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METHODS AND ALGORITHMS FOR ASSESSING COMPUTER NETWORK PERFORMANCE

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ABSTRACT

The article proposes an approach that makes it possible to obtain an assessment of the reliability of a data transmission system, containing a description of computational circuits, algorithms, and models for assessing various aspects of reliability: the method for calculating operability is presented for the first time, although it has already become widespread in the design of special-purpose systems.

KEYWORDS

Reliability assessment, operability, system reliability, computational schemes, algorithms, evaluation model.

1. INTRODUCTION

Quite often, in the works [1,3,4,5,6], to determine the reliability of computer systems, as properties to provide communication, while maintaining the values of established quality indicators in time under specified operating conditions, not only and not so much the characteristics of the condition of technical means, their processing for failure, but also the number of user requirements for message reliability indicators, the probability of timely delivery began to be included messages, i.e. due to a wide range of user requirements for reliability indicators. taking into account all the stated requirements at the design stage of computer systems can be implemented by modeling the functioning of the system taking into account failures – restoration and evaluation of the technical condition of the system identified with network connectivity (structural reliability). The connectivity property does not provide the necessary degree of detail about all possible network states at the current time, allows you to operate only in two categories (whether the connectivity requirements are met or not), without determining how “badly” connectivity is broken in case of non-fulfillment of the specified requirements. This is necessary for a more detailed assessment of the state of the computer network. The step-by-step significance of the task of determining the technical condition of the network is increasing. Almost until recently, the definition of “bottlenecks” of the network, in which there is a high probability of failure of elements that will worsen its functioning or lead to a complete failure of the system, was based on the well-known provisions of the theory of reliability, including the concept of a complete failure of the system in case of failure. At the same time, even in the presence of equipment failure or disconnection of part of the system elements, it is possible to transmit and receive information. Known methods of assessing the reliability of computer systems are not taken into account. The step-by-step introduction [2] of conceptual definitions of the technical condition of objects and systems, as well as corresponding quantitative indicators, made it possible to correctly solve a large number of network operation tasks.

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2. INDICATORS TO EVALUATE NETWORK STATE.

The connectivity property does not provide the necessary degree of detail about all possible network states at the current time, since it allows you to operate only two categories (whether the connectivity requirement is met or not), does not determine how “severely” connectivity is disrupted if the specified requirements are not met. Given this, it is necessary to have a more detailed assessment of the state of the computer network. Therefore, the importance of the task of determining the technical condition of the network is increasing. Almost until recently, the definition of “bottlenecks” in the network, in which there is a high probability of failure of elements that will worsen its functioning or lead to complete failure, was based on well-known provisions of reliability theory, including the concept of complete system failure when its elements fail. However, even in the presence of equipment failures or disconnection of part of the system elements, information can be transmitted and received. Well-known methods for evaluating the reliability of computer systems do not take these features into account. Therefore, the introduction in [2] of conceptual definitions of the technical conditions of the object and system, as well as the corresponding quantitative indicators, made it possible to correctly solve a large number of network operation tasks. When designing and operating a computer network, it is necessary to determine the state of the network and its elements, so that, on the one hand, to assess the state of the network from the position of an external observer (maintenance personnel), and on the other hand, to have more detailed information for operational management of network resources. The methodological concept of the state of complex systems is predominant today. The concept of state plays an important role in describing the changes that occur in the network and its elements over time. To assess the reliability of the network and its elements, the following alternative states are mainly used: serviceability, malfunction or operability, inoperable. In certain stages of the network life cycle, mere observation is insufficient. Therefore, a comprehensive evaluation of serviceability, or specifically network operability, becomes essential. A fundamental concept introduced to gauge the technical condition of the system is the notion of personnel competence and overall network performance as perceived by maintenance personnel. This concept facilitates the development of visual, quantitative representations over time, illustrating the operability level throughout network operation. Consequently, it enables meticulous decision-making regarding maintenance structure. Recently, much attention has been paid to the development and implementation of rational strategies for technical operation as an effective means of ensuring the required values of reliability indicators of complex systems. As such an indicator for assessing the technical condition of the network, the work [2] introduced the indicator α_k^{ij}– the level of network operability, which allows determining the degree of network operability from the position of the *i*–th user when interacting with the *j*–th user. Developing this approach, this section proposes a method for evaluating the network performance as a whole, i.e. from the position of the service personnel. Let's consider a more detailed method of assessing the operability of the communication network from the user's position, described in [2]. Each user is interested in the fact that the computer network meets his needs for the delivery of messages in a certain mode, with specified reliability indicators, the main of which are: the probability of timely delivery of messages, message delivery time and reliability. As a rule, the user is interested in the operability or inactivity of the network. In some cases, it is important to know the health of the network or the quality of its functioning at a given time. The definition of the specific state of the network is delineated from the perspective of the *i*-th user linked with the *j*-th user (where $i,j = 1,2,...,N$, N being the number of users). Network serviceability, denoted as Z_u^{ij}, pertains to the network state characterized by the existence of all m potential paths P_{ij}between the *i*-th and *j*-th users, signifying compatibility. This is mathematically represented by the equation:

$$W_{ij} = \cup_{q-1}^{m} P_{ij}^{q}, \ (1)$$

Where m represents the number of paths. Network nonlinearity, $Z_{\overline{u}}^{ij}$, refers to a state wherein at least one connection S_{ij}^{r} $(r = 1,2, \dots ,\ r -$ denoting the number of regulated message delivery modes) is present. Network operability, $Z_{\overline{u}}^{ij}$, denotes a state characterized by the presence of at least one data transmission path between P_{ij} the *i*-th and *j*-th users. Conversely, network inoperability, $Z_{\overline{u}}^{ij}$, describes a state where the last *f*-th (*where f=1,2,…q*) of all *q* (*where q=1,2 ,…m*) possible paths between the *i*-th and *j*-th users fail. The event leading to the transition from state $\mathrm{Z}_{\mathrm{p}}^{\mathrm{ij}}$ state $\mathrm{Z}_{\mathrm{p}}^{\mathrm{ij}}$ is termed a network failure H_{O}^{ij}. The primary functional objective of the network, denoted as Z_{PF}^{ij}, is to ensure timely and error-free message delivery between the *i*-th and *j*-th users, under specific time and mode conditions. Network malfunction, Z_{PF}^{ij}, denotes a condition where the network achieves timely and error-free message delivery in the designated mode. The event leading to the transition from the state Z_{PF}^{ij} to the state Z_{PF}^{ij} will be called a violation of the network $H_{\overline{H}}^{ij}$. For any user, as noted above, the greatest interest is finding the network in the Z_{p}^{C} state, which is a necessary and sufficient condition for ensuring normal functioning in all modes, that is, for analyzing the visibility of the network state from now on. positions, i.e. classification of network states into two classes of states: operability and network inactivity. $Z^{C} \in Z_{p}^{\mathrm{C}} \quad or \quad Z^{C} \in Z_{\overline{p}}^{\mathrm{C}}$ and

$$Z_{p}^{\mathrm{C}} \cap Z_{\overline{p}}^{\mathrm{C}} = 0 \quad (2).$$

As highlighted earlier, the paramount concern for any user is to ascertain the network's state as Z_{p}^{C} which serves as both a necessary and sufficient condition for ensuring seamless operation across all modes. This entails analyzing the network's visibility from the perspective of categorizing its states into two distinct classes: operability and network inactivity. The listed states can be described using Boolean variables. Each state of the P_{ij} path corresponds to a Boolean variable $Z_{p}^{P_{ij}}$, whose valid implementations are *1* or *0*, i.e.

$$Z_{p}^{P_{ij}} = \begin{cases} 1, \text{if the path is free,} \\ 0, \text{in the opposite case).} \end{cases} \quad (3).$$

In turn, the state of each path is determined by the state of the network elements entering it. Each *i*-th element of the network corresponds to a Boolean variable P_{ij}, valid implementations of which are *1* or *0*, i.e.

$$Z_{p}^{n} = \begin{cases} 1, \text{if the n} - \text{th element is operable,} \\ 0, \text{in the opposite case).} \end{cases} \quad (4).$$

That state of the network is uniquely determined through the known state of its elements forming this path. To provide a more nuanced assessment of the network state, the indicator $\alpha_{k}^{ij}(t)$ is introduced. This indicator represents the level of network operability at a given time, enabling the determination of operability from the perspective of the *i*-th user interacting with the *j*-th users. It is defined as follows:

$$\alpha_{k}^{ij}(t) = \frac{\Pi_{ij}^{l}}{m}. \quad (5).$$

Where: *k* is the index of the level of working capacity, *m* is the number of possible paths between the i-th and j-th users.$P_{ij}^{l}, l(l = 1,2, \dots, m)$ – the number of operable paths existing at a given time between the *i*–th and *j*-th corresponding users. For any moment of time *t ≤ 0*, the state of the network *Z(t)* is interpreted as a random variable. The progression of the network state over time can be construed as a stochastic process *{Z(t), t=0}* characterized by a finite set of states. Consequently, the quantitative assessment of network health from the perspective of two users at any given time can be computed using equation (5). Serviceability is the condition in which the object meets all the established requirements. Malfunction is a condition in which an object does not meet at least one of the established requirements. Operability denotes a state where an object can execute predetermined functions while adhering to specified parameter values and established limits. Conversely, inoperability occurs when at least one specified parameter fails to meet requirements despite the object's ability to perform designated functions. Proper functioning describes a state wherein an object fulfills all regulated functions required at the current time, while maintaining parameter values within predefined limits. On the other hand, improper functioning arises when an object fails to perform some regulated functions necessary at the present time and/or does not maintain specified parameter values within established limits. Based on these technical condition definitions, it's evident that: - In a state of serviceability, the object remains operational. - In a state of operability, the object functions correctly across all modes. - In a state of improper functioning, the object is inoperable and defective. Moreover, a properly functioning object may still be inoperable and defective. A functional object may also be defective. Let's consider the events leading to the transition from one technical condition to another. The event (*H*) that leads to the transition of an object: - from $\mathrm{Z_u}$ to $\mathrm{Z_{\overline{u}}}$ is called damage (H_n); - from Z_{p} to $Z_{\overline{\mathrm{p}}}$ is called damage (H_o); - from $\mathrm{Z_{PF}}$ to $\mathrm{Z_{\overline{PF}}}$ is called damage ($H_{\text{н}}$). The transition process: - from $\mathrm{Z_u}$ to $\mathrm{Z_{\overline{u}}}$ is called the “Restoration of serviceability” of B_u; - from $\mathrm{Z_p}$ to $\mathrm{Z_{\overline{p}}}$ we will call the “Restoration of operability” of B_p; - from $\mathrm{Z_p}$ to $\mathrm{Z_{\overline{p}}}$ we call “Restoration of proper functioning” B_{pf}. To determine the types of technical condition of the communication network, based on the general technical concepts of the technical conditions of the object, secondary concepts are introduced, such as: - network resource, a set of tools necessary to perform one of the network functions; - single resource, the amount of resource determined by the minimum amount of function performed for a given system (for example, a single amount of memory, a single bandwidth); a single connection, denoted as $S_{ij}(i,j = 1,2,\dots,N;\ \ i \neq j)$, exists within the network framework, where *N* represents the total number of users. This connection comprises a sequential arrangement of individual network resources proficient in executing all tasks associated with the data delivery process between the *i* th and *j* th users, characterized by unified quality indicators. - connection $\mathrm{S_{ij}^p}$, the minimum set of single connections capable of delivering data from i and j to the user with the specified destination indicators for the p–th mode ($(\mathrm{p} = \overline{1,\mathrm{p}}$, where *p* – is the number of delivery modes). The connection is characterized by the following parameters: a) length:

$$l\left(S_{ij}^{p}\right) = \textstyle\sum_{q=1}^{k} l\,\underbrace{\left(U_q\right)}_{U\epsilon S_{ij}^{p}}. \quad (6).$$

where *l(U)* – is the length of the communication line between the plate nodes; *K* - the number of communication lines encompassed within this connection. b) Time of existence:

$$\mathrm{t}\,\left(\mathrm{S_{ij}^p}\right) = \mathrm{t_{yer}}\left(\mathrm{S_{ij}^p}\right) + \mathrm{t_{coxp}}\left(\mathrm{S_{ij}^p}\right) + \mathrm{t_{зав}}\left(\mathrm{S_{ij}^p}\right). \quad (7).$$

c) Bandwidth: $\mu\ \left(\mathrm{S_{ij}^p}\right)$; d) priority of service; e) broadcasting capability (multi-targeting); f) the discreteness of the input; g) reliability – the probability of implementation and the probability of connection restoration. Path Пij (*or a set of connections*), the minimum set of network resources that allows you to organize several connections, in any necessary combination of their types between the *i*-th and *j*-th users, i.e.

$$P_{ij} = \cup_{p=1}^{p} S_{ij}^{p} . \quad (8).$$

Note that the path is characterized by the same parameters as the connection. Due to the ultimate reliability of network resources, as well as due to the need to ensure a given probability of timely delivery by i - th and j – th users, in addition to the main path, it provides backup paths that together make up a set of paths. The set of paths W_{ij} is the set of all existing or possible paths between the *i*-th and *j*-th users.

$$W_{ij} = \cup_{q=1}^{m} \Pi_{ij}^{q} . \quad (9).$$

where m-is the number of paths. W_{ij} is characterized by the number of paths and the probability of the existence of at least one workable path between the *i*-th and *j*-th users. Then the communication network can be represented as L sets of paths, where L-is the number of user pairs. The minimum number of independent paths between any two users is referred to as network connectivity, denoted as

$$h = min_{ij \in l} W_{ij} . \quad (10).$$

The serviceability of the set of paths W_{ij} is characterized by the presence of all operable P_{ij}. Failure of any P_{ij} leads to a transition to the fault state. The operability of W_{ij} is characterized by the presence of at least one operable P_{ij}, with a partial failure of which W_{ij} goes into a state of inactivity, and with a full one – into a limiting state. The operability of P_{ij} is characterized by the presence of all operable connections. Failure of any connection leads to the transition of P_{ij} to the state of inactivity. The failure of the last of the existing path connections (*complete path failure*) leads to the transition of P_{ij} to the limit state. The operability of S_{ij}^{p} is characterized by the presence of all single connections, the failure of any of them leads to a transition to a state of inactivity. The definitions of the types of technical conditions of the object discussed above and the introduction of secondary concepts allow us to define the types of technical conditions of a computer network. Let's define the technical conditions of the network from the perspective of the *i*-th user corresponding with the *j*-th user (*where i, j=1,2,..., N; i≠j*), where *N*-is the number of users. Network health, denoted Z_{u}^{c}, represents the state of the network characterized by the presence of all m possible paths P_{ij} between the *i*-th and *j*-th users, depicted as a set of paths

$$W_{ij} = \cup_{q=1}^{m} P_{ij}^{q} . \quad (11).$$

Network malfunction Z_{u}^{c} – is a network condition in which at least one connection is inoperable. The occurrence that triggers the shift from the state of Z_{u}^{c} to the state of $Z_{\overline{u}}^{c}$ is termed network damage, denoted as $H_{\text{п}}^{c}$. Network operability, represented as Z_{u}^{c}, indicates the state of the network characterized by the existence of at least one path P_{ij} between the *i*-th and *j*-th users. Network inactivity Z_{p}^{c} is a network condition in which the last P_{ij} path of $q\ (q = 1,2, \dots, m)$ possible paths between the *i*-th and *j*-th users fails. The event causing the transition from the state of $Z_{PF}^{c}$to the state of $Z_{\overline{PF}}^{c}$ is termed a network failure, denoted as $H_{\text{н}}^{c}$. The state of proper functioning over the established connection, referred to as $Z_{p}^{c}0$, signifies the state of the network where data delivery is accurately and promptly guaranteed. The condition of improper functioning $Z_{\overline{PF}}^{c}$ is a network condition in which error-free and/or timely data delivery is not provided. The event leading to the transition from the state of Z_{PF}^{c} to the state $Z_{\overline{PF}}^{c}$ will be called a violation of $H_{\text{н}}^{c}$. Since for any user, as already noted above, the greatest interest is finding the network in the state $Z_{p}^{c}0$, which is a necessary and sufficient condition to ensure proper functioning in all modes, we will analyze the type of technical condition of the network from these positions, i.e. classify the network states into two subsets of states network operability or inactivity

$$Z^{ij} \epsilon Z_{p}^{ij} \text{ or } Z^{ij} \epsilon Z_{\bar{p}}^{ij} \text{ and } \mathrm{Z}^{\mathrm{ij}} \cap \mathrm{Z}_{\bar{\mathrm{p}}}^{\mathrm{ij}} = \emptyset. \quad (12).$$

The network's state is uniquely determined by the states of the set of paths $(\mathrm{W}_{\mathrm{ij}})$, and the state of W_{ij}, in turn, is determined by the states of the paths between the corresponding i-th and j-th users. The considered basic concepts of the computer system operation process allow us to draw the following conclusions: - to formulate the task of general and technical operation of a computer system in a specific formulation; - identify user classes depending on the set of required delivery modes; - identify the necessary computer system resources to meet the needs of users; -to develop an algorithm for managing computer system resources.

3. ALGORITHM FOR EVALUATING THE OPERABILITY OF A COMPUTER NETWORK.

There are various models and methods for calculating the performance characteristics of a computer system. In most cases, simulation models are used. However, the use of such models to calculate various networks with acceptable accuracy requires significant machine time. Analytical methods are more economical than simulation models in terms of machine time costs, but they do not always fully describe the real process, since they have to introduce strong simplifying assumptions, and thus make it convenient for an analytical solution. Different mathematical methodologies are employed to construct models aimed at computing the performance characteristics of a computer system. A special role is assigned to statistical models of the queuing system, which have a number of advantages compared to other models. The flow of messages transmitted over a computer network usually has a statistical character, i.e. the time intervals between the receipt of messages are random variables with the specified distribution laws. The order of service for incoming messages is assumed to be preset. So, if the transmitted messages belong to different categories of urgency, priority service disciplines are usually used in such systems. he operational model of such a system can be depicted as a multi-phase queuing system, where each phase comprises a multi-channel priority queuing system with expected values. The process of passing a message through such a network is modeled in phases with the preservation and transfer from phase to phase of all the characteristics of each priority message. Let's define a computer network in the form of a directed graph *G (v, u)*, where the vertices V $V = \{v_i\}, i = 1,2, \dots, N$; correspond to the nodes of the computer network, and the arcs *U={u_j},j=1,2,...,S*; represent the communication lines. The laws of propagation of incoming message streams entering the system and circulating in it are assumed to be Poisson, the duration of message service is determined using an exponential distribution law with the same parameter for all streams. For the described computer network, which has a hierarchical structure, it is necessary to develop a model for evaluating the functional characteristics of reliability. When constructing a mathematical model, the functional features of the computer network under consideration should be taken into account: - priority flows; - different communication channel performance; - failure rate and channel recovery. The evaluation of delivery characteristics involves modeling a specific direction of information flow using a multi-phase queuing system model. Each phase of this model is depicted as a multi-channel queuing system of the $\vec{M}_k/M/n/r < \infty$, type, which is elaborated upon in this work. Using this model, it is also possible to calculate the characteristics of a network queuing system, such as the probability of timely maintenance, performance, stay time, waiting time, the number of messages (*requests*) in the system, etc. Let's describe the implementation of some computer network functioning processes in the model. Each message entering the computer network is characterized by the time of receipt and priority. At a random moment in time, the system receives messages (*requests*) for maintenance. Since the input stream is Poisson, the time of receipt of the k - th message is determined recursively by the following equation: The equation

$$t_k = t_{k-1} + (-1)(1/\lambda_{\text{вх}}) \ln \xi_k \, . \quad (13).$$

describes the iterative process where: $\lambda_{\text{вх}}$ represents the intensity of message reception; ξ_k - are random numbers uniformly distributed in the interval (*0,1*). At the input of the system, $q^*(q = 1,2,\dots,q^*)$ incoming message streams are received. Messages are unequal in importance: messages from the q-th stream are more important than messages from the $q+1$-st stream, and the latter, in turn, are more important than messages from the $q+2$-nd stream, etc. (*note that all messages in the stream are equivalent*). Messages are "*lined up*" according to priorities and in the order of receipt. The affiliation of each message to a particular priority is determined randomly from the proportion of messages of each priority in the total stream. The messages are serviced by S^* uniform channels, respectively numbered $(1,2,3,\dots,S,\dots,S^*)$.. The system serves incoming messages in order of importance, so that messages with the lowest priority number from among those in the queue always arrive in the vacant channel. If a low priority request has been received for maintenance in any channel, then its maintenance continues to the end even if messages of higher priorities are received by the system during its maintenance, i.e. there is a service with relative priority (*without interruption*). The transmission rate of the message obeys the exponential distribution law with a value of

$$\mu_{\text{обс}}, \text{ i.e. } \mu_i^* = -\mu_{\text{обс}} \cdot \ln \xi_i \, . \quad (14).$$

The considered model takes into account the failure (*failure*) and restoration of service channels. Each channel has an inherent uptime, which is a random variable with a corresponding distribution law. The duration of channel recovery after failure is also a random variable governed by a specified distribution law. If the channel fails at the moment when another message is being serviced in it, then this message is returned to the beginning of the queue of the appropriate priority. Simultaneously, it's possible for the same message to enter both the service area and the waiting area repeatedly. The model takes into account the following message service failures: - due to queue overflow; - due to exceeding the waiting time for maintenance. Given the significance of the system time advancement mechanism in constructing such models, let's explore potential methods for establishing system time. The model's operation should occur in artificial time, guaranteeing event occurrence in the correct sequence and with appropriate time intervals between them. As events may occur simultaneously in various parts of a real system, it's essential to develop a time-setting mechanism to synchronize the actions of system components within a specified time interval. There are two main methods for setting time: - the fixed time step method, in which the system time is counted at predetermined time intervals of constant length; - the method of the step to the next event. When using which, the state of the simulated system is updated with the occurrence of each significant event, regardless of the time intervals between them. Each of these methods has its advantages and disadvantages. For instance, the method of advancing to the next event eliminates the need to designate an arbitrary artificial time increment. This avoids the danger that the time increment value selected without the user's knowledge will change the simulation results. In addition, in this case, events are considered and served as simultaneous only if they are marked with the same time of occurrence. On the other hand, the fixed-step method works better if many events occur during the simulation cycle, and the mathematical expectation of the duration of events is low, as well as when the exact nature of significant events is not clear, as, for example, it happens at the initial stage of the study. When constructing a model of a computer network's operation, the approach of stepping to the next event is chosen. This is mainly due to the fact that more accurate results are obtained, and there is also no need to determine the magnitude of the time increment. The following significant events are selected in the model: the receipt of a message into the system and the release of communication channels. The promotion of the system time T in the model is performed as follows. At the initiation of the simulation, the variable T is initialized to zero, denoted as $T=0$. Subsequently, the time of arrival for the first message is generated, and T is updated accordingly at this juncture. $T = t^1_{\text{пост}}$. All subsequent promotions of T depend on checking the condition: which of the two nearest events – the receipt of a message or the release of a data channel, will happen earlier, i.e.

$$T = \min(t_{\text{пост}}, t_{\text{осв}}). \quad (15).$$

Let's consider an algorithm for evaluating network performance in terms of correlating parameters of users and service personnel (*the network as a whole*). The computational basis of the method for assessing network performance is the following algorithm: 1. The initial data for the simulation are formulated as follows: - The communication network structure is represented by an oriented graph $G(v, u)$, where vertices correspond to network nodes, and arcs (*edges*) represent communication lines. - the characteristics of communication lines are described by the connectivity matrix $B = \|\beta_{ij}\|$, ($\beta_{ij} = 1$, if there's a connection between sets i and j, and $\beta_{ij} = 0$; otherwise. - the set of switching nodes is denoted as $V = \{v_i\}, i = 1,2, \dots, N$;. - The set of linear connections (*elements*) is represented by $U=\{u\_j\ \}$, where $,j=1,2,\dots,S$. - the simulation time interval is denoted as T_M;. - Failure rates of elements are given by $\lambda_{\text{отк}}$, where $j=1,2,\dots,S$. - the recovery intensities of elements are represented by $\lambda^j_{\text{восст}}$, where $j=1,2,\dots,S$. Determines the number of possible paths between the i–th and j–th users $m_{ij} (i \neq j; i,j = 1,2, \dots, N)$, at the initial (t_0) moment of time (when all network elements are functioning). 2. Defines the number of possible communication paths between all pairs of users, at the initial (t_0) moment of time (when all network elements are functioning). 3. Defines the number of possible communication paths between all pairs of users, at the initial (t_0) time point.

$$M_c = \sum_{ij} m_{ij}. \quad (16).$$

4. A random number n is formed in relation to the law of distribution of the incoming flow (*failures and recoveries*). 5. Formation of the timestamp for the next state change (*either failure or recovery*) of the element is expressed as:

$$t_k = t_{k-1} + \eta\ . \quad (17).$$

where t_k represents the time of occurrence of the subsequent event. t_k the moment of receipt of the previous event. 6. Defines the number of existing paths $P_{ij}(t_k)$ between all users, at t_k point in time. 7. Defines the number of existing $P_{ij}(t_k)$ paths between all users, at t_k point in time. 8. Determines the degree of network operability, from the position of the i–th user corresponding with the t_k user:

$$\alpha_{ij}(t_k) = \frac{P_{ij}(t_k)}{m_{ij}}\ . \quad (18).$$

9. Defines α_c-the level of network operability as a whole (*from the point of view of maintenance personnel*) at a given time

$$\alpha_{ij}(t_k) = \frac{\sum_{ij} P_{ij}(t_k)}{\sum_{ij} m_{ij}} \ \text{or } \alpha\ \alpha_c(t_k) = \frac{P_c(t_k)}{M_c}. \quad (19).$$

10. A check is performed to see if the moment t_k– the arrival of a random event for a given simulation interval has been exceeded $t_k < T_M$. If the condition is met, then control is transferred

to step 4. If the condition is met, i.e. the simulation interval is exhausted, you should proceed to processing the simulation results, step 11. 11. Analysis results.

4. CONCLUSIONS

The reliability of modern computer networks is a complex property characterized by taking into account a wide variety of parameters for its definition. These parameters include structural and operational characteristics of the service. Existing methods of performance assessment: a) analytical – are not suitable for multi-pole systems; b) statistics take into account only failures and recoveries of technical elements of the communication network. The statistics take into account only failures and recoveries of technical elements of the communication network. Many available calculation methods, as a rule, reliability assessment is carried out according to one of the parameters (*for example, network connectivity, time to failure, cost of element restoration, etc.*). This is not entirely true, because in real networks, if some of its elements fail, the network can perform its functions. The operability of a computer system - is a new reliability assessment indicator that takes into account the performance of its functions by the system. The purpose of this study is to create an automation system for evaluating and improving reliability, taking into account the structure of the network properties and functional characteristics. The computation of the principal functional attributes of a hierarchical computer network, assuming arbitrary message transmission flow and predetermined service order, is conducted using a multi-phase queuing system (QS) model. Each phase of this model is depicted as a QS of the $\vec{M}_k/M/n/r < \infty$. type. The structural reliability of the network can be estimated as the average proportion of connections between the elements of the network graph, which is preserved while its arbitrary elements are damaged. The proposed method of assessing the operability has no restrictions on the number of corresponding pairs in the network, it allows you to track the dynamics of network operability. As a criterion of "*operational" reliability*, i.e. an assessment of the necessary costs for the reliable functioning of the communication network, the indicator "*reduced costs*" is justified as reflecting the structural and technical characteristics of the communication network. The developed automation system for evaluating the reliability of a computer network for the first time allows us to obtain the dependence of functional characteristics on the level of operability, structural characteristics. This makes it possible, almost for the first time, to have the dynamics of changes in the system's operability, taking into account failures-restoration of elements on the one hand and their influence (*failures*) on the characteristics of the system's functioning on the other. This conclusion is clearly confirmed by a computational experiment. Three schemes for improving the reliability of a computer network are presented. These are the restoration of network elements, the introduction of a reserve and a combined scheme. The selection of each particular scheme is made considering the costs necessary for its implementation. Consequently, the aforementioned costs are taken into account. A computational experiment conducted on a computer network with a specified configuration validates and demonstrates the viability of the proposed approach for evaluating and enhancing reliability. The analysis of the current state of the reliability problem on computer networks carried out in this study shows that in determining reliability as a property to ensure communication, while maintaining the values of established quality indicators in time under specified operating conditions, not only the characteristics of the state of technical means, their operating time, but also many user requirements for indicators of reliability of message delivery, reliability and the error-free transmission of messages, the probability of timely delivery of messages. Of course, taking into account these requirements does not fit into the schemes of traditional reliability calculation methods and requires a new, systematic approach to the formation of a comprehensive reliability assessment, which is the subject of this work, the scientific and practical results of which are as follows: 1. A systematic approach to assessing the operability of a computer network is proposed, including its functional, structural, and operational aspects for networks of arbitrary configuration, which makes it possible to provide controls with objective and reliable information about the state of a computer network. The need to calculate the structural parameters and performance indicators of a computer network is caused by the following reasons: the need to assess the state of the network in order to make a decision on network management in conditions of damage to elements and the need to evaluate intermediate network options at the stage of its synthesis. 2. A new method for calculating the structural reliability of complex multifunctional structures, such as computer networks, is proposed. The structural reliability of the network can be estimated as the average proportion of connections between the elements of the network graph, which is preserved while its arbitrary elements are damaged. 3. A method is proposed for assessing the technical condition of a computer network based on assessments of the operability of both individual corresponding nodes and the entire network. The method imposes no limitations on the number of matching pairs in the network and enables monitoring the dynamics of network performance. 4. The criterion for estimating the cost of network maintenance was reasonably chosen, based on the assumptions that measures to restore elements should be the simplest and the cost of diagnostic tools should be minimal. 5. The structure and management principles of the automation system for obtaining a comprehensive health assessment have been developed, including blocks for calculating the functional characteristics of health, assessing the level of system performance, mechanisms for improving system performance, in case of failure of its elements. 6. The dependence between the functional characteristics of reliability and the level of its operability is obtained. This allows you to identify the risk zones of the system, putting it into an inoperable state. Therefore, a method is introduced for evaluating the technical condition of a computer network by assessing the operability of individual correlating nodes (pairs) as well as the overall compatibility of the network (users). This method imposes no restrictions on the number of correlating pairs in the network, enables monitoring the network's performance dynamics, and consequently serves as a convenient tool in synthesizing network maintenance solutions. Moreover, it emerges as a key component in the design of future digital systems.

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