*This research addressed the issue of improving the quality of service for the control system of mobile radio networks. The analysis of the forecasting sphere concerning the methods of service quality of mobile radio networks for special purposes, in particular, forecasting the time of congestion of data transmission routes is carried out. It is found that these methods are used in wired and computer networks operating at the network and data link levels. The basic parameters of the protocols of the channel and network layers of mobile radio networks are highlighted. Forecasting methods are analyzed: temporal extrapolation, causality, expert, and the main disadvantages are indicated. A model of a control system for mobile radio networks with a forecasting subsystem is shown. The features of mobile radio networks, which form the requirements for routing methods, are described. A lot of requirements have been put forward for the model of a control system for mobile radio networks. The structure of a model of a control system for mobile radio networks with an improved forecasting subsystem is proposed. On the basis of genetic algorithms, the tasks that arise in the process of identification, training and forecasting in the forecasting subsystem are solved. The operation of the processes consists in building a base of rules aimed at identifying significant dependencies in a time series based on the use of a genetic algorithm. It is based on the use of evolutionary principles to find the optimal solution. Application of the proposed model will allow real-time identification and will significantly improve the quality of service for mobile radio networks. It will increase the speed and volume of data processed during training, improve the quality and reliability of predicting changes in data transmission routes*

*Keywords: radio network, data, control, forecasting, model, routing, congestion, identification, intellectualization, algorithm*

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# DEVELOPMENT OF A MODEL OF A SUBSYSTEM FOR FORECASTING CHANGES IN DATA TRANSMISSION ROUTES IN SPECIAL PURPOSE MOBILE RADIO NETWORKS

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## 1. Introduction

An information and telecommunication network (ITN) is a rather complex system, which consists of a large number of parameters and equipment that are heterogeneous in their physical meaning (nodes, stations, transmission routes, communication facilities, etc.). As a result, it is quite difficult for network administrators to process large amounts of information that are simultaneously received by them. This is especially true of military units performing specific tasks that require significant efficiency in order to carry them out. The reason lies in the failure to take into account modern methods of conducting armed conflicts and hybrid wars, as a consequence of the influence of these factors on the hardware, software and information components of the network. Therefore, it is advisable to use subsystems for identifying and monitoring network states as part of the ITN control and control system. They carry out processing, storage, forecasting, data analysis and reflect information about the state of the network in real time.

Development and implementation of ITN, ensuring the smooth operation of processes, systems, structures, directly depend on the clear and well-coordinated work of information and telecommunication systems plays an important role. Since time is important (speed of execution, response, forecasting, etc.) and mobility when using communication means, then among many ITN it is advisable to use mobile radio networks (MR). Due to their peculiarities, such networks are widely used in the construction of wireless communication networks [1]. The main tasks for the full operation of the MR are to maintain a sufficient quality of their service, which includes the process of changing data transmission routes and predicting the time of changes. This is due to the fact that each type of traffic that circulates in the network requires the definition of parameters of performance, bandwidth, reliability, quick recovery in case of unforeseen situations. It is necessary to determine the requirements for the quality and speed of predicting the congestion time of data transmission routes.

Improving the technical equipment and operation of special purpose units will meet the needs of their control during the performance of specific tasks. The development of the MR control system will improve the quality and speed of work. The mobility of communication centers will increase, the requirements for reliability, performance, and communication between subscribers will be met. The performance of the temporal characteristics of information exchange, the level of automation of the processes of establishing, maintaining and maintaining radio communications, the development of new models of communication means will improve. That is, the search for new options for improving the mobile radio network that meet the requirements is a rather urgent problem.

## 2. Literature review and problem statement

In [2], the analysis of the operation of mobile radio networks is carried out, which consider methods of maintaining the quality of the MR operation MR and predicting the time of congestion of data transmission routes. It is shown that the known methods are usually used in computer (wire) networks. They are used for the operation of the network and data link layers, on which queue control, traffic flow control and its parameters, congestion protection, feedback control, and the like are carried out. But there were unresolved issues related to the application in MR due to the imperfection of existing mathematical models and methods.

In [3], the analysis of the above methods is carried out. Their advantages and disadvantages are described. It is shown that the methods require a sufficiently high quality of service and predict the time of changing data transmission routes. The reason for this may be objective difficulties, which determine a certain imperfection of mathematical methods (models) and, in turn, do not provide the possibility of uninterrupted, efficient use of special purpose communication facilities.

The work [4] describes the method of temporal extrapolation. This method is based on historical events. Prediction of state parameters in the form of temporal extrapolation of characteristics, uses one parameter – time. In addition, the temporal extrapolation method includes heuristic elements, the essence of which is the development of mathematical models and the analysis of forecasting results. Temporal extrapolation is associated with prediction in the space of characteristics. But questions remain as to whether the method works under one condition - the law of state change in the past must be stored in the future. Therefore, changes made to the system will lead to a change in the set of states of the information and telecommunications network, which is a rather difficult task. The process modeling method will not be effective in situations requiring a quick response to changes in the state of the system.

The work [5] shows the method of causality, compares a set of values, will have an impact on the ITN in the future. It is shown that non-linear methods are used for long-term forecasting, and linear methods are used for short-term ones. The methods are being adapted to specific tasks. There is a connection between cause and effect in time: first the cause arises, and already the effect. The root cause of any phenomenon is in the composition of what is happening in the beginning. The disadvantages of this method include the fact that with a combination of reasons, it is much more difficult to determine the cause of the phenomenon than when the phenomenon is caused by only one cause. This leads to the need not only to establish a connection between the phenomenon and the cause that generated it, but also to prove that the phenomenon could not be caused by any other of the possible causes. But there remained an unresolved issue of adapting the method under consideration to work in ITN.

The work [6] analyzes expert methods based on the analysis of views, judgments of various experts, obtained as a result of their accumulation and study. It is shown that according to the method of using information received from specialists, there are such expert forecasting methods: direct assessments and feedback. Their difference lies in the fact that in the first case, the received expert information is processed and comes directly as a result. In the second case, the result appears in the process of several approximations, and at each step, the experts are influenced by the results of processing the previous one that is, feedback is carried out with the experts. The question remains unresolved that the method is based on the individuality of the thoughts of each of the experts and the diversity of the subjectivity of their judgments. This allows to assert that the adaptation of this method to the ITN is not yet expedient.

The work [7] considers the problems arising in the planning of projects with limited resources. A genetic algorithm with two versions of crossovers is proposed, based on the principles of the most rational use of limited resources. The paper explains the technological limitations and benefits of operating with limited resources. This work testifies to the advisability of using genetic algorithms in forecasting. But there were unresolved issues with their use in special purpose MR networks. The reason may be objective difficulties associated with the use of communication means, for work they use wired and computer networks.

The work [8] presents the results of the development of the VBLAST MAP algorithm: a point-to-point algorithm, which is designed to detect symbols in MIMO wireless communication systems. The proposed algorithm is superior in efficiency to the traditional VBLAST MAP algorithm and the improved VBLAST algorithm. But the question of its use in the special purpose MR remains unresolved. A variant of overcoming the corresponding difficulties can be the use of genetic algorithms (GA) for their operation in a special purpose MR.

All this allows to assert that it is advisable to conduct research aimed at developing a model for a subsystem for predicting changes in data transmission routes to a special purpose MR based on genetic algorithms.

## 3. The aim and objectives of research

The aim of research is to develop a model for a subsystem for predicting changes in data transmission routes to determine the possibility of their application in a special purpose MR.

To achieve the aim, the following objectives were set:

– to propose and develop the structure of the model of the MR control system with a forecasting subsystem;

– to find options for solving problems of predicting the congestion time of data transmission routes using genetic algorithms to improve the quality of service of the MR control system.

## 4. Materials and methods of research

To create and substantiate the structure of the model of the MR control system, it is advisable to highlight certain assumptions and simplifications. Let's suppose that the model that is being developed should be applied in case of extraordinary network activity, to carry out data transmission with an increased speed and accuracy of predicting data transmission volumes simultaneously while reducing the time for the prediction itself. The fulfillment of the considered assumptions will provide an opportunity for further search for the conditions of application. This will expand the use cases not only for wired and computer networks, but also for mobile radio networks. The research will provide certain opportunities for reducing the complexity of the mathematical apparatus and simplifying the design features of communication facilities.

The peculiarities of the MR operation, which personify a wireless, decentralized, mobile IP network, is the ability to self-organize, to ensure the establishment of connections between independent nodes, in the absence of base stations with clear routes. In the event of failure of one of the stations, the time to restore operability is essential.

The features of the MR include: dynamic topology, limited power and transmission time to subscribers, a significant number of elements in the network; heterogeneity of network components. It is important to ensure the quality of service requirements for users on rough terrain and in the context of military operations. It is also necessary to minimize the influence of the human factor in planning, organizing and maintaining communications [9].

To transmit information, MR uses: mobile cellular communication (GSM/GPRS/EDGE, CDMA, LTA), Wi-Max networks (IEEE 802.16) Wi-Fi (IEEE 802.11), etc. The listed technologies with multi-hop routing and the ability to self-organize are designed for dynamic , decentralized and distributed networks, in which there are certain design features of communications [10].

MRs allow expanding the range of services in the service area of traditional wire ITN through the use of modulated electromagnetic waves as signal carriers and radio air as a transmission medium. The principle of transferring information to MR causes certain difficulties in the process of its exchange: free access and insecurity of radio air, vulnerabilities of mobile devices, certain restrictions of applications and services; distribution, variable topology; the disadvantages of some protocols by the presence of specific technical limitations [11]. Since MRs operate using protocols of the OSI (Open Systems Interconnection Model) model, namely network and transport, it is advisable to consider the characteristics of some of them [12–14] (Table 1).

Based on the above, one of the rather important processes that characterize the effective operation of the MR control system is precisely forecasting. Prediction allows to set up the network in time to prevent congestion, errors, failure, predict changes in data transmission routes in various situations, which are quite important and relevant.

Various models and methods are used in forecasting. Among the well-known approaches, the following can be distinguished:

– systemic, which involves the study of quantitative and qualitative patterns of probabilistic processes in the system;

– historical, which consists in comprehending each phenomenon in relation to its historical types;

– complex, which exists in a complex of phenomena in their interdependence in the context of various knowledge, describing these phenomena and others;

– structural, which allows to comprehend the structure of the phenomenon that is being investigated;

– system-structural, which provides for the study of the system as a whole, develops in dynamics, the branching of the system into its constituent structural elements and issues of their interaction.

It is a set of such methods that are used in the formation of subsystems, in turn, are part of the MR control system. The operation of this MR control system depends on the formative control goal and the corresponding target functions. Therefore, in order to understand the process of operation of the MR control system, let's consider the existing model of the MR control system with a forecasting subsystem (Fig. 1).

Table 1

The main characteristics of some protocols of the data link and network layers of mobile radio networks

| Link level protocols | | | | |
|---|---|---|---|---|
| IEEE 802.11 | | IEEE 802.16 | HiperLAN 2 | Bluetooth |
| The main characteristics of the protocols | | | | |
| Working Frequency (GHz) | 2.4/5.1 | 2–66 | 5.1 | 2.4 |
| Range of application (m) | Up to 500/up to 100 | 100–20000 | Up to 250 | 10...100 |
| Channel transfer rate Mb/s | 1/2/11/54 | 120 | 54 | 0.7...1 |
| Channel access method | DFWMAC (CSMA/CA) | OFDMA/TDMA/TDD | Polling/TDD | |
| Control type, networking | Decentralized, all nodes are at the same level | Zonal, centralized resource control for individual zones | | |
| Node mobility | At the network level | Complicated, necessitates reconfiguration of network zones | | |
| Network bandwidth | Limited by mutual interference | Set by network configuration | | |

| Network level protocols | | | |
|---|---|---|---|
| TCP/IP | | NWLink | NBF |
| The main characteristics | | | |
| Availability on different operating system platforms | Open to any user | applied by the developer | applied by the developer |
| Configuration and administration | Has potentially complex configuration and administration | Requires little effort for initial setup and administration | Requires little effort for initial setup and administration |
| routing capability | Yes | Yes | Yes |
| Registration of names and permissions | Yes | Yes | Yes |
| Application support | Yes | Yes | Yes |

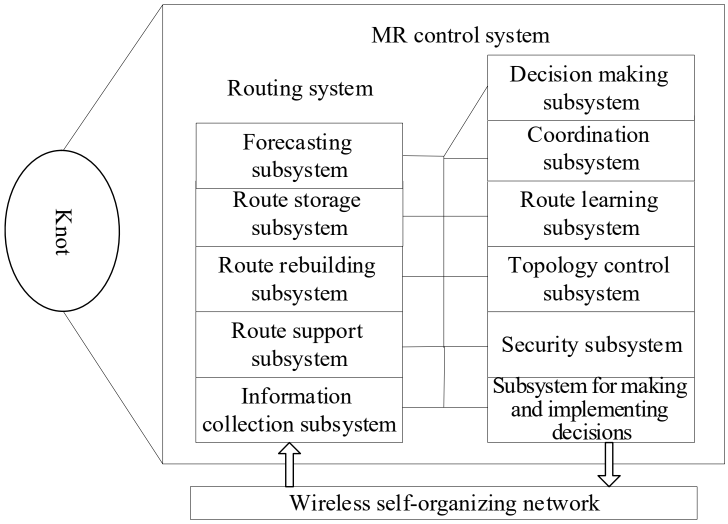


Fig. 1 The existing model of a control system for mobile radio networks with a forecasting subsystem

The routing system is a necessary component for the smooth operation of the MR. In it, the process of determining for the MR one or more routes, which are optimal within the selected criteria, between several nodes or their set. Its task is to find the optimal values of the selected quality of service indicators, as well as to ensure a balanced load of the network and channel resources.

Input data comes from mobile radio networks (nodes, stations, separate communication facilities, etc.) to the information collection subsystem.

The route storage subsystems, building a node and collecting information carry out: exchange, receipt and storage of data about routes, a network in accordance with the conditions of operation of a certain routing method.

The routing subsystem is responsible for creating routes in accordance with the information received about a given network configuration based on a specific route selection parameter. The parameter, in most cases, is the increase in the time it takes for a separate package to travel along the route.

The route support subsystem monitors and quickly responds to current changes in the parameters of nodes in the network and its topology, transmission paths, characteristics of the load on subscriber equipment.

The route storage subsystem ensures the timely storage of routes in the face of unforeseen changes in the conditions of the network operation (equipment failure, a significant increase in the subscriber load, loss of power, etc.).

The forecasting subsystem is designed to quickly replace routes and reconfigure the routing table depending on the conditions and circumstances that arise when an abnormal situation occurs.

The coordination subsystem coordinates the actions of all subsystems and predicts the behavior of routes.

The route learning subsystem uses information from packets that travel through the node (service and information) to update the routing table.

The topology control subsystem of the MR realizes the redistribution of the transmission capacities of the node in accordance with its tasks for the intended purpose. The MR topology control is solved in accordance with the situation that has developed in a particular period.

The route support subsystem operates in passive (the sender receives information about a route failure) or active (a new route segment is being built) modes.

The security subsystem identifies attacks aimed at routing processes, evaluates threats and takes measures to eliminate them.

The subsystem for making and implementing decisions based on the state of certain parameters (type of traffic, quality of radio channels, battery capacity, etc.) and the parameters of the network (load, mobility, etc.) establishes certain functions. Determines the routing method (for an individual user, the number of addressees, security and reliability requirements, the number of routes, types of radio channels (symmetric, asymmetric), the volume of the network (single-level, hierarchical) that performs control tasks are determined. It specifies the routing function (storage, support, construction, etc.) the class of routing information, the method and depth of its distribution or collection (qualified by the type of traffic and the purpose of control), parameters of interaction with other elements of the MR control system [15].

Features of the MR determine the requirements for routing methods, such as: distributed operation; reducing to a minimum network load with service information; no ringing of routes. They also include building a route of appropriate quality, efficient distribution of battery energy, and facilitation of equally directed channels.

For a specific situation in the network, each of the routing methods has a specific result. With insignificant dynamics of the network topology, tabular methods are appropriate, with an average one – probe methods, with a high one – wave methods. At a high load at the input, tabular methods are used mainly, at a low load, probe methods are used [16].

Thus, there is no single routing method that meets all the requirements and ensures the optimization of the parameters of the efficient operation of the network under various operating conditions. To solve this problem, it is proposed to use "active" routing, which includes new approaches to the operation of several routing methods in the network. Dynamic formation of routing information: route metrics, depth, methods and frequency of their distribution; network topology control; intellectualization of measures for making decisions in routing; integration and coordination with other levels of the reference model of systems interaction [16].

It is obvious that the existing methods that form the model of the MR control system when using the algorithms responsible for the operation of each of the subsystems under consideration increase the mathematical complexity and complicate the network devices.

Output data of a new model of a control system for mobile radio networks with a forecasting subsystem. In connection with the impossibility of collecting in real time information about the state of the MR, consider the process of routing data streams in the information direction a-b, which consists of end nodes a and b (sender and addressee) and a set of nodes that are involved in the formation of transmission channels between a and b. Let's suppose there is a route m between nodes a and b, in which the total number of nodes is k. The nodes can vary the transmitter power $p_i(t) \leq p_{i\max}$.

General parameters of the model:

– $T_i(t)$ – lifetime of the i-th node. Information type - $\zeta$=1–3 (speech, data transmission, video)

– the number of recipients for each session $|b|=1$ (transfer for one user)

– radio communication between network nodes is supported by the link layer protocol;

– the signal power at reception and the signal-to-noise ratio are considered unchanged.

The lifetime of a valid route $T_m(t)$ is determined by the minimum "life" time of the i-th university $T_i(t)$ on route m

$$T_m(t)=\min\left(T_1(t),T_2(t),...,T_i(t)\right),\quad i=\overline{1,k}.$$

Network state parameters: $x_1$ – traffic type, $x_2$ – information volume, $x_3$ – number of recipients, $x_4$ – queue size, $x_5$ – route lifetime, $x_6$ – queue size change rate, $x_7$ – packet loss rate, $x_8$ – packet transmission delay in the network , $x_9$ – bandwidth of the channels.

## 5. Results of the development of the model of the forecasting subsystem using genetic algorithms

### 5. 1. Model structure of the subsystem for predicting changes in data transmission routes in special purpose mobile radio networks

On the basis of the above operating model of the MR control system with a forecasting subsystem, the structure of the control system model is proposed, which is built as follows (Fig. 2):

– a mobile radio network, which is designed to collect and process data coming from network nodes, on the basis of which appropriate decisions will be made. This data represents information about the operation, software, hardware and information components of the network at the levels of the OSI model and the set of rules for using this information, that is, it is the environment in which the data is exchanged;

– a node of a mobile radio network, which carries out the deployment, operation, maintenance of devices and provides the necessary communication for network subscribers;

– a subsystem for monitoring, collecting and processing information reflects the operation of the system, provides guidance through the control bodies, coordinates the set of processes for collecting information at different levels of decision-making. It is intended for the accumulation, transmission, archiving, generalization and processing of information on growth, it concretizes the fall in the volume of data, describes information and its state. It provides timely receipt by the user of the necessary and sufficient information for making decisions, the quality of which ensures the effective operation of the network object;

– a knowledge base, which is organized according to certain rules and is supported in the MR by a set of data that characterizes the current state of a certain subject area. It is used to fulfill information requests, a set of facts and rules that allow logical inference and meaningful processing of information;

– a subsystem for the formation of solutions, where, using a common base of control methods, ready-made solutions are formed for specific tasks;

– a subsystem for implementing decisions, which, depending on the tasks set, on the basis of system analysis, makes optimal decisions for their solution;

– a forecasting subsystem collects, processes, stores information, initial data necessary for forecasting. It optimizes the composition of the initial data, methods for measuring and providing information, clarifying and finalizing the structure and composition of the characteristics of the forecasting object. It solves identification, training and forecasting problems in accordance with the tasks that the network performs.

This subsystem is important in that it directly cooperates and influences the processes occurring in such other subsystems of the model: the formation of solutions, the implementation of solutions, the knowledge base, control, collection and processing of data. It is the main element of the proposed model.

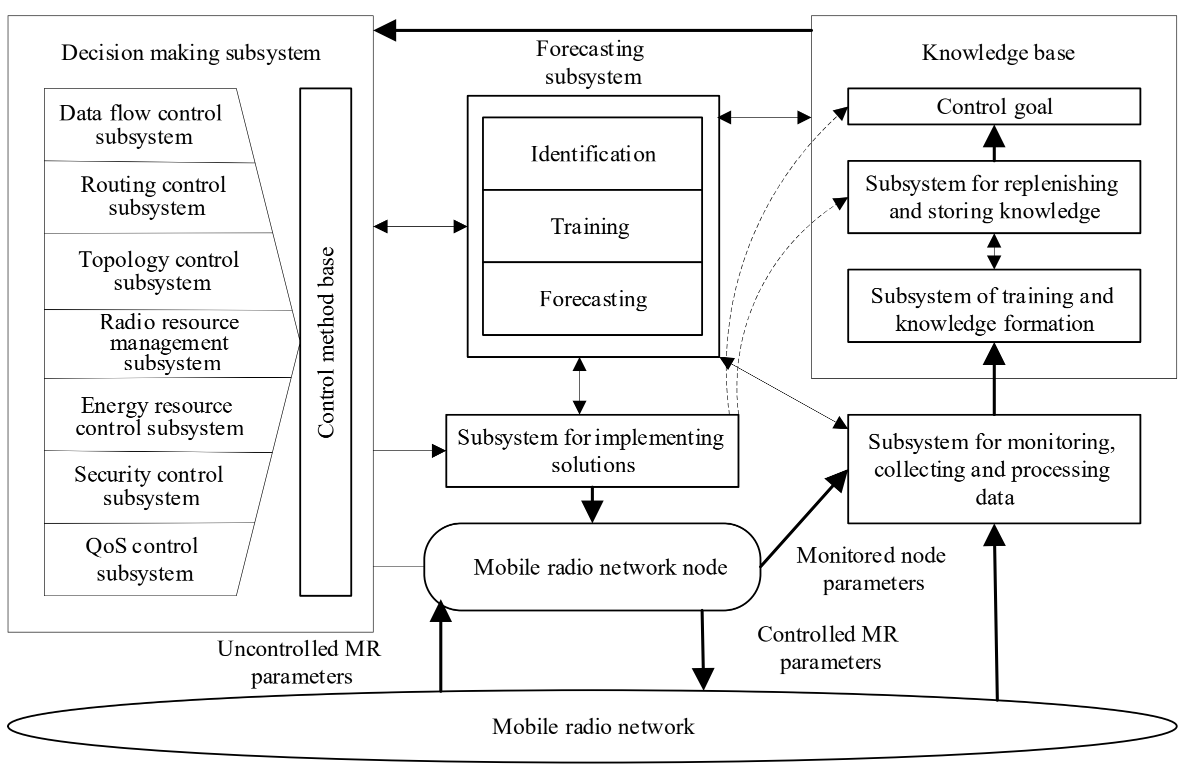


Fig. 2. Prediction subsystem in the structure of the model of the control system of a mobile radio network

The forecasting process is quite complex, it includes a large number of unknown quantities and parameters, to solve the set forecasting problems, it is advisable to use genetic algorithms, including multi-criteria optimization problems. The principle of multiobjective optimization is to find an optimal solution that simultaneously satisfies more than one objective function. In order to find a compromise solution in multicriteria models in optimization theory, there is the concept of the optimal Pareto solution, also known as the solution, does not improve. The formal definition of a Pareto-optimal solution to a multicriteria optimization problem is as follows: a vector $x \in X$ is called a Pareto-optimal solution to the problem when there is no other decoupling vector solution $x^* \in X$ such that $f_i(x^*) \leq f_i(x)$ for $j=1,2,...,k$ за provided that this constraint is strictly satisfied for one j. To solve problems of this type of multicriteria optimization, various methods have been developed that use the traditional technique of optimization and search for solutions [17].

In order to carry out a search in large planes, in the absence of information about the properties of the objective function and restrictions, it is advisable to use genetic algorithms. It is possible to assume that GAs are suitable for solving multicriteria optimization problems when predicting changes in data transmission routes.

**5. 2. Options of solving problems of predicting the congestion time of data transmission routes using genetic algorithms**

**5. 2. 1. A variant of solving identification problems in the identification block of the forecasting subsystem**

The identification block of the forecasting subsystem is considered. The genetic algorithm embodies the idea of Darwinian evolutionary theory based on the generation, testing and selection of the most viable individuals that it is necessary to carry out the identification process [18]. A genetic algorithm is a universal algorithm, since an individual is understood as a solution to a specific problem. Each possible solution represents a point in the search space. For coding the solution of the algorithm, real numbers or the binary alphabet {0,1} can be used. When using a binary alphabet, a string of bits of length m can be thought of as a chromosome. The individual positions (IPs) of the chromosome (bits) act as genes.

GA operation is considered by the example of solving Diophantine equations, which has the form:

$$FD(a,b,c,d)=a+2b+3c+4d=30, \quad (1)$$

where $a$, $b$, $c$ and $d$ are some positive goals.

The solution to this equation occurs by enumerating the options for the values of $a$, $b$, $c$ and $d$. Obviously, the condition $1 \leq a, b, c, d \leq 30$ is satisfied. Therefore, it is necessary to sort out about $30^4=810000$ options. Under normal conditions, it will not be difficult for a computer to find a solution by brute force, but if there are more variables, using GA will significantly reduce the time to find a solution. The chromosome in this example consists of 4 genes: a, b, c and d. Since a gene is an integer less than 30, 5 bits can be used to encode each gene. Then the chromosome will take the form (Fig. 3).

To find a solution, let's use a small population of 5 chromosomes. First, let's generate 5 random feasible solutions

$$F(a,b,c,d)=a+2b+3c+4d,\ a,b,c,d \in \{1, 2, 3 ..., 30\}$$

the value of the decision error is compatible with each option (Table 2):

$$\Delta = \left|F(a,b,c,d) - FD(a,b,c,d)\right|.$$

Table 2

Solution options (in decimal code).

| $i^1$ | Option ($a,b,c,d$) | Error Δ | IP |
|---|---|---|---|
| 1 | (1, 28, 15, 3) | \|114–30\|=84 | 0.012 |
| 2 | (14, 9, 2, 4) | \|54–30\|=24 | 0.042 |
| 3 | (13, 5, 7, 3) | \|56–30\|=26 | 0.038 |
| 4 | (23, 8, 16, 19) | \|163–30\|=133 | 0.0075 |
| 5 | (9, 13, 5, 2) | \|58–30\|=28 | 0.036 |

*Notes: $i^1$ – chromosome number*

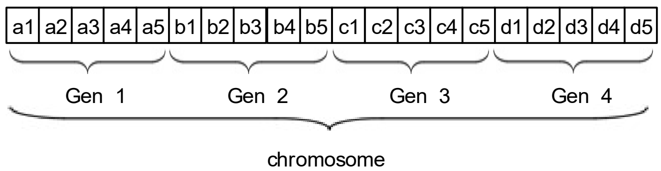


Fig. 3. Coded solutions to Diophantine equations

The essence of GA operation is to leave chromosomes that have a smaller decision error. Therefore, the compliance with the suitability of the chromosome can be described by the expression:

$$IP = 1/\Delta. \quad (2)$$

To calculate the probability of selecting a chromosome in future populations, it is possible to use the formula:

$$P_i = \frac{IP_i}{\sum_{i=1}^{5} IP_i}. \quad (3)$$

The results of applying this expression are shown in Table 3.

Table 3

Probability of chromosome selection

| $i$ | $P_i$ | $S_i$, % |
|---|---|---|
| 1 | 0.012/0.135=0.09 | 9 |
| 2 | 0.042/0.135=0.31 | 31 |
| 3 | 0.038/0.135=0.28 | 28 |
| 4 | 0.0075/0.135=0.06 | 6 |
| 5 | 0.036/0.135=0.26 | 26 |

As a result, there were chromosomes that have a smaller solution error, which indicates the possibility of high-quality identification in the forecasting subsystem.

**5. 2. 2. Option for solving learning problems in the learning block of the forecasting subsystem**

The essence of the operation of the learning unit of the forecasting subsystem was to build a rule base. The formed rules are aimed at identifying significant dependencies in the time series based on the use of the selected GA learning algorithm. They are based on the use of evolutionary principles to find the optimal solution. GAs are designed to solve optimization problems, those that contain a function of several variables $F=(x_1, x_2, ..., x_n)$ and the task is to find its maximum and minimum. The function F is called the objective function, and its variables are called optimization parameters. The function that qualifies fitness must meet a certain condition: the better the person, the better the fitness. GAs operate with a population of a fixed size, which is formed from individuals. These individuals cross with the help of genetic operators and the next generation is formed. Due to this, some of the descendants from the educated generation carry out the replacement of individuals of the old generation, according to the formation strategy. On the basis of a selective strategy, the selection of individuals for crossing is made. The established population makes estimates and on its basis are selected the most preferable for crossing humans. After crossing, descendants are formed and take the place of obsolete individuals. This process continues until a person is found that has an optimal set of gene parameters, the value of the objective function of which is equal to or close to the values of the maximum, minimum. GA stops working if the population degenerates, there is no diversity in the genes of individuals in the population [19].

An example of setting an optimization problem is considered (Fig. 4).

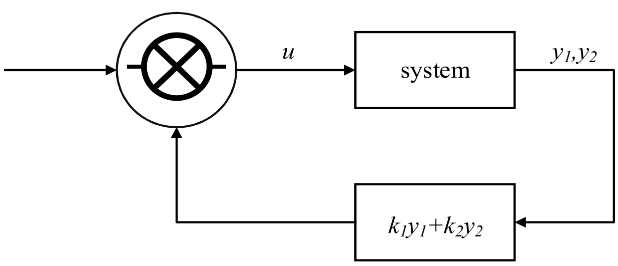


Fig. 4. Scheme of an optimization two-parametric system

For this system, it is worth finding:

$$\min_{k_1 k_2} j = \int_0^t f(y_1, y_2, u)dt, \quad (4)$$

where $k_1, k_2 \in [k_{\min}, k_{\max}]$.

The parameters of this problem are $k_1$ and $k_2$. The search field must contain a finite number of points, which are encoded as chromosomes. The discretized parameters $k_1$ and $k_2$, their set of values in the range from the minimum $k_{\min}$ to the maximum $k_{\max}$ is reproduced in the corresponding binary code sequences. In this case, the value of $k_{\min}$ is comparable to the code sequence made up of zeros, and the value of kmax is the code sequence made up of ones. The length of the data of the code sequences depends on the values of $k_1$ and $k_2$, as well as on the sampling frequency of the interval $[k_{\min}, k_{\max}]$.

Imagine that $k_{\min}$=25, and $k_{\max}$=25, and for each of the parameters $k_1$ and $k_2$, code sequences of length 10 are used. The first 10 genes of all genotypes correspond to $k_1$, the last 10 genes correspond to $k_2$. That is, the length of the chromosomes is 20 (Table 4).

Calculations show that the use of evolutionary principles to find the optimal solution will allow them to be applied in the process of training the forecasting subsystem.

Table 4

Population of 10 persons

| Genotypes | Phenotypes |
|---|---|
| 00000000000000000000 | –25.00–(–25.00) |
| 10100010010011001011 | 6.72–15.08 |
| 01101000101111010010 | –4.57–22.8 |
| 11011010011110000111 | 17.67–19.13 |
| 00011011000000010001 | –19.72–(–24.17) |
| 00110000101011111010 | –15.52–12.24 |
| 11111111111111111111 | 25.00–25.00 |

**5. 2. 3. Option for solving forecasting problems in the forecasting block of the forecasting subsystem**

The forecasting block of the forecasting subsystem is considered. Forecasting is an important area of application for mathematical methods. Methods that use genetic algorithms to predict the behavior and characteristics of time series are considered. Forecasting based on GA is also promising because traditional forecasting methods show low efficiency in many cases, in particular, in the case of processes with a stepwise influence of factors. Traditionally, GAs are used in the field of optimization, but with a certain modification, they can also be used for classification and forecasting [20].

Historically, two approaches to genetic classification have emerged, named after the universities in which they were formed: Michigan and Pittsburgh approaches [21]. The main factor that distinguishes these two approaches is that each element of the population represents one classification rule or a set of such rules. Although these approaches had other differences, let's only use this property to define and distinguish them.

In the Michigan approach, each element of the population encodes one rule, and the population as a whole acts as a concept. In the Pittsburgh approach, each population unit is a complete concept, and the best population unit derived from GA is the final concept that is used for classification. For the better operation of GA, the Pittsburgh approach suits us, which processes a population of populations or a population of a set of rules.

Representation of solutions in the forecasting problem. The internal representation in our case is the classification rules. That is, each individual in the GA population is a species classification rule [21].

If

$$[(v_1 R_1 x_1)\&(v_2 R_2 x_2)\&...\&(v_i R_i x_i)\&...\&(v_n R_n x_n)] \text{ then } D, \quad (5)$$

where $v_i$ – value of the i-th parameter of the classification rule, $x_i$ – value of the i-th indicator corresponding to the test case, $R_i \in \{\leq >\}$ is the comparison ratio, $D \in$ {growth, decline} is the class to which the classification rule assigns test case $i$=1, $n$.

A function called the genome of the classification rule is considered and define it for all and, $i$=1, $n$, as follows:

$$g(v_i, S_i, x_i) = \begin{cases} 1, \text{ if } v_i \leq x_i, S_i = 0, \\ 1, \text{ if } v_i > x_i, S_i = 0, \\ 1, \text{ if } v_i > x_i, S_i = 1, \\ 1, \text{ if } v_i \leq x_i, S_i = 1. \end{cases} \quad (6)$$

$$g(v_i,S_i,x_i): R_1 \times \{0,1\} \times R_1 \to \{0,1\}. \quad (7)$$

An important feature is the introduction of a switch mechanism, which makes it possible to exclude from the rules those genes that are not essential for classification. So, let's define a gene with a switch:

$$\tilde{g}(v_i,s_i,x_i,w_i) = \begin{cases} 1, \text{ if } w_i = 0, \\ g(v_i,s_i,x_i), \text{ if } w_i = 1, \end{cases} \quad (8)$$

$$\tilde{g}(v_i,s_i,x_i,w_i) = R_i \times \{0,1\} \times R_i \times \{0,1\} \to \{0,1\}, \quad (9)$$

$$g_i(v,s,x,w) = \tilde{g}(v_i,s_i,x_i,w_i),$$

$$i = \overline{1,n},$$

where v is a real-valued vector of parameters $x=(x_1,x_2,...,x_n)$, $v=(v_1,v_2,...v_n)$; $x$ is a real-valued diis-valued vector of indicator values that correspond to the test rule $x=(x_1,x_2,...,x_n)$; $s$ is a Boolean vector of sign switches and comparison relation $s=(s_1,s_2,...,s_n)$; $w$ is a Boolean vector of switches $w=(w_1,w_2,...,w_n)$.

Accordingly, the classification rule can be depicted as follows:

$$\text{if} \begin{bmatrix} g_1(v,s,x,w) \,\&\, g_2(v,s,x,w) \,\&\, ... \,\& \\ \& g_1(v,s,x,w) \,\&\, ... \,\&\, g_n(v,s,x,w) \end{bmatrix} \text{TO } D. \quad (10)$$

Thus, each classification rule can be associated with a set of three vectors of length $n$: $v$, $s$, $w$. This correspondence is one of the main features of the proposed approach. After all, the combination of real-valued and Boolean vectors in one person makes it possible to combine within one GA the whole spectrum of evolutionary operators and local search, which are usually divided into operators for lifelong and continuous GA. This feature will allow forecasting in the forecasting subsystem.

## 6. Discussion of the research results of the application of genetic algorithms in the forecasting subsystem

A model of a control system for a mobile radio network with a forecasting subsystem using genetic and evolutionary algorithms has been developed. The operation of the model is based on natural processes reproduced with the help of GA.

The model is based on a subsystem for predicting changes in data transmission routes, which consists of identification, training and forecasting units. The blocks for their operation are considered using evolutionary processes and GA.

The processes described for the identification block embody the idea of Darwinian evolutionary theory based on the generation, testing and selection of the most viable individuals (parameters) that are used in the course of identification. Each possible solution represents a point in the search space (Fig. 3). The calculation of the probability of selection of a chromosome in future populations is carried out according to the formula (3), the corresponding selection results are shown in Table 3. As a result, there were chromoa somes that have a smaller solution error, which indicates the possibility of high-quality identification in the forecasting subsystem.

The essence of the operation of the learning unit of the forecasting subsystem was to build a certain base of rules. The formed rules are aimed at identifying significant dependencies in the time series based on the use of the GA learning algorithm. Calculations were carried out according to the formula (4) on the example of the formulation of the optimization problem (Fig. 4). The learning outcomes are shown in Table 4. The corresponding calculations reflect the possibility of using evolutionary principles to find the optimal solution, which will make it possible to use them in the learning process of the forecasting subsystem.

Forecasting is based on processes that use genetic algorithms to predict the behavior and characteristics of time series. The work itself was carried out on the basis of the Michigan and Pittsburgh approaches with the corresponding representations of solutions in the forecasting problem [21]. The internal representation was the classification rules (5). The function of the genome of the classification rule is calculated according to (6), (7). Introduced mechanisms of "switches" to exclude genes from the rules, which are not essential for classification (8), (9). The classification rule is depicted as follows (10). According to the combination of Boolean and real-valued vectors in one person, it is possible to combine the entire spectrum of evolutionary operators and local search within one GA. The considered feature will help to carry out forecasting in the forecasting subsystem.

In contrast to [7], where a genetic algorithm with two versions of crossovers is proposed, based on the principles of the most rational use of limited resources, the result of work on the blocks of the forecasting subsystem makes it possible to apply evolutionary processes not only in wire and computer networks, but also in MR. This is made possible by bringing Darwinian evolutionary theory to work.

Unlike [8], which presents the results of the development of the VBLAST MAP algorithm: a point-to-point algorithm, which is designed to detect symbols in MIMO wireless communication systems, the result of work on the prediction subsystem blocks indicates the expediency of using GA. This becomes possible due to the fact that GAs do not work directly with numbers, but with a set of criteria (parameters). This feature will allow the implementation of technologies developed on the basis of GA for special purpose MR.

One of the main results of the development of the model is that it can be applied to MR. Due to this, the complexity of the mathematical apparatus is reduced and the design of network devices is simplified. Forecasting based on evolutionary GA has prospects for using the fact that traditional forecasting methods demonstrate low efficiency in many cases, in particular, in processes with a stepwise influence of factors.

Some of the disadvantages of this study include the fact that certain calculations do not always guarantee an optimal solution, but only approach it. In the future, they can be solved by combining computations by GA methods with non-evolutionary types of algorithms, in which the evolution process continues as long as the necessary resources are available.

The conducted research shows the possibility of using it in case of extraordinary network activity with an increased data transfer rate. It improves prediction accuracy and data growth while decreasing prediction time. It decreases sensitivity to delays or packet loss; minimization of negative consequences while packets are in queues while maintaining the positive role of queues. The introduction of this study, taking into account the specified requirements, will make it possible to respond on time and with the necessary quality of service to the tasks set to solve forecasting problems. This technology can be used in mobile radio networks of structures and organizations that perform operational tasks as intended as part of mobile teams.

In the future, research will be carried out on the development of methods for the operation of processes in the blocks of identification, training and forecasting. The essence of the work of which will be provided using a genetic algorithm, evolutionary strategy and evolutionary forecasting, respectively.

## 7. Conclusions

1. The proposed structure of the forecasting subsystem model, in contrast to similar models existing today, which do not take into account the peculiarities of the MR operation, applies the specified features and requirements to it in the case of use in the MR. This is due to the distribution of the forecasting process into three stages of identification, training and forecasting itself. The application of the developed model is possible in MRs, which ensure the performance of special and operational tasks as intended with increased quality and reliability.

2. In order to carry out a search in large planes, in the complete absence of information about the properties of the objective function and restrictions, options for solving problems for predicting the time of congestion of data transmission routes using a genetic algorithm are proposed. They are based on the use of genetic algorithms, which are advisable to use to solve multicriteria optimization problems when predicting changes in data transmission routes. According to the results of the study, the quality of service of the MR control system was improved through the use of identification, training and forecasting units. As a result, chromosomes remain in the identification block, which have a smaller solution error, which indicates the possibility of high-quality identification in the forecasting subsystem. In the training block, calculations show that the use of evolutionary principles to find the optimal solution will allow them to be applied in the learning process. In the prediction block, real-valued and Boolean vectors are combined in one person to combine the entire spectrum of evolutionary operators and local search within one GA, which makes it possible to carry out prediction. It is possible to assume that using the above options will improve the forecasting quality in the forecasting subsystem.

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