УДК 681.516.77
DOI: 10.22213/2413-1172-2022-1-100-107

Identification of Structural Reliability Parameters in Distributed Telecommunication System

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The article considers estimation of structural parameters for communication network. The article aims to calculate the key indicators of structural reliability. Proposed method consists of mathematical expectation estimation for number of connections and connectivity probability in different structured networks. The methodology is based on solution to the problem of network optimization structure for reliability view. Classification of equipment is proposed in terms of failure impact on quality management of network traffic. According to the accepted classification, reliability parameters are listed characterizing each of the classified equipment groups. Reliability parameters are divided into single and complex ones. The reliability and quality of the communication network functioning is assessed by the estimated values of these parameters. A probabilistic graph of network model and state diagram of communication lines for one hierarchical level were plotted. When plotting, it was assumed that switching nodes are absolutely reliable. The reliability of communication lines is expressed in terms of availability. The calculation of parameters was carried out on the assumption that communication line failures are statistically independent events.

Reliability indicators are estimated, such as the probability of connectivity between each pair of telecommunication nodes and the absolute value of mathematical expectation for number of connections. For convenience, practical application of the proposed method, calculation results of the mathematical expectation of number of connections is expressed as a percentage.

The article considers a mathematical model of the functioning of a separate communication line with the absolute reliability of the system for monitoring its technical condition. The mathematical model is presented in the form of a state diagram. It is assumed that the network monitoring system performs the functions of periodic and continuous monitoring. A method for calculating complex indicators of reliability, such as the availability factor and the downtime factor, is proposed. The calculation method is based on the matrix method for analyzing probabilistic systems. The calculation formulas include statistical data from the system for monitoring the technical condition of communication lines.

Modelling is used to simulate the process of communication network functioning in experimental research. The process of communication network functioning is simulated. Depending on the incoming load, a search for free algorithmic resources and communication lines is performed. The calculation of the reliability indicators of the selected way of servicing calls is performed, taking into account the selection criterion set by the program. The monitor displays a dependency graph of the reliability indicators on the intensity of the incoming load. The calculation of the relative statistical frequency of the success of servicing requests is carried out, and the frequency of communication lines failure is also calculated. The program output is proposals for communication network reconstruction due to network resources redistribution.

Keywords: reliability, communication network, structural reliability, mathematical expectation, reliability indicators, failure rate.

Introduction

Estimation parameters of structural reliability are an issue. Solution to this problem is considered in the article. One of the main indicators of structural reliability in communication network is considered to be connectivity probability or mathematical expectation of the number of links in the network.

According to GOST 27.002-89, a communication network is topological system that includes communication nodes and lines. For general case interaction of users from different communication networks is achieved by building territorial communication networks, that is well known distributed telecommunication systems (DTS). The main task is to find out the optimal network structure excluding network redundancy for DTS building.

DTS, as usual, is built according to hierarchical principle of construction. It has a multi-level architecture. Optimization issues are managed to be solved at each level of the hierarchy. Well-known optimization problems are formulated similarly to Steiner problems and travelling salesman problem. For solving process mathematical models are compiled that correspond to real network structures. Two groups of parameters are introduced. The values in first group are alternative and selected to the optimization goals. The values of second group are derived from the first. As the result of decision groups of parameters are found and target optimization function achieves an extremum according to given criterion. However, according to this approach it is not clearly possible to obtain a result suitable for practical application [1-3].

It should be noted that there is no unambiguous definition for optimization concept in communication networks since goals of topological optimization can be very different. The general optimization problem includes number of subtasks, such as problem of shortest path finding for information flow transmitting. One more problem is optimal values finding of the transmission line capacity, determination of structural reliability indicators, and many others.

Problem Statement

Regardless type of communication network and classification signs there are characteristic features of TDS. For instance:

- Network elements are distributed over a large area.
- Different types of communication channels use.
- Limiting number of channels in a given direction.
- Restrictions on bandwidth of communication channels for different types of traffic.
- Compliance with specified reliability parameters.

In terms of construction with listed features, optimization issues in communication networks remain relevant from network topology of view. This is also explained by the fact that network topology optimization tasks can be very different and depends on the specific sub-tasks. Such solution is required at different stages of design process and networks operation for different purposes.

Nowadays information is transmitted over communication networks. That is combined digital streams transmitted at different speeds from different transmission systems and information sources but in the same directions. Modern communication networks are separate devices. That is telecommunication systems united into a single system. Along with user information service information is transmitted over communication networks [4-6].

As usual, two goals are set on regards topology chooses for communication network building:

- Cost reduction.
- Compliance with reliability parameters and survivability.

For performance these values optimization tasks, particularly, analysis and synthesis are solved. However, there is one more aspect in network topology optimization, which is supply of functions performed by the communication network. Standard parameters for transmission and delivery, such as probability of information loss, reliability and others have to be taken into consideration.

Optimal network structure is a quantitative assessment of qualitative state in the system. With regard to DTS optimization problem is reduced to solving the problem of redistributing network resources in event of network scaling, changes in operating conditions, input / output of network equipment, introduction of additional types of services or telecommunication services that imply expansion of network bandwidth, etc. [7-10]

The result of redistributing network resources is estimation specific probabilistic-temporal network parameters, cost parameters and reliability parameters. For ensuring information security in DTS estimation reliability indicators is a priority.

Reliability is property of an object to keep the values for all declared technical parameters in time and within established limits, operating conditions in accordance with GOST R 5311-08.

Regarding consequences of possible failures DTS equipment failures can be classified into:

– Negatively affects quality of service for network traffic as a whole.

– Negatively affects service of traffic in a certain direction.

– Leads to decrease in quality of service for a certain group of users.

– Reliability indicators representing each of listed groups are as follows:

- Availability / downtime ratio.
- Average downtime.
- Mean time between failures (MTBF).
- Mathematical expectation of the number of links.
- Probability of connectivity.
- Average recovery time.

As a whole reliability and quality of DTS functioning is assessed based on estimation results listed reliability indicators.

With solving DTS optimization problems criterion can be single or complex reliability indicators.

For mathematical model compiling of one hierarchical level, it is assumed that all network elements (nodes and communication lines) are in working state. This means that situation of network element blocking and its disconnection from the working network configuration is considered. An alternative direction of service is being obtained. The total amount of network bandwidth resources is decreasing in order to determine overall level of service quality. It is necessary to estimate average blocking probability in relation to all information flows taking into account probability of communication link failure in considered direction. Thus, deterioration quality of service degree in DTS is assessed by direct comparison with conditions of absolute reliability elements. Regarding information security and in case of limited reliability communication lines as part of DTS, availability of information is also decreased [11-14].

In general, reliability of network objects that include communication lines is represented by number of single reliability indicators. The probability of communication line uptime is one of them. In practice probability of no-failure operation of network element can be determined from statistical data recorded by network monitoring system.

For determination probability of failure-free operation of network as a whole, one should take into account such probabilistic reliability indicators as probability of network nodes connectivity and mathematical expectation of number of connections.

To calculate mathematical expectation, communication network is described by a probabilistic graph, where switching nodes (SN) are vertices of graph with fixed reliability indicators, and communication lines are edges those connecting vertices of graph.

For parameters estimation of structural reliability and for design formulas, it is assumed that switching nodes, which are vertices of graph, are absolutely reliable, i.e. $K_{\Gamma}=1$. The edges of graph are also assigned as a weight expressed in terms of K_{Γ}. Figure 1 shows fully connected probabilistic graph of network model. The switching nodes are numbered.

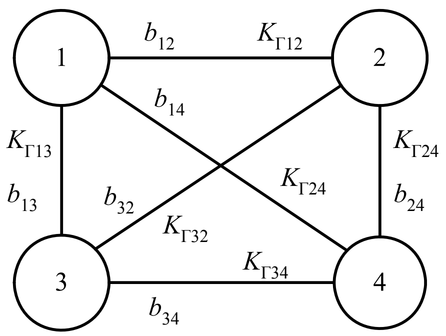

Fig. 1. Full connected probability graph: K_{ij} - availability factor of network section (communication line); b_{ij} - network section between pair of nodes

For mathematical expectation calculation of number of links $M(X)$, it is assumed that failure of one communication line does not lead to occurrence of failure of communication lines used in other directions, i.e. failures are statistically independent events.

For the calculation $M(X)$ one can use the following algorithm. Initially, probability of connectivity between node *i* and node *j* is calculated. A list of all possible paths between any pair of switching nodes is determined. Each path is assigned an accepted indicator of reliability, in this case, availability factor. Using formula for probability calculation of joint events sum, probability of connectivity P_{ij} is calculated. Then absolute value $M(X)$ is calculated by summing connectivity probabilities between each pair of switching nodes. $M(X)$ is calculated as:

$$M(X)_{\text{отн}}=\frac{M(X)}{N_{\max}}100\,\%.$$

For the network structure shown in Figure 1, maximum number of links $N_{\max}=m(m-1)=$ $=4(4-1)=12.$

Following algorithm described above, probability of connectivity between switching node 1 and switching node 2 in Figure 1 is initially estimated. A list of paths connecting considered switching nodes is determined:

$$\mu_{12}^{1}=\{b_{12}\},\quad \mu_{12}^{2}=\{b_{13},b_{32}\},$$

$$\mu_{12}^{3}=\{b_{14},b_{42}\},\quad \mu_{12}^{4}=\{b_{13},b_{34,}b_{42}\}.$$

Each link has corresponding rib weight expressed in terms of availability. Availability factor of each track:

$$H(\mu_{12}^{1})=H(\mu_{12}^{1})=K_{\Gamma 12},\quad H(\mu_{12}^{2})=K_{\Gamma 13}K_{\Gamma 32},$$

$$H(\mu_{12}^{3})=K_{\Gamma 14}K_{\Gamma 42},\quad H(\mu_{12}^{4})=K_{\Gamma 13}K_{\Gamma 34,}K.$$

To calculate probability of connectivity P_{12} formula for estimation probability of joint events sum is used:

$$P_{12}=P_{21}=K_{\Gamma 12}+K_{\Gamma 13}K_{\Gamma 32}+\ldots-$$
$$-K_{\Gamma 12}K_{\Gamma 13}K_{\Gamma 32}K_{\Gamma 14}K_{\Gamma 42}K_{\Gamma 34}.$$

Subject to compatibility condition, parameter K_{Γ} is used in first degree.

$M(X)$ is defined as connectivity probabilities sum of all switching nodes included in the communication network:

$$M(X)=P_{12}+P_{21}+P_{13}+P_{31}+\ldots+P_{34}+P_{43}.$$

Thus, to estimate probability of connectivity, and moreover, mathematical expectation of number of connections in network, it is necessary to determine values of availability factor of each communication line included in network taking into account data of monitoring system.

Identification of network element reliability

Figure 2 shows mathematical model. Separate communication line functioning has absolute reliability of system for monitoring its technical condition. The mathematical model is presented in form of state graph. It is assumed that network monitoring system performs functions of periodic and continuous monitoring. Then, failures can be detected either by continuous monitoring or by periodic testing. As a rule, these failures are independent.

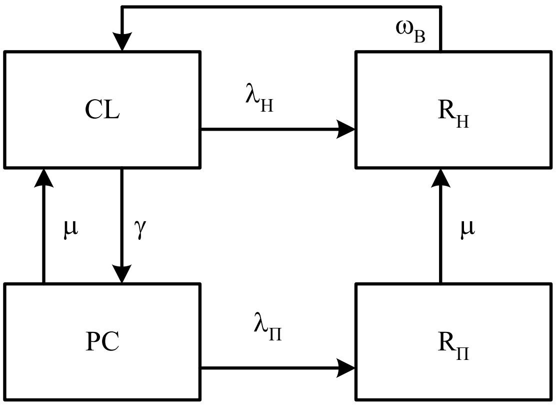

Fig. 2. Link state graph: *CL* - communication line; *PC* (periodic control) - communication line is blocked and is in state of checking its operability by system of periodic control; R_H (recovery) - communication line is blocked and is being restored due to failure detected by continuous monitoring system; $R_П$ (recovery) - communication line is blocked (process of localization of the failure), is being restored due to failure detected by periodic monitoring system; $\lambda_Н$ - failure rate (continuous monitoring); $\lambda_П$ - failure rate (periodic monitoring); $\omega_В$ - link recovery rate; γ - periodic monitoring intensity; μ - control completion rate

During the process of continuous monitoring the communication line is in working configuration and is not blocked for duration of test. In the process of carrying out periodic monitoring, communication line is blocked and removed from working configuration of network.

To derive the final formula, a calculation method based on a matrix method for analyze probabilistic systems was used. The step-by-step algorithm of the proposed calculation method is published in the work Sherstneva O. G., Sherstneva A.A. (2018) “Fundamentals of the theory of reliability of communication facilities and networks”.

As a result, the following expression is obtained:

$$K_П = \frac{(\lambda_Н + \gamma)\lambda_П \omega_В}{(\lambda_Н + \gamma)\lambda + (\lambda + \gamma)\omega_В},$$

$$K_Г = 1 - K_П.$$

For given formulas:

$$\lambda = \lambda_Н + \lambda_П.$$

Parameters included in calculation formula $K_П$ are estimated according to statistical data collected and processed by network monitoring system, i.e. according to data of continuous and periodic monitoring systems.

Obtained estimated values allow getting a real estimate of reliability of each communication line included in overall network structure. It assesses influence degree of separate communication line on quality of traffic service and ordering DTS elements according to their importance, thereby eliminating network redundancy.

Program modelling results

Research and development network models allow solving wide class of problems that arise during operation of telecommunication systems. In practice, result obtained for solving optimization problem is characterized by linear objective function or linear constraints, i.e. methods of linear programming are used. However, to obtain a practical result, as a rule, a number of restrictions are introduced, since optimization problems are characterized by large dimension of initial data.

The external interface of simulation modeling program reflects structure of building telecommunications network in the form of model. The internal structure of program reflects studied process of servicing calls in network, as presence of free network resource (communication line) in it. An example of user interface is shown in Figure 3.

During the developing a program to determine current estimate of the mean recovery time and mean time between failures two types of events were identified. The first type consists in collection the point in time when the network element is excluded from the working configuration. The second type is to include a network element in the running configuration. This event is preceded by either the replacement of the failed functional element or its blocking. It is assumed that the first event is the beginning of recovery, and the second is its completion. The mean time between failures and mean recovery time are estimated for the same set of network elements.

To estimate the probability of events the number of events corresponding to each state of the network element is fixed. For example, the total observation time; the total number of checks performed; the number of devices or network elements that have been restored with failures detected by various types of control (continuous, periodic, as a result of scheduled checks, etc.); the number of devices that have been restored to a healthy state, for example, due to a control system error or software failure, etc.

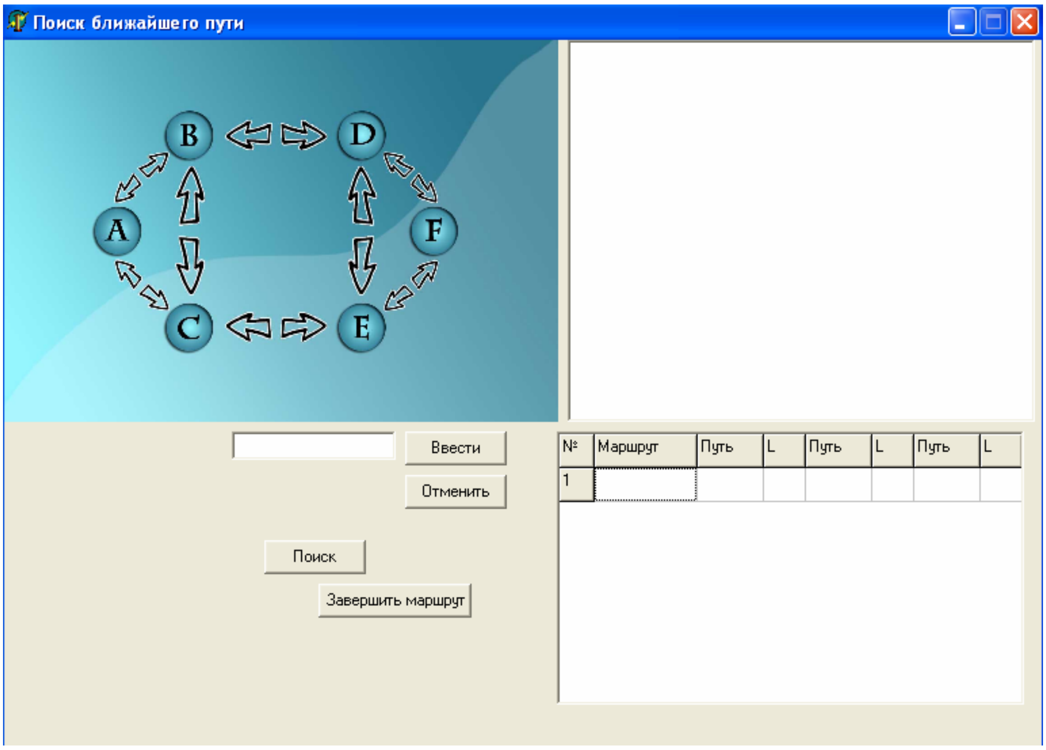

Fig. 3. Program user interface

The program has highlighted a triplet of initial data «entry point - algorithmic element - transition levels» in form of an element of three-dimensional matrix H of dimension [N, E, W], with N - an entry point, E - number of algorithmic elements, W - conditions transition number. The employment of specific system resource of algorithm unambiguously corresponds to mark about employment in element [i, j, l] of matrix H, where l defines corresponding communication line (information flow path). Searching for free algorithmic resources these numbers are compared with current call service time.

Depending on investigated network functioning algorithm and corresponding mathematical model, service program is divided into two subprograms. Subroutines in turn calculate same data arrays, and calculate an integer function at the stage of servicing a specific call: $X(\delta)=\{0;1\}$, where δ - aggregate state parameter of intersystem resources, 0 and 1 - denial of service and service success, respectively.

As a result, relative statistical frequency of service success is calculated P_1, failure rate $P_1 = 1 - P_1$.

The result of program execution is determination of shortest service route and construction of graphs:

• Dependence of mathematical expectation from number of links on calculated value of availability factor taking into account rank of path (Fig. 4).

• Dependence of downtime ratio from total rate of failures detected by both continuous and periodic monitoring systems (Fig. 5).

In general, program allows building various graphs. For example, to build a dependency graph of downtime rate on rate of failures detected only by periodic monitoring or only by continuous monitoring. Taking these data into account, the mathematical expectation of number of connections in network is corrected. It provides possibilities for one or more communication lines exit from working configuration in given direction. Program considers all possible paths from source to destination.

Conclusion

In modern conditions high demands are made on quality of services provided to communication networks and systems. Without compliance with regulatory and technical indicators of reliability in communication network, it is difficult to ensure guaranteed quality and timely delivery of information. Reliability is complex property of communication network that includes complex performance parameters. The article proposes an approach to estimation main indicators of structural reliability for distributed telecommunication network taking into account data from monitoring and control systems [15-20].

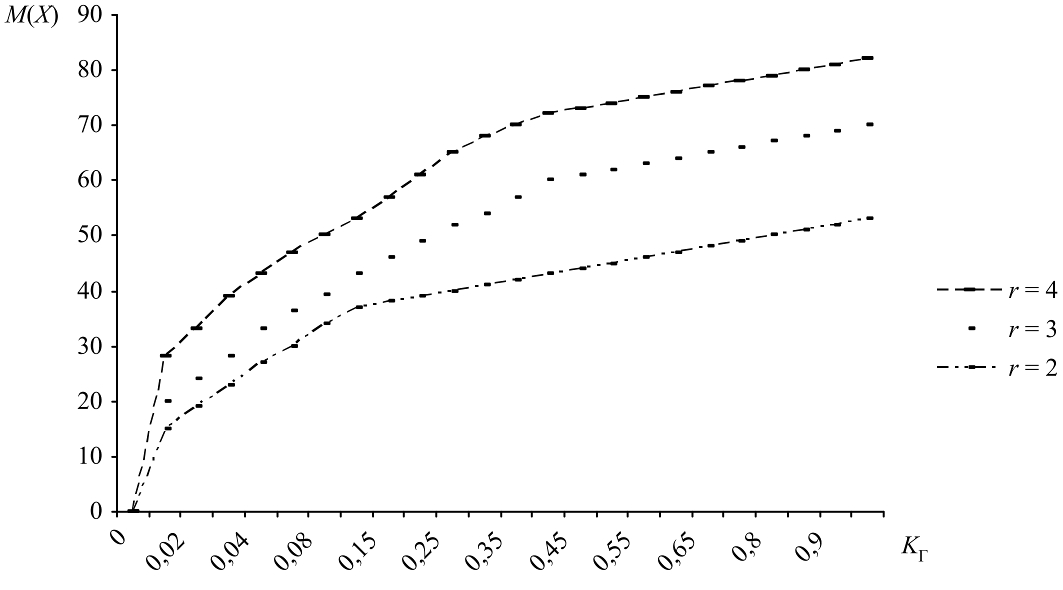

Fig. 4. Dependency graph $M(X)$ from $K_Г$

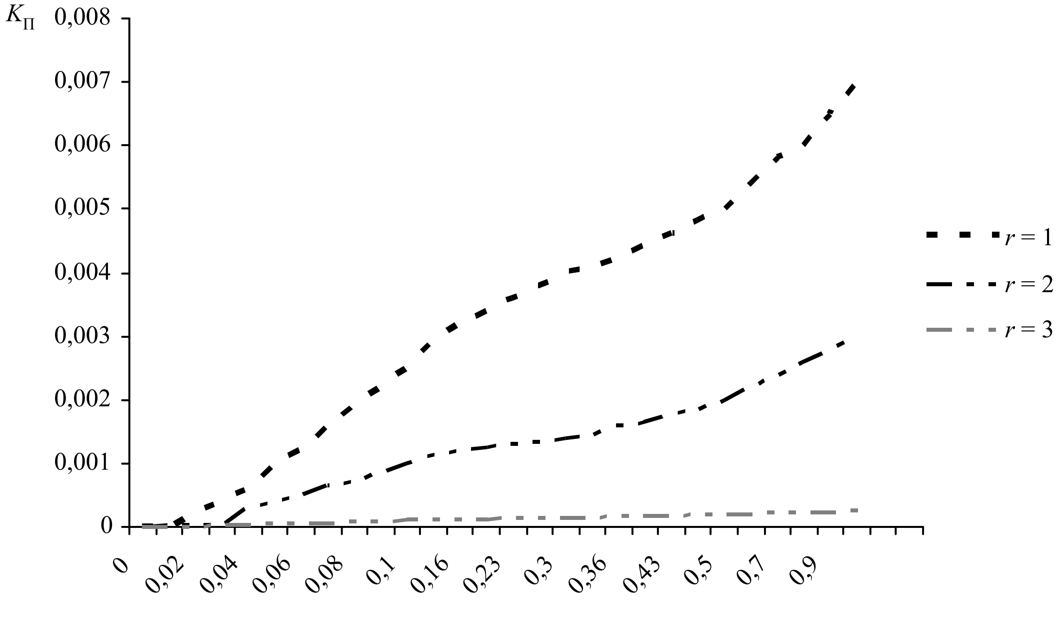

Fig. 5. Dependency graph $K_П$ from λ

The mathematical models of investigated processes are made for distributed communication network. Software implementation is proposed. It makes possible to conduct research and analysis of structural reliability parameters of communication networks.

From the beginning, classification of equipment is proposed according to failure influence degree on quality of service in network traffic. In accordance with accepted classification reliability parameters represent each of listed equipment groups. Reliability parameters are divided into single and complex. The reliability and quality of functioning is assessed by estimated values of these parameters.

For construction switching nodes as assumed are absolutely reliable. Reliability of communication lines is expressed in terms of availability. Estimation of parameters was carried out with assumption about communication line failures are statistically independent events. Reliability indicators are calculated, such as probability of connectivity between each pair of telecommunication nodes and absolute value of mathematical expectation of number of connections. For convenience of practical application calculation results, mathematical expectation of number of links is expressed as a percentage.

To determine values of availability factors, complex reliability indicators for probability of connectivity and mathematical expectation of number of links, second probabilistic graph was drawn up (Fig. 2).

A mathematical model is considered for functioning of separate communication line with absolute reliability of its technical condition system. Mathematical model is presented in form of state graph. As assumed, network monitoring system performs functions of periodic and continuous monitoring. A method for calculating complex reliability indicators, such as availability factor and downtime factor, is proposed. The calculation method is based on matrix method for analyzing probabilistic systems. Calculation formulas include statistical data from monitoring system technical condition of communication lines.

Reliability indicators estimation of selected call service path is performed, taking into account selection criterion set by program. Monitor screen displays dependency graph reliability indicators and incoming load intensity. Calculation is carried out relative statistical rate of success in servicing requests. And rate of failure in communication lines is also calculated. Thus, conclusion is made about structural reliability of network.

The practical significance of the work lies in the implementation of dynamic routing methods taking into account the reliability of the selected route. The proposed calculation algorithm, on the one hand, makes it possible to eliminate network redundancy for building or scaling a communication network, and, on the other hand, to determine a bottleneck, from the reliability point of view, a place in the network infrastructure and make appropriate changes to the routing tables.

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Определение показателей структурной надежности в распределенных телекоммуникационных системах

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Рассмотрена задача расчета структурных характеристик сети связи. Целью работы является вычисление ключевых показателей структурной надежности. Предложена методика расчета математического ожидания числа связей и вероятности связности в сетях разной структуры. В основе методики лежит решение задачи оптимизации сетевой структуры с точки зрения надежности. Предложена классификация оборудования по степени влияния его отказа на качество обслуживания сетевого трафика. Согласно принятой классификации перечислены параметры надежности, характеризующие каждую из классифицируемых групп оборудования. Параметры надежности разделены на единичные и комплексные. Надежность и качество функционирования сети связи оцениваются расчетными значениями этих параметров. Построен вероятностный граф сетевой модели и граф состояний линий связи одного иерархического уровня сети связи. При их построении предполагалось, что коммутационные узлы абсолютно надежны. Надежность линий связи выражена через коэффициент готовности. Расчет параметров выполнен при условии того, что отказы линии связи являются статистически независимыми событиями.

Вычислены показатели надежности, такие как вероятность связности между каждой парой телекоммуникационных узлов и абсолютное значение математического ожидания числа связей. Для удобства практического применения результатов расчета по предлагаемой методике математическое ожидание числа связей выражается в процентах.

Рассматривается математическая модель функционирования отдельно взятой линии связи с абсолютной надежностью системы контроля ее технического состояния. Математическая модель представлена в виде графа состояний. Принято, что система мониторинга сети выполняет функции периодического и непрерывного контроля. Предложена методика расчета комплексных показателей надежности, таких как коэффициент готовности и коэффициент простоя. Методика расчета основана на матричном методе анализа вероятностных систем. В состав расчетных формул вошли статистические данные системы контроля технического состояния линий связи.

При экспериментальных исследованиях применялся метод имитационного моделирования. Моделируется процесс функционирования сети связи. В зависимости от поступающей нагрузки выполняется поиск свободных алгоритмических ресурсов, линий связи. Выполняется расчет показателей надежности выбранного пути обслуживания вызовов с учетом установленного программой критерия выбора. На экран монитора выводятся графики зависимости показателей надежности от интенсивности поступающей нагрузки. Выполняется расчет относительной статистической частоты успешности обслуживания запросов, а также рассчитывается частота отказов линий связи. Результатом работы программы являются предложения по реконструкции сети связи путем перераспределения используемых сетевых ресурсов.

Ключевые слова: надежность, сеть связи, структурная надежность, математическое ожидание, показатели надежности, интенсивность отказов.

Получено 22.12.2021

For Citation

Sherstneva A., Sherstneva O. Identification of Structural Reliability Parameters in Distributed Telecommunication System. *Vestnik IzhGTU imeni M.T. Kalashnikova*, 2022, vol. 25, no. 1, pp. 100-107. DOI: 10.22213/2413-1172-2022-1-100-107.