($I_{1Q}, U_{1Q}$). Each subsystem consists of a control unit (identification) $I$ and a control unit $U$. We introduce into consideration $Q$ zero-level subsystems, which are located at a distance of two edges from the root of the tree. These subsystems represent interacting processes of exchange of operational and service information flows in control systems $P_1, ..., P_q, ..., P_Q$ [3–5].

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

– $X_{1q}(k)$ is the set of vectors, the state of the $q$-th managed subnet, where $x_{1q}(k)=\{x_{1q}^a(k)\}$, $a=\overline{1,a_{1q}}$ 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 subsystems of the lower-level control $z_{2q}(k)=\{z_{2q}^d(k)\}$, $d=\overline{1,d_{2q}}$ 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 $\Pi_q(k)=\{\pi_q^l(k)\}$, $l=\overline{1,l_q}$ with the dimension $l_q\times 1$.

The set of state vectors $X(k)=\bigcup_{q=1}^{Q}X_{1q}(k)$ can include vectors of any state variables that affect the quality of the radio system and the efficiency of the military radio system. The main ones are:

– the vector of parameters of information load of the military radio communication system (characterizes the number of information messages that need to be transmitted per unit time at a given bandwidth):

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

– the vector of delays in the transmission of information messages of the military radio communication system (characterized by a deterioration in the bandwidth of military radio communication systems):

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

– the vector of parameters of the electronic environment in the network of the military radio communication system (the number of suppressed operating frequencies by the RES devices that do not meet the requirements for bandwidth):

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

– the vector of frequency resources of the military radio communication network (total number of operating frequencies of military radio communication systems):

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

etc.

It was previously noted that the bandwidth of military radio communication systems is one of the main indicators that characterize the efficiency of the military radio communication system in general and the quality of service (QoS) of the transmitted traffic in particular. Maximizing the bandwidth of military radio systems, by optimizing the parameters of the channel and network levels, will increase the efficiency of military radio systems.

Therefore, the maximum bandwidth of the military radio communication system at the channel and network level of the open networks interconnection model with the military radio communication system in accordance with expression (1) is chosen as the optimization criterion.

$$C_{Ch,N}\rightarrow\max_{m,f,w,\varpi,f_{EW},F_{opt}},\tag{1}$$

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, $\varpi$ is the total number of routes, $f_{RES}$ is the number of suppressed frequencies by electronic warfare devices, $F_{opt}$ is the optimal operating mode of the radio.

Bandwidth $C$ when:

– fixed stations in the network $m$;

– load intensity $\lambda/\mu$ (where $\lambda$ is the package appearance intensity, $\mu$ is the package processing intensity);

– package lengths $L_p$ and the probability of damage to the package by interference $p_f$ are represented as the following functional (objective function):

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

where $\kappa$ is the number of radio communication modes in the network.

$$p_f=1-\exp\{-L_p\cdot P_b\},$$

where $P_b$ is the bit error probability.

Bandwidth value $C$, for different configurations $f$, $w$, $\lambda/\mu$, $p_f$, $\kappa$, $L_p$ 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 determining the direction of search for the maximum of the objective function unambiguously.

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

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

At small values $f$, $w$, $\lambda/\mu$ $p_f$, $\kappa$, $L_p$ and $m$ for example, it is possible to use the method of full directional 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-Seidel method.

The essence of the Gauss-Seidel method consists in the equivalent replacement of 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 functional that is optimized in this case has the following general form:

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

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

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

As can be seen from expression (4), the search for optimal parameter values $x_i^{opt}$, corresponding to the extremum $dI(\vec{x})/dx_i = 0$, can be performed 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.

Thus, the proposed problem statement allows us to describe the processes occurring in military radio communication systems. The criterion of efficiency in this method is the bandwidth of the military radio system and the task of control influences at the channel and network level aimed at increasing it.

Depending on topology, each military radio network is characterized by an information matrix, the elements of which determine the values of relative bandwidth in a particular link.

Information matrix $M_I$ of the military radio network of a typical separate mechanized brigade is shown in Table 2.

Symbols that are used in Table 2: $A$, $A'$, $A''$ are the KP, FCP, RCP crews respectively; $B_i$, $B_j$ is the OP $i$-th ($j$-th) battalion, respectively; $i, j$ are the indices that determine the number of the battalion, $i,j=1,...,I$, $I$ is the number of battalions in the brigade; $b_k$, $b_l$ is the KOP $k$-th ($l$-th) company, respectively; $k$, $l$ are the indices that determine the company number, $k,l=1,...,K$, $K$ is the the number of companies in the battalion; $b'_{kk}$, $b'_{ll}$ is the OP $kk$-th ($ll$-th) platoon, respectively; $kk$, $ll$ are the indices that determine the platoon number, $kk,ll=1,...,KK$, $KK$ is the number of platoons in the company; $C_m$, $C_n$ is the KP $m$-th ($n$-th) division (artillery (art) and AD), respectively; $m$, $n$ are the indices that determine the division number, $m,n=1,...,M$, $M$ are the number of divisions in the brigade; $c_u$, $c_v$ is the KOP $u$-th ($v$-th) of batteries, respectively; $u$, $v$ are the indices that determine the battery number, $u,v=1,...,U_v$, $U_v$ is the number of batteries in the $v$-th division; $c'_{uu}$, $c'_{vv}$ is the OP $uu$-th ($vv$-th) platoon, respectively; $uu$, $vv$ are the indices that determine the platoon number, $uu,vv=1,...,UU_{vv}$, $UU_{vv}$ is the number of platoons in the $vv$-th battery; $d_s$, $d_t$ is the OP $s$-th ($t$-th) of the individual company, respectively; $s$, $t$ are the indices that determine the number of an individual company, $s,t=1,...,S$, $S$ is the number of individual companies in the team; $d'_{ss}$, $d'_{tt}$ is the OP $ss$-th ($tt$-th) platoon of a separate company, respectively; $ss$, $tt$ are the indices that determine the platoon number, $ss,tt=1,...,SS_t$, $SS_t$ is the number of platoons in the $t$-th separate conpany.

Table 2

Information matrix of military radio communication of a typical separate mechanized brigade

| | brigade | battalion | company/ battalion | platoon / company | division (art. and AD) | battery/ division | platoon/ battery | separate company | platoon/separate company |
|---|---|---|---|---|---|---|---|---|---|
| | $A$, $A'$, $A''$ | $B_j$ | $b_l/B_j$ | $b'_{ll}/b_l/B_j$ | $C_n$ | $c_v/C_n$ | $c'_{vv}/c_v/C_n$ | $d_t$ | $d'_{tt}/d_t$ |
| $A$, $A'$, $A''$ | 0 | $c_{AB}$ | $c_{Ab}$ | 0 | $c_{AC}$ | $c_{Ac}$ | 0 | $c_{Ad}$ | 0 |
| $B_j$ | $c_{BA}$ | 0, $i=j$; $c_B$, $i\neq j$ | $c_{Bb}$, $i=j$; 0, $i\neq j$ | $c_{Bb'}$, $i=j$; 0, $i\neq j$ | $c_{BC}$ | 0 | 0 | 0 | 0 |
| $b_k/B_i$ | 0 | $c_{bB}$, $i=j$; 0, $i\neq j$ | 0, $i=j$; $c_b$, $i\neq j$ | $c_{bb'}$, $i=j$; 0, $i\neq j$ | 0 | 0 | 0 | 0 | 0 |
| $b'_{kk}/b_k/B_i$ | 0 | $c_{b'B}$, $i=j$; 0, $i\neq j$ | $c_{b'b}$, $i=j$; 0, $i\neq j$ | 0, $i=j$; $c_{b'}$, $i\neq j$ | 0 | 0 | 0 | 0 | 0 |
| $C_m$ | $c_{CA}$ | $c_{CB}$ | 0 | 0 | 0, $m=n$; $c_C$, $m\neq n$ | $c_{Cc}$, $m=n$; 0, $m\neq n$ | $c_{Cc'}$, $m=n$; 0, $m\neq n$ | $c_{Cd}$ | 0 |
| $c_u/C_m$ | 0 | 0 | 0 | 0 | $c_{cC}$, $m=n$; 0, $m\neq n$ | $c_c$, $m=n$; 0, $m\neq n$ | $c_{cc'}$, $m=n$; 0, $m\neq n$ | 0 | 0 |
| $c'_{uu}/c_u/C_m$ | 0 | 0 | 0 | 0 | 0 | $c_{c'c}$, $m=n$; 0, $m\neq n$ | $c_{c'}$, $m=n$; 0, $m\neq n$ | 0 | 0 |
| $d_s$ | $I_{ij}$(t) | $c_{dB}$ | 0 | 0 | $c_{dC}$ | 0 | 0 | $c_d$, $s=t$; 0, $s\neq t$ | $c_{dd'}$, $s=t$; 0, $s\neq t$ |
| $d'_{ss}/d_s$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | $c_{d'd}$, $s=t$; 0, $s\neq t$ | $c_{d'}$, $s=t$; 0, $s\neq t$ |

Initial data used for calculations:

1) 25 kHz FHSS-TDD-QPSK military radio communication system; the devices of transmitting information that is used in the control units to the company inclusive have a radiation power of 50 W, and the devices that are used in the platoon link are characterized by a radiation power of 5 W;

2) a company of RES consisting of three platoons, which are equipped with multifunctional REO stations in the amount of 3 samples per platoon.

The power of the interference station is up to 2 kW, but the energy potential is distributed in such a way that 0.5 kW is used to suppress the telecommunications network.

The antenna system of the REO station is characterized by a radiation pattern with a width of 120° (at the level of 3 dB) and a gain of 10 dB. Each REO station places a barrier with vertical polarization in the range of the network.

## 5. Development of an algorithm for adaptive control of military radio network parameters

Let us consider the basic procedures of the method of adaptive control of military radio network parameters.

1. Entering initial data.

The data of the radio communication system $\Psi=\{\psi_i\}$, are entered, as well as the value of the allowable bit error probability $P_{b\ allow}$ and the minimum data rate for each element of the military radio communication system (MRCS) and the allowable network load.

2. Assessment of the electronic environment.

The assessment of the electronic situation on the network sections is carried out by the coordinating nodes for the neighboring nodes. On radio directions, it is nodes that transmit information using one of the known methods developed by the authors in [17, 18].

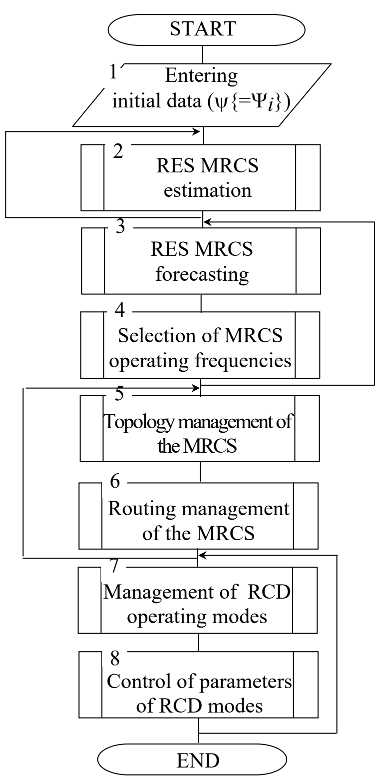


Fig. 1. Algorithm of the method of adaptive control of MRCS parameters

3. Forecasting the state of the electronic environment.

Forecasting of the signal-interference situation for the network as a whole and for each individual radio direction of the network is carried out. The procedure differs from the known ones because it additionally contains the following operations:

– recirculation of input data for one reading;

– resampling 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 to be resampled,

– calculation of the maximum value of 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:

1. Entering initial data.

2. Temporary compression of the process. A class of implementations is formed, which differs from each other by the one count shifts. To form a class of discrete samples, each implementation is subject to the operation of logarithmization and sampling.

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

$$H(f)=-\int_{-1/2}^{1/2}\ln\left(\frac{X(f)}{\int_{-1/2}^{1/2}\left(X(f)\right)\mathrm{d}f}\right)\mathrm{d}f, \quad (6)$$

where $X_n(f)=\frac{X(f)}{\int_{-1/2}^{1/2}\left(X(f)\right)\mathrm{d}f}$ is the energy spectrum of the sample, $X(f)=\sum_{n=-\infty}^{\infty} r_{ss}(n)\exp(-2\pi fn)$, $r_{ss}(n)$ is the correla tion function of the process.

3. Selection of operating frequencies.

The analysis of a radio frequency resource is carried out. This procedure differs from the known ones because the choice of operating frequencies is as follows:

– determination of the number of suppressed frequency bands and the degree of their suppression (overlap coefficients of the channel). Thus, if the frequency channel is suppressed completely, it is eliminated and considered unsuitable for information transmission, if partially, it is possible to transmit information with minimum bandwidth using high-energy signal code structures, and if the channel is free from interference, then the transmission of information occurs using high-speed signal structures;

– the ellipses of continuous suppression and zones of radio communication disturbance are determined;

– using the method of nonlinear programming, the strategies of electronic suppression of the enemy are determined;

– on the basis of the data received after the procedure of forecasting the condition of the radioelectronic situation, selection of working frequencies is carried out.

On the basis of the specified information, rational MRCS topology is formed.

4. Formation of MRCS topology.

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

Let us consider the problem of building a topology of a military radio network. The procedure of choosing the topology of the military radio communication system is based on the method of AMCO (Ant Multi-Colony Optimization). The main idea of the new option of ant colony optimization is that instead of one colony of the traditional ant algorithm, several colonies are used that work together in a common search space. Thus, each colony on the basis of the mechanism of a stigmergy solves the subtask, forming the part in the joint decision. To take into account special conditions of each subtask, colonies can interpret input data differently and have different parameters that influence decision-making. To avoid confusion while referring to previous experience, different pheromones are used, which are perceived only by the same colonies that left them. Moreover, in certain cases, the repulsive effect of a foreign pheromone is appropriate. Thus, the pheromone directs the colony to find a solution to its own subtask. In this case, pheromones are deposited by all colonies for the corresponding parts of the solution with the same concentration, proportional to the cost of solving the problem as a whole. Evaporation also occurs simultaneously and at the same rate.

In an ant multi-colony system, part of the solution is built by several ants at the same time. Firstly, groups of ants are formed, including one representative from each colony. In essence, each such intercolonial group is a replacement for a separate ant of the traditional version of the algorithm. The ants of the group, as a result of the "draw", form a step-by-step solution, including the vertices at each step in the order determined presumably on the basis of a combined set of alternatives. The ant in the group $k$, belonging to the colony $x$, will include in its part of the solution the vertex $i$ on the iteration of $t$ with a normalized probability:

$$p_{x,i}^{k}(t)=\frac{\left(\left[\tau_{y,i}^{k}(t)\right]^{\alpha}\cdot\upsilon\right)\cdot\left(\left[\eta_{x,i}^{k}\right]^{\beta}\cdot\iota\right)}{\sum\limits_{y\in Y}\sum\limits_{j\in J^{k}}\left(\left[\tau_{y,i}^{k}(t)\right]^{\alpha}\cdot\upsilon\right)\cdot\left(\left[\eta_{x,i}^{k}\right]^{\beta}\cdot\iota\right)}, \qquad (7)$$

$Y$ is the set of colonies; $J^k$ is the set of available vertices for the group $k$; $\eta_{x,i}^{k}$ is the priori attractiveness of the alternative, the reverse cost of the transition from the current top of the ant group $k$ of the colony $x$ to the top $i$; $\tau_{y,i}^{k}$ is the posteriori efficiency of the alternative, which is determined by the amount of pheromones of the colony $x$ in the transition from the current top of the ant group $k$ of the colony $x$ to the top $i$; $\alpha$, $\beta$ are the customizable algorithm parameters; $\upsilon$ is the evaporation rate of pheromone levels; $\iota$ is the information uncertainty coefficient.

To avoid repeated calculation of the sum of products in the denominator of the formula, in the software implementation it is advisable to normalize the latter. To do this, it is proposed firstly to use the formula for calculating abnormal probabilities:

$$p_{x,i}'^{k}(t)=\left[\tau_{y,i}^{k}(t)\right]^{\alpha}\cdot\left[\eta_{x,i}^{k}\right]^{\beta}, \qquad (8)$$

then calculate once the sum of the obtained values of the non-normalized probabilities of the whole group $k$:

$$p_{x,i}^{k}(t)=\frac{p_{x,i}'^{k}(t)}{P^{k}(t)}, \qquad (9)$$

then perform normalization for each value according to the formula:

$$P^{k}(t)=\frac{p_{x,i}'^{k}(t)}{\sum\limits_{y\in Y}\sum\limits_{j\in J}p_{x,i}'^{k}(t)}. \qquad (10)$$

If a more aggressive strategy of dividing the vertices among the colonies is needed in order to improve the quality of the routes themselves, a complicated formula for calculating abnormal probabilities can be used:

$$p_{x,i}'^{k}(t)=\frac{\left[\tau_{y,i}^{k}(t)\right]^{\alpha}\left[\eta_{x,i}^{k}\right]^{\beta}}{\left[\sum\limits_{z\in Y,z\neq x}\tau_{y,i}^{k}(t)\right]^{\gamma}}, \qquad (11)$$

where $\gamma$ is the new parameter of the ant algorithm that controls the repulsive effect of pheromones from other colonies. Obviously, the presence of an additional amount in the denominator affects the time of probability calculation, especially with a large number of colonies, and another controlled parameter complicates the configuration of the algorithm. Therefore, the choice between formulas (8), (11) should be based on the conditions of a particular problem and taking into account its dimension.

5. Routing management (step 6 in Fig. 1).

Finding the shortest path between a pair of points is an NP-hard problem that requires listing all possible routes. In addition, most users today need not only routes with the fewest hops to the destination, but also routes that can meet other important needs. Such users often need to provide support for QoS [19, 20] and to be able to take into account the energy component [13, 15, 21–24] due to the fact that in special-purpose networks there may be a significant number of nodes running on batteries, taking into account the speed of the communication channel, the delay time between the sender of the packet and its recipient, the number of available routes and the reliability of packet delivery by the appropriate route.

The general structure of the proposed routing procedure consists of four main components [20], such as route support system, route search system, IP packet routing decision-making system and memory system with which all the above systems interact.

The proposed procedure uses a combination of fuzzy logic (FL) algorithm [12–15, 19, 21, 25–31] and ant colony system (ACS) [18, 20, 22, 31–34] to find the optimal route between a pair of NS/ND nodes. The optimal route refers to a route that satisfies all the desired parameters necessary to select the best route. Such parameters are: "QoS", "channel speed", "packet delivery reliability", "energy component", "End to End Delay" and "number of available routes" (Fig. 2).

The main steps of the algorithm for determining the sending of an IP packet to the destination node routing procedure in military networks with the possibility of self-organization are:

– Step 1. Collect node status data in the network to the node status cache in the network.

– Step 2. Receive a request to send a packet to the destination node.

– Step 3. Check the availability of the route to the destination node. If there is no route in the routing table, the route search system searches for the route to the destination node (step 4).

– Step 4. The route search system executes the route search request.

– Step 5. If you receive a response to the route request, the route is recorded to the node status cache in the network.

– Step 6. Fuzzification and defuzzification of route indicators.

– Step 7. The route is searched.

– Step 8. Forming a database of routes.

– Step 9. The decision-making system for sending IP packets based on the available routes in the database of routes decides to send the IP packet by the appropriate route to the destination node based on QoS.

– Step 10. Send the IP packet to the destination node.

MDSR receives all packets and reads the sender's IP address and MAC from them, which allows you to populate the ARP table. This reduces the overhead of maintaining the ARP protocol.

The fuzzy neural network (FNN) proposed for routing consists of five layers: linear transmission function, fuzzification, "yes" operation, fuzzy inference and defuzzification.

*Layer 1.* The function of linear transmission is obtaining indicators of nodes in the network of special-purpose parameters from the received IP packets such as information transmission rate, time of packet transmission to the destination node, node battery charge level, IP packet delivery reliability.

The indicator of information transmission rate $P_{speed}$ is the minimum speed of radio communication among nodes from the whole route, so

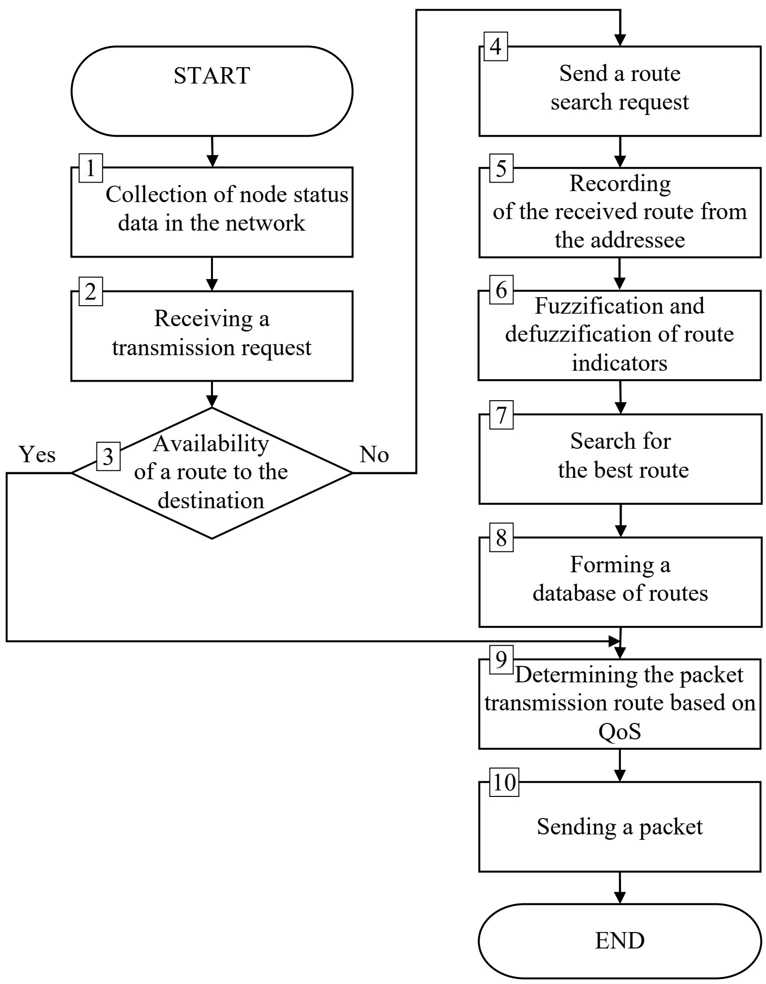


Fig. 2. Description of the routing procedure in military networks with the possibility of self-organization

$$P_{speed} = \min V_{ij_{speed}}, \quad (12)$$

where $V_{ij}$ is the node involved in the transmission of the packet on the route *ij*.

The battery charge indicator also determines the minimum battery charge on the node that is involved in the route

$$P_{power} = \min V_{ij_{pover}}. \quad (13)$$

The packet delivery delay is the sum of the IP packet delivery time of all intermediate nodes and thus shows the time of packet delivery to the destination node on the route as a whole

$$P_{delay} = \sum_{i=1}^{N} V_{i_{delay}}. \quad (14)$$

The indicator of IP packet transmission reliability is the probabilistic indicator of packet transmission along the entire route

$$P_{reliability} = \prod_{i=1}^{N} V_{i_{reliability}}. \quad (15)$$

Layer 2. The process of fuzzification for the transition from a clear value of parameters to a fuzzy value of some linguistic variable. To achieve the adaptability of the routing protocol to changes in the network, the minimum and maximum values of the parameters of the database state of the nodes are taken into account.

$$\xi_{ij_{speed}} = S(i,j,t),$$

where

$$0 \le q \le 1, \quad 0 = \min P_{speed}, \quad 1 = \max P_{speed}, \quad (16)$$

$$\xi_{ij_{power}} = P(i,j),$$

where

$$0 \le q \le 1, \quad 0 = \min P_{power}, \quad 1 = \max P_{power}, \quad (17)$$

$$\xi_{ij_{delay}} = S(i,j,t),$$

The dynamic routing protocol of DSR was taken as a basis in the specified work [30].

MDSR unlike standard DSR has been designed to support traffic priority (QoS). MDSR uses IPv6, which significantly increases the address space, and while building a network allows you not to use DHCP to automatically assign IP addresses or manually configure the IP address. The use of IPv6 in modern conditions allows the rapid deployment of a special-purpose network.

where

$$0 \le q \le 1,\ \ 0 = \min P_{delay},\ \ 1 = \max P_{delay}, \tag{18}$$

$$\xi_{ij_{reliability}} = S(i, j, t),$$

where

$$0 \le q \le 1,\ \ 0 = \min P_{reliability},\ \ 1 = \max P_{reliability}. \tag{19}$$

Each node of this layer represents one term of the membership function. Membership functions for all four parameters are constructed according to the equations:

$$\mu_{Low}(x) = \max\left(0, \min\left(1, \frac{\Delta - x}{\Delta}\right)\right), \tag{20}$$

the membership function determines the weak and medium values of the parameter

$$\mu(k,x) = \max\left[0, \min\left[\frac{x - \Delta\cdot(k-1)}{\Delta}, \frac{\Delta\cdot(k+1) - x}{\Delta}\right]\right], \tag{21}$$

the membership function that determines the high value of the parameter

$$\mu_{High}(x) = \min\left(1, \max\left(0, \frac{x - (N-1)\Delta}{\Delta}\right)\right), \tag{22}$$

where $N$=3, $\Delta = \frac{1}{N}$, $\mu(1,x) \equiv \mu_{Weak}(x)$, $\mu(2,x) \equiv \mu_{Medium}(x)$.

The construction of membership functions that determine the overall metric of the route is the level of pheromones that the ant will leave after each pass, will look like:

$$\mu_{Ph1}(x) = \max\left(0, \min\left(1, \frac{\Delta - x}{\Delta}\right)\right), \tag{23}$$

$$\mu(k,x) = \max\left[0, \min\left[\frac{x - \Delta\cdot(k-1)}{\Delta}, \frac{\Delta\cdot(k+1) - x}{\Delta}\right]\right], \tag{24}$$

$$\mu_{Ph13}(x) = \min\left(1, \max\left(0, \frac{x - (N-1)\Delta}{\Delta}\right)\right), \tag{25}$$

де $N$=12;

$$\Delta = \frac{1}{N};\ \ \mu(1,x) \equiv \mu_{ph2}(x),\ \ \mu(2,x) \equiv \mu_{Ph3}(x),$$

$$\mu(3,x) \equiv \mu_{Ph4}(x),\ \ \mu(4,x) \equiv \mu_{ph5}(x),\ \ \mu(5,x) \equiv \mu_{ph6}(x),$$

$$\mu(6,x) \equiv \mu_{ph7}(x),\ \ \mu(7,x) \equiv \mu_{ph8}(x),\ \ \mu(8,x) \equiv \mu_{ph9}(x),$$

$$\mu(9,x) \equiv \mu_{ph10}(x),\ \ \mu(10,x) \equiv \mu_{ph11}(x),\ \ \mu(11,x) \equiv \mu_{ph12}(x),$$

$$\mu(12,x) \equiv \mu_{ph13}(x)$$

are the pheromone level functions.

*Layer 3.* Each fuzzy system is implemented in the form of fuzzy rules. Fuzzy rules perform logical "yes" or "or" operations. This network layer has the number of nodes corresponding to the number of "and" operations. So for a complete search of 4 parameters, each of which has 4 terms, you need 256 neurons that correspond to all possible variations of the terms of the parameters.

if $P_{speed}$ is $A_x$ and $P_{power}$ is $B_x$ and
$P_{delay}$ $C_x$ and $P_{reliability}$ $D_x$ so, (26)

where $A_x$, $B_x$, $C_x$, $D_x$ are the membership functions that are defined according to $P_{speed}$, $P_{power}$, $P_{delay}$, $P_{reliability}$. That is, at the input of the neuron of the third layer will have the form:

If $I_1$ is *Low* and $I_2$ is *Low* and
$I_3$ is *High* and $I_4$ is *Low* then. (27)

At the output of the neuron of the third layer, the aggregation of the preconditions of fuzzy rules is carried out and is determined by the expression, which is a logical conjunction, if $\mu_g = \mu(P_{speed} \cap P_{power} \cap P_{delay} \cap P_{reliability})$, then:

$$\mu_g = \min\{\mu(P_{speed}), \mu(P_{power}), \mu(P_{delay}), \mu(P_{reliability})\}. \tag{28}$$

*Layer 4.* Activation of the inference of the fuzzy rule is carried out. At the fourth level, a specific output is determined on each of the corresponding input combinations that were at the input. So, for example, the neuron of the fourth layer will look like

*If* $I_1$ is *Low* and $I_2$ is *Low* and
$I_3$ is *High* and $I_4$ is *Low* then $O$ is *Ph*1.

*Layer 5.* The fuzzy result, which is the result of inference, is converted into a real value that can be used as a control input. Since the desired output is an indistinct result, the quantitative value of the control output is determined by defuzzification. The procedure uses the center of gravity method. The definition of the center of gravity is calculated by expression

$$y = \frac{\int_{\min}^{\max} x_i \cdot \mu(x) \cdot dx}{\int_{\min}^{\max} \mu(x) \cdot dx}, \tag{29}$$

where $y$ is the result of defuzzification, $x$ is the initial linguistic variable ω, $\mu(x)$ is the membership function of the fuzzy set that corresponds to the original variable ω after the accumulation step, min, max are the right and left point of the interval of the carrier of the fuzzy set of the output variable ω.

Layer 6. The function of neuronal activation is often a continuous and nonlinear function, which is called sigmoid function and is defined as

$$f(x) = \frac{1}{1 + \exp(ax^2)}, \tag{30}$$

where $a$ is the constant and $a \ge 0$.

The route search procedure based on fuzzy logic and an ant colony system has the following steps:

*Step 1. Initialization.* It consists of the initial values of the algorithm parameters, such as the number of ants, pheromone evaporation rate, data rate, battery charge, packet transmission time, packet transmission reliability.

*Step 2. Initial exposure of ants.* At this stage, the ants are located at the starting points from which the iteration will take place. Active ant refers to an ant that has not yet arrived at its destination and is not blocked at the tops (nodes). Because each ant can pass each vertex (node) once in each iteration, the ant is blocked at the junction when it has no chance to continue transition to its destination and has no possible way to move back.

*Step 3. Construction of probable routes.* At this stage, the probability of each possible direct route is calculated based on its cost function for each active ant. The probabilistic transition of ants among nodes can also be specified as a node transition rule. The probability of transition of the $k$-th ant from node $i$ to node $j$ is given by:

$$P_{ij}^{k}=\begin{cases}\dfrac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{h\notin tabu_k}(\tau_{ih})^{\alpha}(\eta_{ih})^{\beta}} & j\notin tabu_k,\\ 0, & \text{otherwise,}\end{cases} \quad (31)$$

where $\tau_{ij}$ and $\eta_{ij}$ are the pheromone intensity and cost of the route between nodes $i$ and $j$, respectively. The relative values $\tau_{ij}$ and $\eta_{ij}$ are controlled by the parameters $\alpha$ and $\beta$ respectively. $tabu_k$ is the list of unavailable routes (visited nodes) for the ant $k$.

*Step 4. Selection of a route.* The random parameter $0\le q\le 1$ with the same probability is compared with the parameter $Q$, where $0\le Q\le 1$. The result of the comparison between $Q$ and $q$ takes one of two methods to select the active ant route of the next transition as follows:

$$j=\begin{cases}\arg\ \max\left(p_{ih}^{k}\right) & q>Q,\\ \text{roulette wheel}\ \left(p_{ih}^{k}\right) & \text{otherwise.}\end{cases} \quad (32)$$

If $q$ is larger than $Q$, the active ant chooses the route with the highest probability, otherwise the roulette wheel rule is selected to select the next transition through the probabilities.

*Step 5. Updating of the taboo list.* At this stage, the route (selected node) that was selected by the ant $k$ is added to the list in the table. This direction will not be re-selected and its probability is no longer calculated.

If the ant $k$ has reached its destination or has been blocked at the top (node), this step deactivates the ant blocked or arrived in the current iteration.

*Step 6. Updating of the pheromone.* The ACS pheromone system consists of two basic rules: the first is applied while building solutions (local pheromone update rule), and the second rule is applied after all the ants have finished building the solution (global pheromone update rule). The sum of the pheromones of the route between the transitions $i$ and $j$ is updated for the $k$-th ant as:

$$\tau_{ij}^{new}=\tau_{ij}^{old}+(10\times\Delta\tau), \quad (33)$$

where $\Delta\tau$ is the number of local pheromone update. The value $\Delta\tau$ is the FL inference system.

The temporary route cache contains the routing information required for the node. The knowledge base stores all studied routes with indicators of residual battery charge, data transmission rate, route delay time, route reliability, route load and number of relays (hops). The database is populated by studying route information from data packets and route request packets.

Based on the knowledge base, a routing table is formed.

The cost of the route is formed using fuzzy logic, using a modified algorithm of ant colonies, the search for the best route is performed, and then the found routes are recorded in the routing table. No more than four available routes are recorded in the routing table. In case of exceeding the number of routes to the destination node, the best four routes are selected by ranking. The presence of several routes in the routing table allows you to balance the load of routes.

6. Selection of the operating mode.

It is proposed to use the energy and frequency component of the use of system resources (their efficiency) to select the operating mode of the RCD. The boundaries between energy and frequency efficiency do not meet the requirements for changing the operating mode, so to clarify it is proposed to introduce an additional indicator, namely the importance of the radioelectronic environment (REE).

Convolution of partial quality criteria to general is carried out using a certain scheme of compromises, which determines the specific principle of optimality

$$F_{opt}=\max F(\mathrm{Im},\beta_E,C), \quad (35)$$

where $F_{opt}$ is the radio communication device mode, Im is the coefficient of importance of the electronic environment.

According to [13–16, 21], the importance of REE indicators can be considered as a non-metric criterion of usefulness (NCU).

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 Ultra-Wideband Signal);

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

Non-metric partial utility criteria (NPUC), which should characterize the operating mode is the frequency efficiency of RCD ($\beta_F$); bandwidth, the degree of use of radio frequency resources by the RCS devices. We present the main NPUC using quantitative characteristics (Table 3).

Table 3

NPUC for selection of the RCD operating mode

| NPUC | Quantitative characteristics of the indicator | Areas of change in indicators | Indicators taken into account while determining the importance of REE |
|---|---|---|---|
| $\beta_E$ | Energy efficiency of the RCD | 0.1–0.4 | MIMO-OFDM |
| | | 0.401–0.79 | MIMO-UWB |
| | | 0.801–1.0 | MIMO- FHSS |
| $C$ | Bandwidth | 0.81–1.0 | MIMO-OFDM |
| | | 0.41–0.79 | MIMO-UWB |
| | | 0.1–0.4 | MIMO-FHSS |
| $X_{RES}$ | Degree of use of radio frequency resources by the RES devices | 0.1–0.8 | Interference in part of the lane |
| | | 0.801–1 | Obstructive barriers |
| Im | REE importance | 0.1–0.4 | Low |
| | | 0.401–0.79 | Middle |
| | | 0.801–1.0 | High |

7. Selection of signal parameters for the operating mode.

For each of the modes, rational values of the signal parameters, where the initial input of the RCD and the communication channel parameters, rational values of the parameters for each of the modes are selected, as indicated in [25, 26].

## 6. Discussion of the results of developing the method for adaptive control of military radio network parameters

It is proposed to use the method of adaptive control of military radio network parameters. The simulation of the proposed method was carried out in the Mathcad and MathCad 2014 software environment. Evaluation of the method was carried out using simulation and measuring tools that simulated the RES.

Simulation of channel resources management was performed with the following parameters:

– radio communication devices with the pseudo-random tuning of the operating frequency (PTOF): frequency range is 30–512 MHz; transmitter power is 10 W; radiated frequency bandwidth – 12.5 kHz, receiver sensitivity – 110 dB; the number of PTOF in the network – 4; the number of frequency channels for reconfiguration – 10,000; the amount of adjustment – 333.5 jumps/sec;

– the number of radioelectronic suppression complexes (RSC) is 4; frequency range is 30–2,000 MHz; transmitter power is 2,000 W; maximum frequency band that can be suppressed is 80 MHz; the number of radio lines with PTOF that can be suppressed at the same time is 4, the type of interference is the noise obstruction with frequency manipulation, as one of the most common and the impact of which is well known; the strategy of the RSC complex is dynamic.

4 programmable LimeSDR transceivers (USA) with GNU radio software (Germany) were connected to the PC and the RIGOL DG5252 noise generator (Germany), which simulated the operation of the RES complex.

To test the effectiveness of the proposed method, we assume that the operating time of the programmable radio communication device with the PTOF on the same frequency is the same as the RES complex.

At this stage of efficiency evaluation, only the effectiveness of the improved channel-level resource management procedures of the developed method is evaluated, namely the improved procedure for selecting operating frequencies and the advanced procedure for forecasting the electronic environment and the improved procedure for selecting the radio communication mode.

Fig. 3, 4 were obtained by averaging the signal-to-noise ratio on the frequency subchannels.

This advantage is the greater accuracy of estimating the signal-to-noise ratio in the frequency subchannels due to the use of advanced procedures for estimating the electronic environment, the use of the procedure for predicting the law of interference (Fig. 3, 4). This means that the optimal operating frequencies were selected according to the criterion of maximum throughput (which were not suppressed), the optimal signal-code design and operating mode were selected.

Fig. 4 shows the graph of the dependence of the bit error probability on the signal-to-noise ratio (for the case of noise interference in the part of the band with frequency manipulation ρ=0.5).

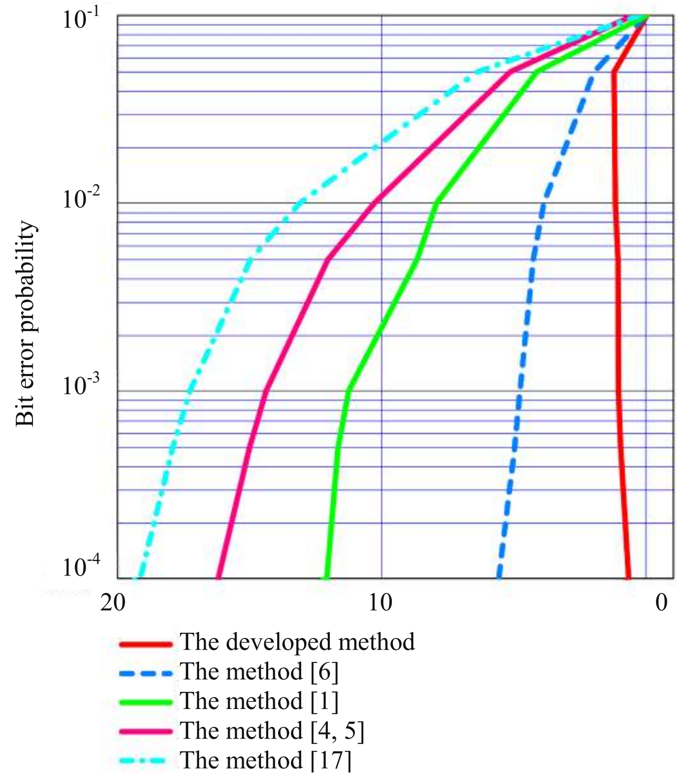


Fig. 3. Dependence of the bit error probability on the signal-to-noise ratio for different methods under the influence of fluctuation noise and noise barrier with an overlap coefficient ρ=1

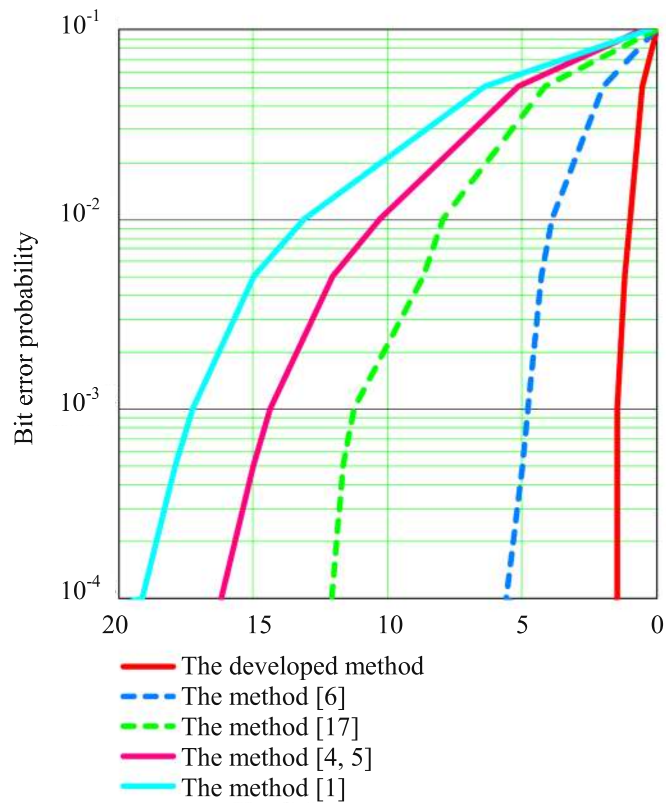


Fig. 4. Graph of the dependence of the bit error probability on the signal-to-noise ratio (for the case of noise interference in the part of the band with frequency manipulation with the overlap coefficient ρ=0.5)

Thus, as can be seen from Fig. 4, the gain in energy terms due to advanced procedures averages a bit error probability of $10^{-3}$ to 3 dB. It should be noted that the bit error probability of $10^{-3}$ is critical for most radio communication devices and in fact leads to disorganization of control and communication systems.

In the following steps, improved channel resource management procedures were not used.

Modeling of network resources management was carried out in the following conditions (Fig. 5–10):

– the number of nodes is 50, the routes are built among 10, 20 and 30 randomly selected pairs of nodes;

– packet size is $ln$=512 bytes, channel access protocol IEEE 802.11, node speed is $\omega$=0...20 m/s;

– the size of the queue at the node is 64 packets, the waiting time of the packet in the queue is $t_{wait}$<30 sec, baud rate in the radio channel is $r$=1 Mbit/s, the traffic type is data $\xi$=3 (Fig. 5–10).

Evaluation of the computational complexity of the developed algorithm showed that for a given source data and using the processor ADSP-21261 (USA), control of channel and network resources of the radio system can be carried out in real time. It takes into account the delay required to transmit information about these values through the feedback service channel.

An advantage in the range of 10–16 % was obtained during the operational control of the current state and noise situation in the channels that are occupied for transmission, for a time comparable to the duration of the information exchange cycle. The ambiguity in determining the state of the channels is caused by different parameters of the received signal, due to different trajectories of the signal and signal/noise levels in the subchannels.

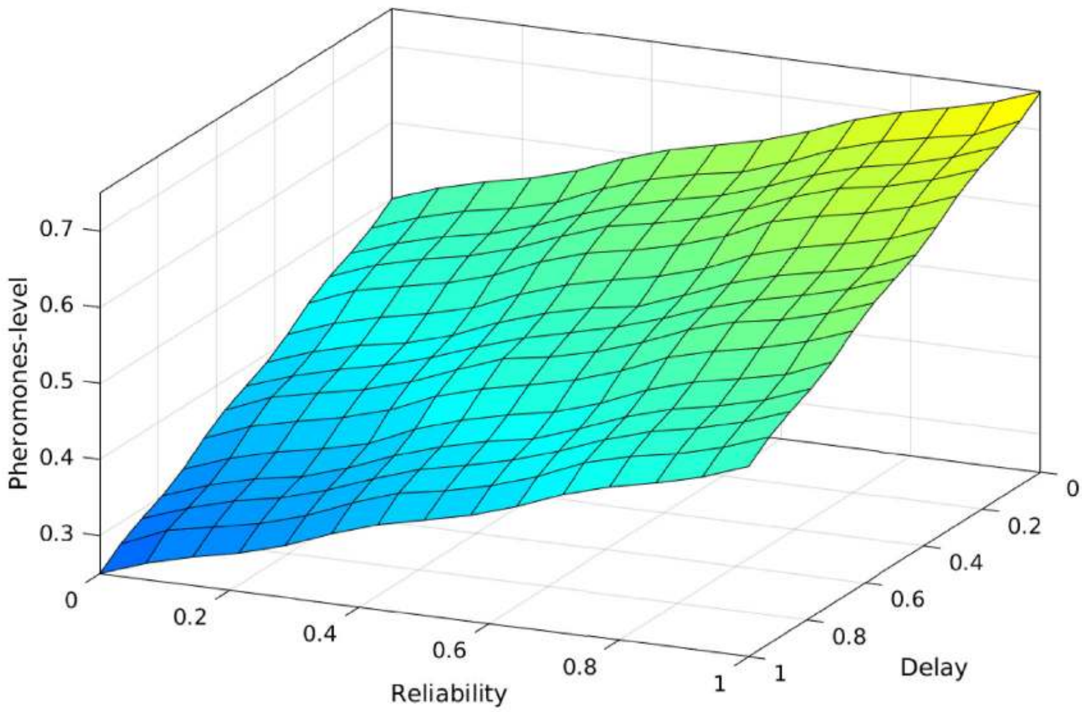


Fig. 5. Graph of the dependence of the pheromone level on the time of packet delivery to the recipient to the packet delivery reliability

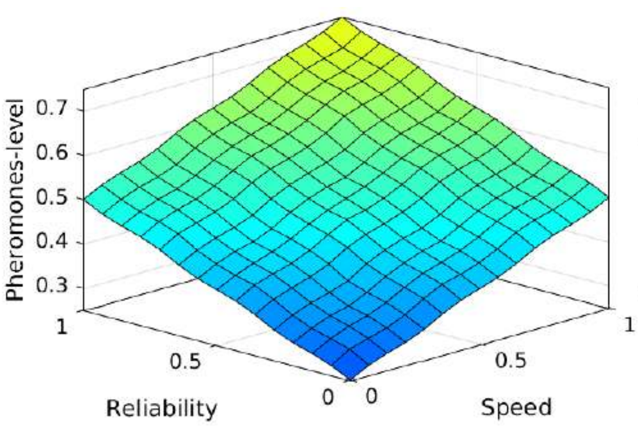


Fig. 6. Graph of the dependence of the pheromone level on the data rate to the packet delivery reliability

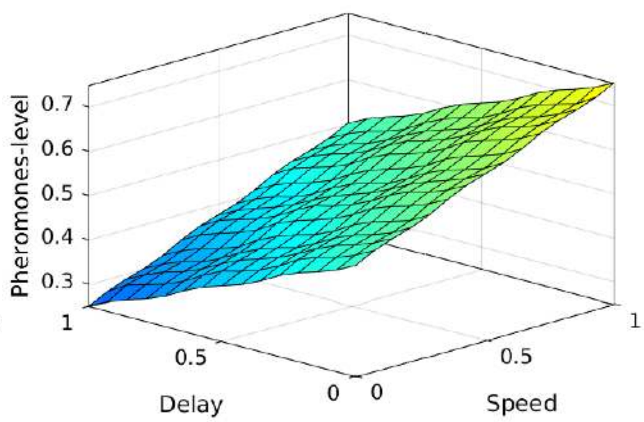


Fig. 7. Graph of the dependence of the pheromone level on the data rate to the packet delivery time

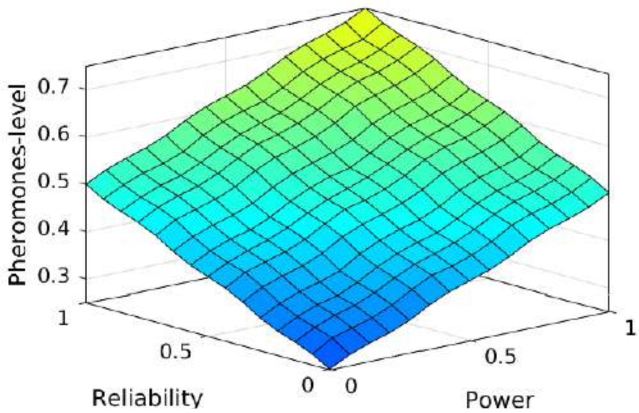


Fig. 8. Graph of the reliability of the packet delivery to the battery level

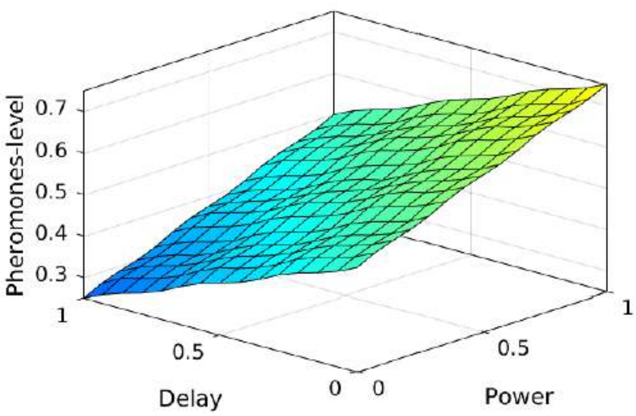


Fig. 9. Graph of the dependence of the pheromone level on the delivery time of the destination packet to the battery level

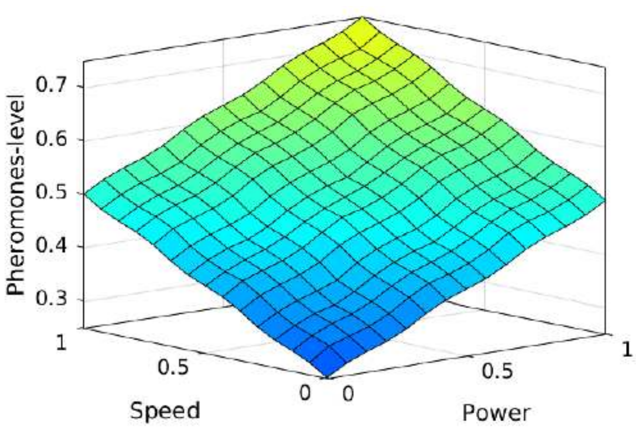


Fig. 10. Graph of the dependence of the pheromone level on the data rate to the battery level

The main advantages of the proposed method are:

– unambiguity of the obtained results;

– forecasting the state of the radioelectronic environment;

– reduction of time of package delivery to users;

– wide scope of use (data transmission systems, civil and special-purpose radio communication systems);

– simplicity of mathematical calculations;

– ability to adapt the system during the operation;

– possibility of synthesizing the optimal structure of the decision support system;

– increase in the efficiency of radio frequency resource use;

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

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

– ability to work at low signal/noise ratios in the channel;

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

– ability to determine the optimal location of radio communications, taking into account the zones of electronic suppression;

– ability to determine the optimal route for information transmission, taking into account the zones of electronic suppression;

– ability to determine the optimal operating mode of the radio to maximize the radio bandwidth;

The disadvantages of the proposed method include:

– loss of informativeness in the assessment (forecasting) due to the construction of the membership function during the procedures of fuzzification/defuzzification of the input parameters (transition from clear to fuzzy evaluation and vice versa). This loss of informativeness can be reduced by choosing the type of membership function and its parameters in the practical implementation of the proposed method. The choice of the type of membership function depends on the computing resources of a particular electronic computing device;

– lower accuracy of assessment on a single parameter of condition assessment;

– loss of results accuracy during the restructuring of the architecture of the artificial neural network.

This research is a further development of research conducted by the authors, aimed at developing the theoretical foundations for improving the efficiency of military radio systems published earlier [1, 2, 17, 18, 20, 27–32].

Areas of further research should be aimed at reducing computational costs in the processing of various data types in special-purpose systems.

## 7. Conclusions

1. The problem of channel and network resources management is set. This formalization allows us to describe the processes that take place at each level of the military radio network. In the course of setting the problem of managing channel and network resources, a description of the processes occurring in military radio communication systems was made. The bandwidth of the military radio communication system was chosen as a criterion for the effectiveness of this method.

2. It is proposed to use the method of adaptive control of military radio network parameters, which realizes:

– the choice of operating frequencies of radio communication devices taking into account the strategy of electronic warfare;

– rational network topology. The procedure for selecting the topology of the military radio communication system is based on the method of an ant multi-colony system. The main idea of the new option of ant colony optimization is that instead of one colony of the traditional ant algorithm, several colonies are used that work together in a common search space. Thus, each colony on the basis of the mechanism of a stigmergy solves the subtask, forming the part in the joint decision. However, this procedure additionally takes into account the type of a priori uncertainty and the evaporation coefficient of the level of pheromones;

– rational route of information transmission. The proposed procedure is based on an improved DSR algorithm;

– the operating mode of radio communication devices taking into account the capacity of the military radio communication system.

This is achieved through improved procedures for controlling the parameters of military radio networks.

3. The gain in the range of 10–16 % was obtained during the operational control of the current state and noise situation in the channels occupied for transmission, for a time comparable to the duration of the information exchange cycle. The ambiguity in determining the state of the channels is caused by different parameters of the received signal, due to different trajectories of the signal and signal/noise levels in the subchannels.

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