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DEVELOPMENT OF METHODOLOGICAL PRINCIPLES OF ROUTING IN NETWORKS OF SPECIAL COMMUNICATION IN CONDITIONS OF FIRE STORM AND RADIO-ELECTRONIC SUPPRESSION

Oleg Sova
Department of Automated Control Systems
Military institute of Telecommunications and Informatization named after Heroes of Kruty
45/1 Moskovsky str., Kyiv, Ukraine, 01011

Yurii Zhuravskyi
Department of Electrical Engineering and Electronics
Zhytomyr Military Institute named after S. P. Koroliov
22 Myru ave., Zhytomyr, Ukraine, 10004

Yuliia Vakulenko
Department of Information Systems and Technologies
Poltava State Agrarian University
1/3 Skovorody str., Poltava, Ukraine, 36003

Andrii Shyshatskyi✉
Research Department of Electronic Warfare Development[1]
ierikon13@gmail.com

Olha Salnikova
Educational and Research Center of Strategic Communications in the Sphere of National Security and Defence
National Defence University of Ukraine named after Ivan Cherniakhovskyi
28 Povitrofloski ave., Kyiv, Ukraine, 03049

Oleksii Nalapko
Research Laboratory of Automation of Scientific Researches[1]

[1]*Central Scientifically-Research Institute of Arming and Military Equipment of the Armed Forces of Ukraine*
28 Povitrofloski ave., Kyiv, Ukraine, 03049

✉**Corresponding author**

Abstract

Decision making support systems are actively used in the processing of large data sets, process forecasting, providing information support to the decision-making process by decision-makers. However, there are problems with the transmission of information: the transmission of information takes place in a complex electronic environment against the background of interference; radio communication systems are the objects of primary fire damage due to high radio visibility. This article develops the methodological principles of routing in special communication networks in the conditions of fire damage and electronic suppression. The purpose of this research is to increase the efficiency of information transfer under the influence of destabilizing factors. The proposed methodological principles are based on the theory of artificial intelligence. The research presents a mathematical formulation of the problem of routing in special-purpose radio networks and developed a method of routing in special-purpose radio networks.

The efficiency of information processing is achieved through training in the architecture of artificial neural networks; taking into account the type of uncertainty of the information to be assessed; use of the ant algorithm. 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. The proposed methodological principles should be used in the development of software for programmable devices of commu-

nication and in the modernization of existing and development of new radio communication devices. This example showed an increase in the efficiency of information transmission in radio communication systems at the level of 15–25 % on the criterion of efficiency.
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. The creation of intelligent DMSS has become a natural continuation of the widespread use of DMSS of the classical type. Intelligent DMSS have been widely used to solve specific tasks of military purpose, namely [1, 2]:

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

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

The analysis of works [1, 3–6] 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 the objects of primary fire damage due to high radio visibility for radio intelligence.
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 determine the search for new scientific approaches and technological solutions that will allow [7–12]:

– 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.

To achieve this aim, the following objectives are set:

– to perform mathematical formulation of routing tasks in special purpose radio networks;
– to develop a method of routing in special purpose radio networks;
– to evaluate the effectiveness of the proposed method.

2. Materials and methods

The research used evolutionary algorithms and evolving artificial neural networks 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 of artificial neural networks developed in previous works, which allows for in-depth training of artificial neural networks. The essence of deep learning is to research the architecture, type and parameters of the membership function. Also in the specified research methods of the multidimensional description of a radio-electronic situation developed by authors earlier are used. The simulation was performed using MathCad 2014 software (USA) and Intel Core i3 PC (USA).

3. Results and discussion

To describe the mathematical model of a special purpose radio network, let's introduce the necessary notation. Let $N = \{1, 2, ..., n\}$ 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 $t = 1, 2, \ldots, T$, which corresponds to a specific time delay of information transmission. The delay happens because of 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 of:

$$z_i(t) + \sum\nolimits_j k_{ji} x_{ji}(t) - \sum\nolimits_j x_{ji}(t) = r_i(t) + y_i(t),\ z_i(T+1) = z_i. \quad (3)$$

In the conditions (3), the coefficients k_{ji} determine the percentage 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, $T = (\tau_s, \tau_n)$, where the duration of messages is τ_s, pauses after them are τ_n.

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 time function on the route 1–z; S is the total delay time of the information transmission on the route.

The dynamic model proposed in the research in the form (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 disparate 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.

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 step, the radio communication system is represented as a directed 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 stage 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 step, 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). Each ant can pass each vertex (node) once in each iteration. The ant is then blocked at the junction when it has no chance of continuing its journey 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 specified as a rule of the node transition. The probability of transition of the k-th ant from node i to node j is set:

$$P_{ij}^{k}=\begin{cases}\dfrac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{h\notin tabu_k}(\tau_{ih})^{\alpha}(\eta_{ih})^{\beta}} & j\notin tabu_k,\\ 0, & \text{in the other case,}\end{cases} \quad (5)$$

where τ_{ij} and η_{ij} pheromone intensity and route cost 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 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 $0\leq q\leq 1$ is compared with the same probability to the parameter Q, where $0\leq Q\leq 1$. The result of the comparison between Q and q takes one of two methods of choosing the active ant route of the next transition as follows:

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

If q is greater 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: it is first used while building solutions (local pheromone update rule). The second rule applies 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:

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

where $\Delta\tau$ is the number of local pheromone updates. The value $\Delta\tau$ is the original system of fuzzy logic developed by the authors in the work [1].

The input data of fuzzy logic are «data transfer rate», «battery charge», «packet delivery time», «packet delivery reliability» of the direction chosen by the k-th ant and «bit error probability». Considering computational difficulties, only four fuzzy input sets are defined for each input, «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 to achieve greater local renewal of pheromones.

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

$$\tau_{ij}^{new} = \rho\tau_{ij}^{old}, \tag{8}$$

where $0 \leq \rho \leq 1$ is the evaporation rate that 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 can examine received from the route request packets, route response packets, the original route. The node also removes from the route cache those connections between nodes in the radio network that have broken connections. For example, a node may learn about a broken link by receiving a packet containing route error information or through the OSI model layer retransmission mechanism. This is done by getting a transmission error while transmitting the frame to the node of the next jump. Each time a node adds information to the route cache, the node checks its cache for the route to the destination address in the cache. If such a route is available, the node sends a packet along this route and is removed from the send cache. This will allow to use the network with other external networks. The knowledge base stores all studied routes with indicators of residual battery charge, data transfer rate, route delay time, route reliability, route load and number of relays (hops). The database is populated by researching 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 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. Determination of 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 [1, 2].

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

Simulations were performed with the following parameters:

– radio communication devices 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 PRAOF 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;

– complexes of radio electronic suppression (RES)-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 the noise interference with frequency manipulation, as one of the most common and the impact of which 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**).

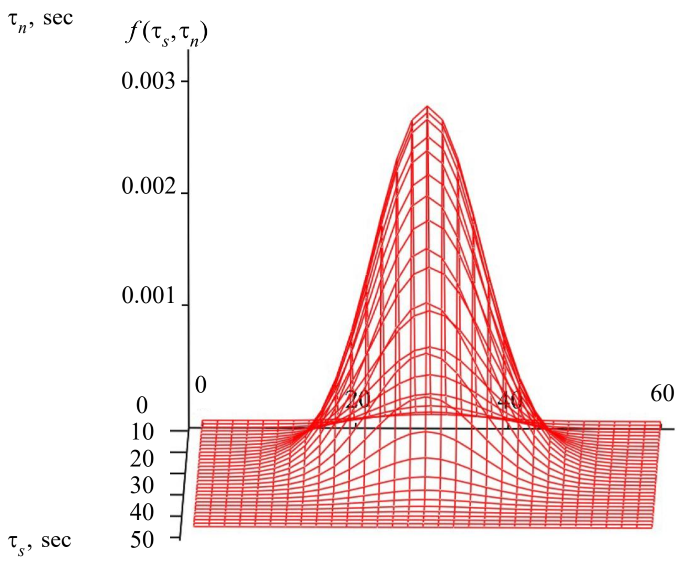

Fig. 1. Dependences of message duration on the reaction time of the RES complex

Analysis of the obtained dependences (**Fig. 1**) shows that the value $f(\tilde{\tau}_s,\tilde{\tau}_n)$ (**Fig. 1**) 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 $(\tilde{\tau}_s)$, and the pause after it $(\tilde{\tau}_n)$.

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 had 2,000 observations.

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

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 (training)	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 method are:

– it has a 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 the route condition of information 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;

– relies on the memory of the whole colony instead of the memory of the previous generation.

It is worth noting that the proposed training procedure showed the best PC (partition coefficient) result in comparison with EFCM and the best result in time compared to FCM. 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 include:

– the change in the distribution of probabilities of the transmission route selection during iterations of the state assessment 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;

– the dependence on intelligence to adjust the parameters, which are selected only on the basis of available data.

The mentioned method will allow to:

– assess the state of the radio communication system and choose a rational route for information transmission;

– identify effective measures to improve management efficiency;

– 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 [1, 2, 12].

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

4. Conclusions

The dynamic model of the route optimization of information transfer in a radio network is offered in 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 information transfer in conditions of uncertainty;

– train artificial neural networks for intelligent decision making support systems.

– 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 information transmission under the influence of destabilizing factors is shown. 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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