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Article

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DEVELOPMENT OF A SIMULATION MODEL FOR A SPECIAL PURPOSE MOBILE RADIO NETWORK CAPABLE OF SELF-ORGANIZATION

The object of research is the military radio communication system. Effective operation of routing protocols is possible only if there is reliable information about the network topology for each of the network nodes. Construction of special purpose radio networks with the possibility of self-organization is possible only in the presence of adequate and reliable models of their work in different applications and the impact nature. It necessitates the development of new and adequate algorithms (methods, techniques) for modeling routing algorithms in special purpose radio networks with the possibility of self-organization. This work solves the problem of developing a simulation model of a mobile radio network for special purposes with the possibility of self-organization.

In the course of the research, the authors used the main provisions of the queuing theory, the theory of automation, the theory of complex technical systems and general scientific methods of cognition, namely analysis and synthesis. This simulation model was developed to assess the effectiveness and adequacy of the developed scientific and methodological apparatus for routing management in special purpose radio networks with the possibility of self-organization.

The research results will be useful in:

– *development of new routing algorithms;*
– *substantiation of recommendations for improving the efficiency of the route selection process in networks with the possibility of self-organization;*
– *analysis of the electronic situation during hostilities (operations);*
– *while creating promising technologies to increase the efficiency of mobile radio networks;*
– *assessment of adequacy, reliability, sensitivity of routing algorithms;*
– *development of new and improvement of existing simulation routing models.*

Areas of further research will focus on the development of a methodology for the operational management of interference protection of intelligent military radio communication systems.

Keywords: *routing protocols, Ad Hoc Networks, self-organizing networks, data transmission systems.*

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1. Introduction

As the experience of local wars and armed conflicts of recent decades has shown, in the course of operations (combat operations), radio communication devices are usually the basis of any military and weapons control system, as well as communication and information transmission systems. It happens because of the high dynamics of combat operations, long range and the ability to work in motion [1, 2].

Currently, the work is an underway to implement data transmission systems using networks with the possibility of self-organization (Ad Hoc Networks).

The main tasks of the networks with the ability to self-organize data transmission are:

– construction of fault-tolerant network infrastructure;
– increasing the use of radio frequency resources;
– ensuring the adaptation of networks to the action of external factors;

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– reducing the cost of deployment and operation of the network in comparison with the classical principles of construction.

A self-organizing decentralized network consists of routers and mobile devices that are interconnected and perform both client and router functions at the same time.

Effective operation of decentralized, self-organizing networks is possible only if reliable information about the network topology is available. Thus, with this information, packets can be redirected correctly between sender and recipient. That's why modeling self-organizing radio networks is one way to increase the efficiency of special-purpose radio systems.

The object of research is the military radio communication system.

The aim of research is to develop a simulation model of a mobile radio network for special purposes with the possibility of self-organization.

2. Methods of research

The essence of simulation is to reproduce the process of managing special purpose radio networks (SPRN) at each level of the OSI model using probabilistic and deterministic procedures.

The purpose of developing a simulation model (SM) is an experimental research of the effectiveness of the developed scientific and methodological apparatus of routing and the choice of its optimal parameters, in terms of accepted efficiency criteria [2, 3]. At the same time the following basic requirements are put forward to SM:

– to fully reflect the conditions of SPRN functioning and the process of their management, taking into account the peculiarities of the synthesized scientific and methodological apparatus (adequacy of the model);
– the initial characteristics obtained as a result of experiments should provide an opportunity to compare the effectiveness of the developed scientific and methodological apparatus of routing (the usefulness of the model);
– to guarantee the accuracy and reliability of modeling results.

In the course of the research, the authors used the main provisions of the queuing theory, the theory of automation, the theory of complex technical systems, the theory of information transfer and general scientific methods of cognition, namely analysis and synthesis.

3. Research results and discussion

In accordance with the principles of simulation given in the work [4], let's present the process of simulation of a mobile radio network (MRN) in the form of a set of stages.

Meaningful description of the object of modeling and creation of a conceptual model. At this stage, the object of simulation and the composition of the source information sufficient to study the processes of its operation is determined. A possible list of model limitations that is permissible while organizing the simulation. The goals of modeling are defined and the main criteria of efficiency are formulated, according to which it is supposed to make comparisons on models of various design decisions or variants of system architecture.

The initial data for simulation are the SPRN characteristics and developed scientific and methodological apparatus of routing in self-organizing military networks [5]. The characteristics of SPRN are: the number of nodes, radio channels and their parameters, the structure and dynamics of changes in the network topology. Each node in the network during its simulation can be described by a set of parameters that are diversely shown by the process of its operation. The input load of each node is determined by its neighbors. Each of them generates messages of different size, priority, type (language, data, video), which define different requirements for service quality. In turn, the node can be described from different positions: mobility (speed and direction of movement), reliability (failure/recovery intensity), survivability (destruction intensity, residual battery capacity).

Thus, taking into account the features of the developed scientific and methodological apparatus of routing [2, 3] in self-organizing military networks, the routing process in SPRN can be modeled at the physical, channel, network, transport and application levels [5]. At the physical level, the simulation parameters are the probability of data packet loss, signal strength, bit error probability and signal-to-noise ratio at reception. At the channel level, the simulation parameters are the method of channel division (frequency, time, code) and the channel access protocol (random, with carrier control, etc.). At the network level, where are many methods of routing and topology management. At the transport level, information exchange protocols (number of retransmissions, receipt waiting time, etc.), queue and load management are taken into account. At the application level, the requirements for the quality of service and secure transmission of each type of traffic, the priority of traffic and its estimated volumes (provided that non-pulsating data traffic is transmitted).

The purpose of simulation is to study the impact of the developed scientific and methodological apparatus (SMA) of routing on the SPRN functioning. The parameters of the node or radio channel according to the OSI model levels will be used as indicators of the simulation quality. The controlled parameters are:

– the amount of transmitted information;
– the residual capacity of the batteries of the nodes on the transmission route;
– the size of queues in intermediate nodes and the rate of change of queue size;
– packet transmission delay time;
– node bandwidth (information direction).

The influence of the functioning of the developed SMA on the functioning of the SPRN occurs at the network and transport levels of the OSI model. Moreover, the description of the external environment in SM is reduced to a description of the processes occurring at other levels of the OSI model, to determine their impact on decision-making by the studied methods of intelligent control. However, it is currently impossible to take into account all the parameters of MRN functioning in the model, due to incomplete research of SPRN at all levels of the OSI model. Therefore, the physical level of node operation is simplified (without loss of adequacy of simulation results) by the threshold model of the radio channel, if the signal level at the reception between nodes i and j is greater than the limit value, then radio channel i–j exists and nodes can exchange information. At the channel level, to model the process of access to the radio channel, it is proposed to use a random value of access time to the radio channel t_{dc}, which varies within certain limits (from t_{dcmin} to t_{dcmax}).

Fig. 1 shows a block diagram of a simulation model of SPRN, which includes two main components: the model of the node and the model of the radio channel. Taking into account the features of SPRN as an object of modeling, it is proposed to simulate its work using the transaction method [6, 7]. This method assumes that both the node model and the radio channel model are represented in the form of a queuing system (QS), the elements of which are blocks that simulate the operation of message generators, queues, devices and multi-channel service devices. One run of the model is to generate a message (transaction) in the sending node, its passage through the network (through the elements of the QS) to the destination node, according to the protocols of its operation and destruction. Statistics are being collected at this time. The number of runs is determined by the required accuracy and reliability of the simulation results [8, 9].

The parameters of the blocks that simulate the operation of message generators are the intensities of messages of different types: service messages λ_z (probes or receipts) and information messages λ_ξ. In order to simplify SM, it was assumed that the generation of messages is according to Poisson's law. Variables for blocks that simulate the operation of input and output queues, processor devices and transceivers, are the delay time during which the message is processed by a device. In this case, the processing time of messages in the device processor includes the time spent on decision-making knowledge base (it is believed that the knowledge base of the node inteligent control system (ICS) does not require training in decision-making).

The statistics in the simulation will be:
– sizes of input l_{in} and output l_{out} queues;
– time delay of messages during transmission in MRN (includes processing time t^{ξ}_{proc} on transmission and reception, time of access to the channel t^{ξ}_{dc} and time of transmission in the radio channel t^{ξ}_{tran});
– number of generated N_{tr} and delivered N_d information messages;
– the number of generated service messages N_{of};
– the number of routes between the nodes sender and recipient $m^{ab}=\{m^{ab}_r\}, r=\overline{1,R}$;
– the capacity of the node batteries $e_{b_i}, i=\overline{1,N}$ that make up the r-th transmission route.

Since the main task of the mobile radio network is to transmit traffic with a given quality of service, the efficiency criteria are selected bandwidth $S=N_d/N_{tr}$ and computational complexity of the developed scientific and methodological apparatus of routing in self-organizing military networks to the SPRN process of functioning.

Formal description of the simulation object. The model assumes that each node generates a message according to its input load. The process of passing the packet from the node and (transmitting node) to the node j (receiving node) is shown in Fig. 1.

In the process of radio transmission, the message may be lost (in the model – destroyed) due to the influence of internal system interference (the influence of the protocol of access to the channel, the problem of «hidden terminal») or interference created by the enemy. Modeling of influence of the specified disturbances is carried out by the block generator of disturbances which are formed randomly according to the indicator law. The number of lost information messages due to interference is calculated as a variable N^{QoS}_{tr}.

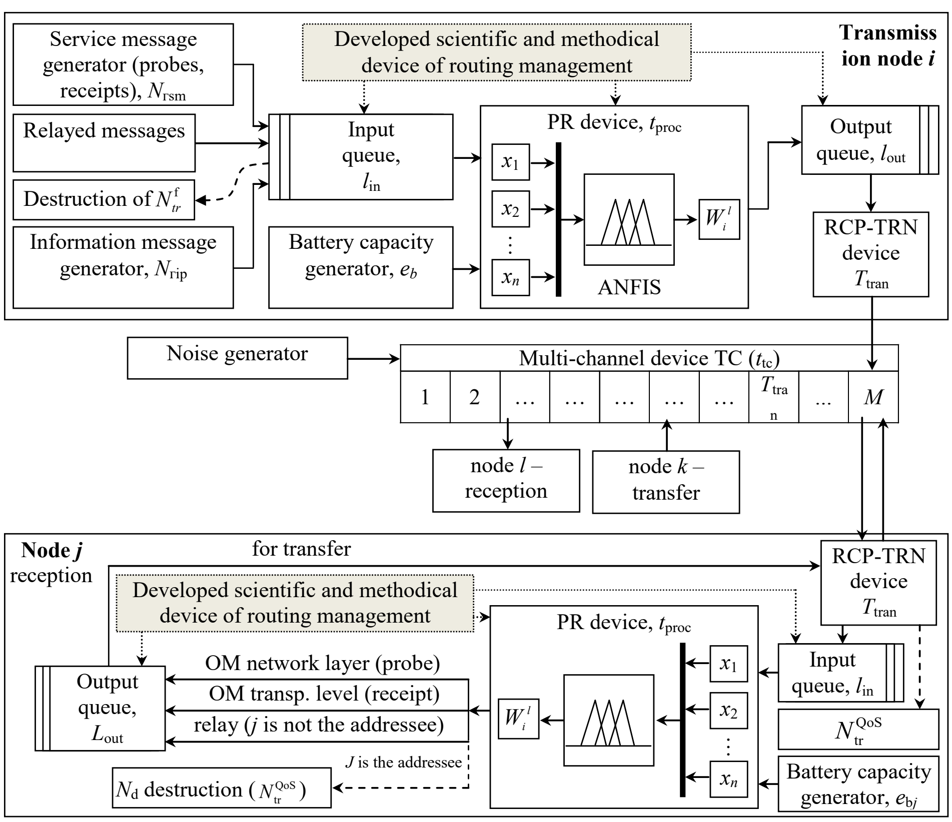

Fig. 1. Block diagram of the simulation model using the transactional simulation method: PR is the processor; OM is the official message; RCV is the receiver; TRN is the transmitter

Creation of a simulation model. Modeling the process of routing SPRN includes the following procedures: generation of service messages (receipts, probes), their distribution, formation (adjustment) of the knowledge base about the state of the network in the nodes while receiving official messages (OM) (receipts, probes). Variable parameters are:

– method of OM sending (receipts, probes) – periodic or related to events;
– frequency of OM generation (receipts, probes);
– depth of OM sending (receipts, probes);
– metrics for choosing the method of data flow management (OM format, probes).

The following can be distinguished as the main ones:

– the generation of a package (information, service) for transmission;
– occupation and release of the incoming (outgoing) queue of the node by the package;
– occupation and release of the processor package by the node;
– occupation and release of the processor package of the transceiver;
– occupation and dismissal of a radio channel package;
– failure and restoration of the radio channel;
– emergence of the peak of incoming traffic, its normalization, etc. The scheme of the functioning algorithm of the simulation model is shown in Fig. 2.

As mentioned above, the simulation of the SPRN is proposed to be carried out using the transaction method, which assumes that for each generated message a time coordinate is set, which changes its value while passing SM blocks. In this case, the internal synchronization of transactions (including the resolution of conflict situations that arise when it is necessary to simultaneously serve different blocks of their transactions) is through queues and certain disciplines of their service.

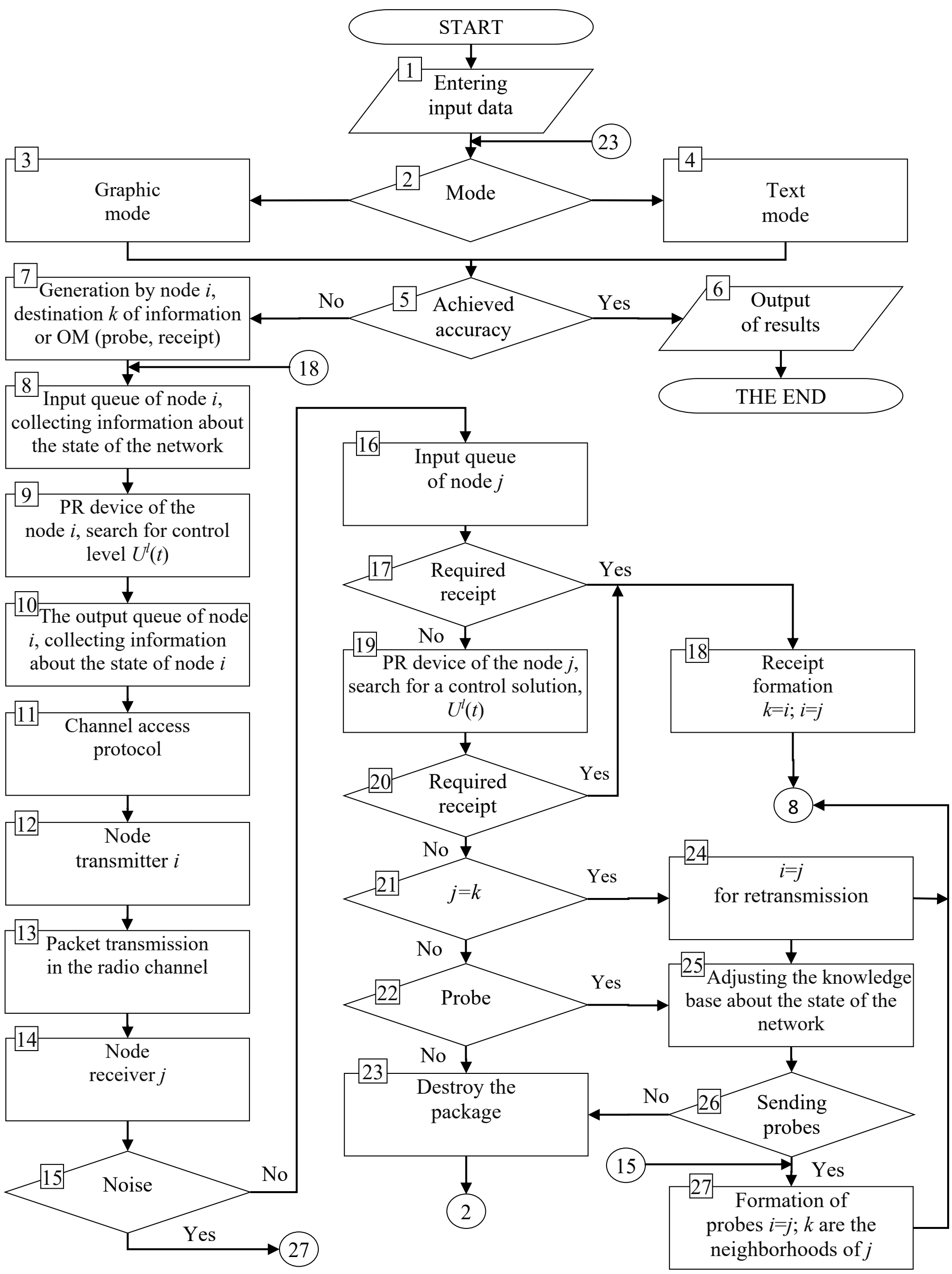

Fig. 2. Scheme of the functioning algorithm of the simulation model of the mobile radio network: OM is the official message; PR is the processor

Programming. In general, the simulation model is a set of procedures in C^{++} [9, 10] and can be used to analyze and synthesize intelligent control methods SPRN at the network and transport levels of the OSI model. As mentioned above, the features of SMA SPRN require the inclusion in the SM procedures related to the introduction and adjustment of the knowledge base, which contains the rules of «behavior» of the node depending on the state of the radio network. To this end, it is proposed to simulate the MRN control process using the computer mathematics system MATLAB + Simulink [11, 12], which includes a very functional set of tools for modeling the operation of nodes and communication networks, as well as for statistical analysis of simulation results.

Assessment of the model adequacy. In the general case, adequacy is understood as the degree of conformity of the model to the real phenomenon or object for the description of which it is built. One of the most common ways to formally substantiate the adequacy of the developed model is to use the methods of mathematical statistics. The essence of these methods is to test the hypothesis of the adequacy of the model on the basis of some statistical criteria, the implementation of which is possible in different ways, the most common of which are:

– by the average values of model and system responses;
– by the variance of the deviations of the model responses from the average value of the system responses;
– by the maximum value of the relative responses of the model and system.

In this case, the evaluation procedure is based on a comparison of measurements on a real system (or its prototype) and the results of experiments on the model. However, if the prototype of the system is absent, then for comparison, it is possible to use a system of nested SM, which differ from each other in the degree of detail of the same phenomena. In this case, a more detailed model serves as a prototype for generalized SM. If it is impossible to build such a sequence of SM due to lack of resources to perform this work or due to lack of information about the object of modeling, the assessment of the model adequacy is not performed [13].

Since there is currently no existing prototype SPRN, the assessment of the adequacy of the proposed SM was by comparing it with a simulation model, which provided a more detailed description of the SPRN operation at the channel and physical levels of the OSI model. In this case, the adequacy check can be performed in different ways:

– on average values of the model responses;
– by the variances of the response deviations of the studied model from the average value of the prototype model;
– by the maximum value of the absolute deviations of the responses of the studied model and prototype model.

The first method was used to research the adequate proposed SM [14].

Thus, it is possible to use the table of distribution of t-statistics [12], taking the number of degrees of freedom equal to $\gamma=N+N^*-2$. Usually set by the level of dependence $\alpha=0.05$ and according to the specific value of the number of degrees of freedom γ in the tables find the critical value of t-statistics t_{cr}. If the inequality $t_n \le t_{cr}$ holds, then the hypothesis of the closeness of the mean values of the n-th component of the model responses is accepted. Only when the responses for all components of the vectors Y_k^* and Y_k are close and it is possible to talk about the adequacy of the models.

Estimation of the model stability. While assessing the adequacy of the model of the designed system, only a limited subset of all possible values of the input parameters can be used, according to which the assessment of both the system and the environment is carried out. In this regard, to justify the reliability of the simulation results, it is important to check the stability of the model, which reflects its ability to maintain adequacy in the research of system efficiency over the entire possible range of workload and changes in system configuration. Thus, the degree of insensitivity of the studied system to changes in input conditions is estimated.

Checking the SM stability is to compare the results of modeling before and after making changes to it. The stability of modeling results can also be assessed by methods of mathematical statistics. The point is to test a hypothesis about the properties of a set of elements, called a population, by evaluating the properties of the population (a sample) subset.There is no universal procedure for checking the stability of the model. Therefore, to test the hypothesis of the SM stability in this work, Wilcoxon's test was used [13], which allows to establish not only the direction of change of parameters, but also the intensity of such changes. The essence of the method is that the absolute values of the deviations of the components of the response vector in one direction or another are compared. To do this, first all the absolute values of the deviations are ranked, and then the ranks are summed. If shifts in one direction or another occur by chance, then the sums of their ranks will be approximately equal. If the intensity of shifts in one direction is greater, then the sum of the ranks of the absolute values of shifts in the opposite direction will be much lower than it could be with random changes.

Estimation of the model sensitivity. If the change of input effects or model parameters (in a given range) does not affect the values of the output parameters, the benefit of such a model is small, as the model is insensitive to changes in parameters. Therefore, it is necessary to assess the sensitivity of the model to changes in the parameters of the workload and the internal parameters of the system itself. This assessment is performed for each parameter separately.

During the sensitivity check, the range of changes in the response of the SM Y while changing each component of the vector of parameters X. Depending on the range of changes in the response of Y, the strategy of planning experiments on the SM is determined. If at a significant amplitude of change of some component of the parameter vector of model X of the response Y does not change significantly, it means that the accuracy of display of this component in SM does not play a significant role and in planning the simulation experiment this component will not be used as the main. Otherwise, such a component should be represented in the model with maximum accuracy.

The limitations of this research include the fact that it is a research of a priori known data for correct modeling and powerful computing resources. In turn, a number of factors were not taken into account by the authors. It necessitates the clarification of the research in practical testing.

Areas of further research will focus on the development of a methodology for the operational management of interference protection of intelligent military radio communication systems.

4. Conclusions

In this research, a simulation model of a mobile radio network for special purposes with the possibility of self-organization was developed.

The peculiarities of the developed model are:

– the versatility, which allows modeling the operation of mobile radio networks for special purposes with the possibility of self-organization with different data transmission technologies;

– the breadth of use due to the possibility of implementation in different programming languages and the ability to take into account the peculiarities of radio networks.

This simulation model was developed to assess the effectiveness and adequacy of the developed scientific and methodological apparatus for routing management in special purpose radio networks with the possibility of self-organization.

Research results will be useful in:

– development of new routing algorithms;

– substantiation of recommendations for improving the efficiency of the route selection process in networks with the possibility of self-organization;

– analysis of the electronic situation during hostilities (operations);

– creating promising technologies to increase the efficiency of mobile radio networks;

– assessment of adequacy, reliability, sensitivity of routing algorithms;

– development of new and improvement of existing simulation routing models.

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