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DEVELOPMENT OF METHODOLOGICAL PRINCIPLES OF ROUTING IN NETWORKS OF SPECIAL COMMUNICATION IN THE CONDITIONS OF FIRE DAMAGE AND RADIO ELECTRONIC FLOW

The object of research is a system of special communication. Decision making support systems (DMSS) are actively used in all spheres of human life. They are especially common in the processing of large data sets, forecasting processes, providing information support in the decision-making process by decision-makers. Systems of analysis of information transmission in special purpose radio communication systems are no exception. However, there are a number of problems in the transmission of information, namely: the transmission of information takes place in a complex electronic environment against the background of intentional and natural interference; elements of the radio communication system are the objects of primary fire damage due to high radio visibility for radio intelligence. The best solution in this situation is to integrate with the data of the information system analysis of the electronic environment, artificial neural networks and the ant algorithm. Their advantage is also the ability to work in real time and quickly adapt to specific situations. Therefore, in this paper the methodological principles of routing in special communication networks in the conditions of fire damage and electronic suppression are developed.

Improving the efficiency of information processing (reducing error) evaluation is achieved through the use of evolving neuro-fuzzy artificial neural networks; learning not only the synaptic weights of the artificial neural network, but also the type and parameters of the membership function. Efficiency of information processing is also achieved through training in the architecture of artificial neural networks; taking into account the type of uncertainty of the information to be assessed; synthesis of rational structure of fuzzy cognitive model. It reduces the computational complexity of decision-making; absence of accumulation of an error of training of artificial neural networks as a result of processing of the information arriving on an input of artificial neural networks. The approbation of the use of the offered technique on the example of the estimation of information transfer in the conditions of influence of destabilizing factors is carried out. This example showed an increase in the efficiency of evaluation at the level of 15–25 % on the efficiency of information processing.

Keywords: artificial intelligence, electronic environment, intelligent systems, decision making support systems.

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1. Introduction

Decision making support systems (DMSS) are actively used in all spheres of human life [1–3]. The creation of intelligent DMSS has become a natural continuation of the widespread use of the classical type DMSS. Intelligent DMSS have been widely used to solve specific tasks of military purpose, namely [4, 5]:

- planning the deployment, operation of communication systems and data transmission;
- automation of troops and weapons control;
- data collection, processing and generalization, etc.

In this work, let's limit ourselves to a narrow issue, namely the choice of a rational route for the information transmission in DMSS of special radio networks in destabilizing conditions.

The analysis of works [6–8] showed that the transmission of information between nodes of special radio networks raises a number of problematic issues, namely:

1. The transmission of information takes place in a complex electronic environment against the background of intentional and natural interference.
2. Elements of the radio communication system are objects of primary fire damage due to high radio visibility for radio reconnaissance devices.
3. High dynamics of changes in the electronic situation during the military conflict.
4. High ephemerality of hostilities (operations).
5. Limited energy life of radio batteries.
6. Presence of cyber attacks on elements of radio communication systems.

These circumstances lead to the search for new scientific approaches and technological solutions that will allow:

- to ensure guaranteed delivery of messages between nodes of the radio network with a given quality;
- to build alternative routes of information transfer during suppression;
- to take into account the impact of intentional and natural interference in the transmission of messages between subscribers of the radio network;
- to take into account the impact of fire damage and cyber attacks on the radio communication system.

Thus, *the object of the research* is a system of special communication.

The aim of the research is to increase the efficiency of information transfer in special communication networks operating under the influence of destabilizing factors.

2. Research methodology

In the course of the research, evolutionary algorithms and evolving artificial neural networks were used to solve the problem of analyzing the electronic environment, choosing a rational route for transmitting information and adjusting knowledge bases. This research also used the method of training artificial neural networks developed in previous works [4, 9], which allows for in-depth training of artificial neural networks. The essence of deep learning is to teach the architecture, type and parameters of the membership function. Also, in this research let's use methods of multidimensional description of the electronic environment, which was developed earlier. The simulation was performed using MathCad 2014 software and an Intel Core i3 personal computer.

3. Research results and discussion

3.1. Mathematical statement of the problem of information transfer in the conditions of destabilizing influences on the radio communication system. To describe the mathematical model of a special purpose radio network, let's introduce the necessary notation. Let $N = \{1, 2, \dots, n\}$ be nodes of a special purpose radio network. For node with number i let's consider known (predicted) the delay of information transmission on the node of the radio network $r_i(t)$ at time $t = 1, 2, \dots, T$, which corresponds to a specific time delay of information transmission. The delay is due to the influence of destabilizing factors (fire damage to network nodes, cyber attacks and electronic suppression).

The values of the delay time of information transmission on a specific node of a special purpose radio network are calculated directly by analyzing the available statistical information, etc. Let's consider that the limits of z_i^{\min} and z_i^{\max} of the maximum allowable delay of information transmission on a specific node of a special purpose radio network are known. Also known are the limits a_i and b_i of the possible decrease and increase of this time during the unit of measurement as a percentage of the total time. Let's denote the planned location of the message packet on the node i at time t through $z_i(t)$ which must meet the conditions:

$$z_i^{\min} < a_i z_i(t) < z_i(t+1) < b_i z_i(t) < z_i^{\max}. \quad (1)$$

Let's denote by $x_{ij}(t)$ the maximum allowable amount of information transmitted from node i to node j at time t

through the radio network with restrictions on the bandwidth of radio channels by the bandwidth of radio lines:

$$0 < x_{ij}(t) < x_{ij}^{\max}. \quad (2)$$

Let's assume that the node and the radio network at time t are influenced by a certain part of the destabilizing factors of the volume $y_i(t)$, which affects the efficiency of information circulation in the radio network. Then the estimated delay of information transmission in the radio network node must meet the requirements:

$$\begin{aligned} z_i(t) + \sum_j k_{ji} x_{ji}(t) - \sum_j x_{ji}(t) &= r_i(t) + y_i(t), \\ z_i(T+1) &= z_i. \end{aligned} \quad (3)$$

In the conditions (3), the coefficients k_{ji} determine the percentage of reduction in the efficiency of information transmission on the radio line $i-j$. The last equality corresponds to periodic (cyclic) processes with the length of the period $T = (\tau_i, \tau_p)$, where the duration of messages is τ_i , pauses after them are τ_p .

As a criterion for the effectiveness of the special purpose radio communication system, it is possible to take the total time delays associated with the transfer of information from node l to node z during the observation period under the influence of destabilizing factors:

$$t(1, z) < T, S(1, z) \rightarrow \min, \quad (4)$$

where t is the function of time on the route $1-z$; S is the total delay time of the transmission of information on the route.

The dynamic model proposed in the research in the form of (1)–(4) corresponds to the problem of optimizing the route of information transmission in the radio network. This task can be attributed to the types of dynamic routing tasks with periodic values of vertices and nodes that change as a result of destabilizing factors.

Given the above, it is necessary to create methods (techniques) of routing that must meet the following set of requirements:

- the ability to aggregate heterogeneous indicators (both quantitative and qualitative) of evaluation and selection of solutions that differ in measurement scales and ranges of values;
- taking into account the compatibility and different significance of partial indicators in the generalized evaluation of decisions;
- flexible adjustment (adaptation) of evaluation models while adding (excluding) indicators and changing their parameters (compatibility and significance of indicators);
- high efficiency of decision-making in conditions of uncertainty.

3.2. Development of a routing method in special purpose radio communication networks. The method of routing in special purpose radio networks based on the ant algorithm consists of the following sequence of actions:

Step 1. Initialization. At this stage, the radio communication system is represented as a directional graph. Initialization consists of the initial values of the algorithm parameters, such as the number of ants, pheromone evaporation rate, information transfer rate, battery charge, packet transmission time, packet transmission reliability and information transmission delay time. During the delay,

the influence of destabilizing factors is taken into account. This step also takes into account the type of uncertainty about the electronic environment and the set of destabilizing factors based on available intelligence.

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 its transition to its destination and has no possible way to move back. 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 its 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 between nodes can also be set as a rule of transition of the node. The probability of transition of the k -th ant from node i to node j is set:

$$P_{ij}^k = \begin{cases} \frac{(\tau_{ij})^\alpha (\eta_{ij})^\beta}{\sum_{h \in \text{tabu}_k} (\tau_{ih})^\alpha (\eta_{ih})^\beta} & j \notin \text{tabu}_k, \\ 0, & \text{otherwise,} \end{cases} \quad (5)$$

where τ_{ij} and η_{ij} is the intensity of pheromones and the cost of the route between nodes i and j , respectively. The relative values of τ_{ij} and η_{ij} are controlled by the parameters α and β , respectively tabu_k is a list of inaccessible routes (visited nodes) for the ant k . Unacceptable routes are calculated according to the ellipses of suppression of the radio communication system by the devices of radio electronic suppression, separation from the devices of fire influence on the radio communication system.

Step 4. Select a route. The random parameter $0 \leq q \leq 1$ with the same probability is compared with the parameter Q , where $0 \leq Q \leq 1$:

$$j = \begin{cases} \arg \max(p_{ih}^k) & q > Q, \\ \text{roulette wheel } (p_{ih}^k) & \text{otherwise.} \end{cases} \quad (6)$$

If q is bigger than Q , the active ant chooses the route with the highest probability, otherwise the roulette wheel rule is chosen to select the next probability transition.

Step 5. Update the Tabu list. At this stage, the route (selected node), which 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 ant k has reached its destination or has been blocked at the top (node), this step deactivates the blocked or arrived in the current iteration of the ant.

Step 6. Pheromone update. The pheromone system in the ant algorithm consists of two basic rules: first it is used while building solutions (local pheromone update rule), and the second rule is applied after all ants have finished building a 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:

$$\tau_{ij}^{new} = \tau_{ij}^{old} + (10 \cdot \Delta\tau), \quad (7)$$

where $\Delta\tau$ is the amount of local pheromone renewal. The value of $\Delta\tau$ is the original system of fuzzy logic, developed by the authors of the work [4].

The fuzzy logic inputs are «baud rate», «battery charge», «packet delivery time», «packet delivery reliability», «bit error probability» in the direction chosen by the k -th ant. Considering computational difficulties, only four fuzzy input sets are defined for each input are «Low», «Weak», «Medium» and «High». Thirteen fuzzy sets are considered for the original variable. At the final stage, defuzzification of methods, in this system of fuzzy logic the method of «center of gravity» is used to solve one initial value from a fuzzy set. Therefore, areas with higher rates allow achieving greater local renewal of pheromones.

Step 7. Global pheromone update. It occurs by the expression:

$$\tau_{ij}^{new} = \rho \tau_{ij}^{old}, \quad (8)$$

where $0 \leq \rho \leq 1$ is the evaporation rate and is usually set at 0.9.

Step 8. Creating a database of routes. The route database includes the following components: temporary route cache, route knowledge base, routing table.

The temporary route cache contains the routing information required for the node. A node adds information to the route cache as it explores new connections between nodes on the radio network. For example, the node may examine the source route received from the route request packets of the route response packets. The node also removes from the route cache those connections between nodes on the radio network that have broken connections. For example, a node may learn of a broken link by receiving a packet containing route error information or through the OSI layer model link layer retransmission mechanism by obtaining a transmission error while transmitting a frame to the next jump node. Each time a node adds information to the route cache, the node checks its cache for a route to the destination address in the cache if such a route exists, the node sends a packet on that route and is removed from the send cache. This will allow using the network with other external networks. The knowledge base stores all studied routes with indicators of residual battery charge, data transfer rate, delay time on the route, route reliability, route load and the 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 the modified ant colony algorithm, the best route is searched, 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. Having multiple routes in the routing table allows to balance the congestion of routes.

Step 9. Determining the packet transmission route taking into account the quality of service. The decision-making system for sending IP packets based on the available routes in the route database decides on sending the IP packet by the appropriate route to the destination node based on QoS. The direction decision-making system uses and performs steps in accordance with the method of predicting

the time of congestion of data transmission routes in networks with the possibility of self-organization, which is presented in the works [4, 5].

Step 10. Write the IP packet to the source IP packet cache, waiting for the packet to be sent and the connection available in the OSI channel layer protocol.

3.3. Modeling results and discussion of them. Simulations were performed with the following parameters:

- devices of radio communication with pseudo-random adjustment of the operating frequency (PRAOF): frequency range is 30–512 MHz; transmitter power is 10 W; radiated frequency band width is 12.5 kHz, receiver sensitivity is 120 dB; the number of radio devices in the network is 5; the number of frequency channels for reconfiguration is 10000; the number of adjustments is from 333.5 to 1000 jumps/sec;
- the number of radio electronic suppression (RES) complexes is 2; frequency range is 30–2000 MHz; transmitter power is 2000 W; the maximum frequency band that can be suppressed at the same time is 80 MHz, the type of interference is noise interference with frequency manipulation, as one of the most common and whose effect is well known; the strategy of the RES complex is dynamic.

4 programmable LimeSDR transceivers (USA) with GNU Radio software (Germany) were connected to the PC and connected to the RIGOL DG5252 noise generator (Germany), which simulated the operation of the RES complex (Fig. 1).

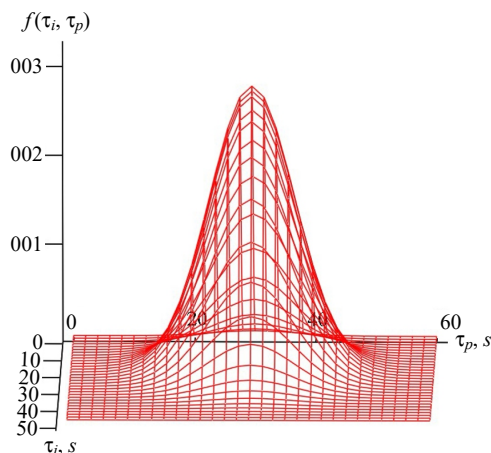


Fig. 1. Dependences of message duration on the reaction time of the RES complex

Analysis of the obtained dependences (Fig. 1) shows that the value $f(\tilde{\tau}_i, \tilde{\tau}_p)$ (Fig. 1, a) is less than the threshold value. Therefore, in this case, the decision is made mainly on the basis of analysis of changes in the duration of the message, which was affected by interference ($\tilde{\tau}_i$), and the pause after it ($\tilde{\tau}_p$).

To demonstrate the effectiveness of evolving artificial neural network learning, a forecast of the network's temporal security was made. The evolving artificial neural network was used directly to train the knowledge bases of the ant algorithm. A training sample containing data on the monitored object was used for the experiment. 5,000 observations from this sample were used for the experiments. The training sample contained 3,000 observations, the test sample contained 2,000 observations.

The square root of the root mean square error was used as a criterion for the quality of forecasting.

The multilayer perceptron (MLP), radial basis neural network (RBNN), and evolving artificial neural network were used to compare the quality of the prediction.

The forecasting results for different systems are presented in Table 1.

Table 1
Forecasting results for different systems

System name	Number of customizable parameters	RMSE (teaching)	RMSE (test)	Time, s
Multilayer perceptron	51	0.1058	0.1407	0.1081
Radial-base neural network	21	0.1066	0.2155	0.1081
Evolving cascade system with neo-phase nodes	20	0.0784	0.1081	0.1081

These results can be seen from the results in the last terms of Table 1 as the difference of the Xi-Beni index.

The main advantages of the proposed assessment methodology are:

- flexible hierarchical structure of indicators, which allows to reduce the task of multi-criteria evaluation of alternatives to one criterion or to use a vector of indicators for selection;
- unambiguity of the received estimation of a condition of an information route transfer;
- wide scope of use (decision making support systems);
- simplicity of mathematical calculations;
- it does not accumulate a learning error;
- the ability to adapt the system of indicators in the course of work;
- learning not only the synaptic weights of the artificial neural network, but also the type and parameters of the membership function;
- learning the architecture of artificial neural networks;
- calculation of data for one epoch without the need to store previous calculations;
- ease of adaptation to work in dynamic applications;
- it relies on the memory of the whole colony instead of the memory of the previous generation.

It should be noted that the proposed training procedure showed a better result in terms of PC (partition coefficient) in comparison with EFCM (evolving fuzzy clustering method) and a better result in terms of time compared to FCM (Fuzzy Classifier Means). The research showed that this learning procedure provides an average of 10–18 % higher learning efficiency of artificial neural networks and does not accumulate errors during training (Table 1).

The disadvantages of the proposed method are:

- the change in the distribution of probabilities of the transmission route selection during iterations of the assessment of the state of the information transmission route;
- the need for further research to increase the efficiency of determining the time of convergence;
- it requires the use of additional methods, such as local search;
- dependence on intelligence to adjust the parameters, which are selected only on the basis of available data. This method will allow:
- to assess the state of the radio communication system and choose a rational route for information transmission;

- to identify effective measures to improve management efficiency;
- to reduce the use of computing resources of decision making support systems.

According to the results of the analysis of the effectiveness of the proposed method, it is seen that its computational complexity is 15–25 % less, compared with the methods used to assess the effectiveness of decisions, which are presented in Table 1. This research is a further development of research aimed at developing method principles for improving the efficiency of information and analytical support, published earlier [4, 5, 10].

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

4. Conclusions

The dynamic model of optimization of information transmission routes in the radio network is offered in the research. The proposed model refers to dynamic routing problems with periodic values of vertices and nodes that change as a result of destabilizing factors. As a criterion for the effectiveness of a special-purpose radio communication system, the total time delays associated with the transmission of information from the sender's node to the destination's node during the observation period under the influence of destabilizing factors can be taken.

In the course of the research a method of routing in special purpose radio communication networks was developed, which allows:

- to choose a rational route for the transfer of information in conditions of uncertainty;
- to train artificial neural networks for intelligent decision making support systems;
- to process the values of relationships between factors, represented in the form of numbers, verbal descriptions, intervals, fuzzy triangular and trapezoidal numbers.

An example of using the proposed method on the example of choosing the route of transmission of information under the influence of destabilizing factors is given. This example shows an increase in the efficiency of data

processing efficiency at the level of 15–25 % through the use of additional advanced procedures.

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