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Comprehensive Reliability Assessment Technique of Telecommunication Networks Equipment with Reducible Structure

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Introduction. The effectiveness of the functioning of telecommunication systems, which belong to the class of complex technical systems, depends on the reliability of its subsystems and elements, as well as the complexity of the relationships between them. The aim of the article is to substantiate a general approach to a comprehensive assessment of the reliability of telecommunication equipment telecommunications network with a reducible structure with the development of a methodology for calculating equipment reliability indicators. *Main material. Formalized statement of the problem.* The section provides a formalized description of the problem, as well as the limitations and assumptions used in this study. *General approach to solving the problem.* The general approach to solving the problem is based on the use of the decomposition principle, which allows a phased assessment of the reliability of a telecommunication network at three interconnected levels: the first stage is at the level of individual equipment elements (such typical devices as routers, switches, servers, workers stations, IP-encryption equipment, etc.), in which various types of redundancy can be provided separately or jointly: structural, load, temporary; the second stage – at the telecommunication equipment level of information paths (routes); the third stage is at the telecommunication equipment level of information areas, which are a combination of equipment of various paths. *Methodology for solving the problem.* A technique has been proposed for a comprehensive reliability assessment of telecommunication equipment of communication networks with a reducible structure, taking into account a combination of factors, some of which are aggressive and lead to a decrease in reliability (failures causing short-term interruptions in operation; steady equipment failures that need to be restored to serviceability of failed devices in a repair body ; insufficient qualification of the attendants), and others – support the normal functioning of the telecommunication equipment in at the given level (using separately or jointly various types of redundancy – structural, temporary, load, which leads to an increase in the efficiency of using redundancy). *Example.* The given numerical example allows us to identify some new features of the reliability of the operation of the telecommunication equipment telecommunications network due, in particular, to the reliability models not only of steady failures, but also of failures leading to short-term interruptions in operation. *Conclusions.* A promising area of further research is the justification of ways and methods to reduce the intensity of failures in existing and developing equipment, as well as the development of effective ways to neutralize (reduce) their impact on the functioning of telecommunication equipment telecommunication networks.

Key words: reliability; telecommunication equipment; refusals; failures; redundancy

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Introduction

A profound change in communication and computer technology in recent decades has led to the integration of communication networks and computer networks, which made it possible to create a long complex information network and develop a global information structure. There is no doubt that the functioning of such a large system will be significantly affected by the reliability of its subsystems and elements, as well as the complexity of the relationships between them. Despite the continuous improvement of the production technologies of highly reliable elements, assemblies and blocks, as well as methods of their assembly and debugging at the level of subsystems and complexes, nevertheless, the increasing complexity of modern and promising systems does not always allow us to ensure the given reliability of their functioning.

At the same time, an analysis of a number of publications by native and foreign experts indicates a decrease in attention to questions of studying the reliability of the operation of telecommunication equipment (TE) of communication systems and networks [1–14]. The scientific results known in this subject area are devoted mainly to the study of various particular aspects of the reliability of TE and are obtained, as a rule, without comprehensively taking into account the totality of factors affecting reliability. Some of these factors can lead to a decrease in reliability (malfunctions that cause short interruptions in operation; steady equipment failures that require restoration of the failed devices in the repair body; insufficient qualification of the maintenance staff), while others maintain the normal operation of the TE at a given level (using separately or jointly various types of redundancy – structural, temporary, load, as well as increasing productivity of the repair body).

This circumstance has led to the fact that now there is no single methodology and effective scientific and methodological apparatus (methods, models, techniques) for assessing the reliability of TEs and making scientifically sound recommendations for its provision when modernizing existing and building advanced communication networks.

The purpose of the article is to substantiate a general approach to the integrated reliability assessment of TE communication networks with a reducible structure with the development of a methodology for calculating equipment reliability indicators at various levels of the structure: at the level of individual standard devices (switches, routers, servers, etc.), as well as at levels TE structures of individual information routes (paths) and individual communication directions [15].

The comprehensiveness of the reliability assessment of TE means the possibility of jointly taking into account in the proposed mathematical models the main factors that most significantly affect the reliability of equipment: failures, various backup methods (structural, load, temporary), the performance of the repair body, as well as the ability to build reliability models with arbitrary laws distribution of some initial random variables (time of current repair, duration of connecting the structural reserve, time the existence of failures and the elimination of their consequences). By TE of communication networks with a reducible structure will be referred equipment that has a rather complicated structural reliability scheme, which can be reduced to one equivalent element using the regular procedure of replacing all separate serial and parallel sections of the circuit with equivalent elements, with the calculation of the corresponding reliability indicators for them. The reliability indicators obtained as a result of such a conversion of a single equivalent element are taken as indicators of the reliability of the TE with the original complex structure [16–18].

1 Main material. Formalized statement of the problem

The structure of the communication network, as a complex, spatially separated system, can be represented in the form of a graph $G(N, M)$, where $N\{n_i\}$ – variety of peaks (routers, switching centers), $M\{m_{ij}\}$ – variety of edges. The path $\pi = n_1^0 \cap n_2^\tau \cap n_3^\tau, \ldots, \cap n_{k-1}^\tau \cap n_k^0$, where n_1^0, $n_k^0 \in N^0$; $n_2^\tau, n_3^\tau, \ldots, n_{k-1}^\tau \in N^\tau$; n^0 – terminal router, n^τ – transit router. Communication direction $n_1^0(\pi_1) = n_1^0(\pi_2) = \ldots = n_1^0(\pi_k)$ and $n_k^0(\pi_1) = n_k^0(\pi_2) = \ldots = n_k^0(\pi_k)$, that is, all paths in the same communication direction contain the same (n_1^0 and n_k^0) terminal routers. The paths π_1 and π_2 of one direction of communication are independent, if $n_i^\tau(\pi_1) \notin N^\tau(\pi_2)$, and $n_i^\tau(\pi_2) \notin N^\tau(\pi_1)$, that is, the paths of one direction of communication do not contain the same transit routers.

Let the operational and technical characteristics of the TE, which is part of the information paths and communication directions, be known (or set): reliability $P^{(T)} = \{\lambda, \lambda_f, \bar{t}_f, \sigma_f\}$; maintainability $P^{(M)} = \{\bar{t}_R, \sigma_R, l\}$; redundancy $P^{(S)} = \{m, \alpha, \bar{t}_c, \sigma_c, t_a\}$, where λ, λ_f – rate of sustained failures in line; $\bar{t}_f, \sigma_f$ – average value and variance of the time of existence of a failure and its consequences; $\bar{t}_R, \sigma_R$ – average value and variance of the recovery time of a failed device; l – number of crews in a repair body; m – number of backup devices; α – degree of load of structural reserve devices ($\alpha = 0$ – unloaded reserve or $\alpha = 1$ loaded reserve); $\bar{t}_c$, σ_c – average value and variance of the backup device connection time; t_a – allowable connection time (time reserve value).

It is necessary to develop mathematical models of reliability, i.e. analytical dependencies that establish a relationship between the reliability indicators of the TE of the communication network, the reliability characteristics of the elements of its structure and the parameters of the functioning principle: mean time between failures $T_0(t_a) = f_1\left(P^{(T)}, P^{(M)}, P^{(S)}\right)$; probability of uptime $P(t, t_a) = f_2\left(P^{(T)}, P^{(M)}, P^{(S)}\right)$; average recovery time $T_R(t_a) = f_3\left(P^{(T)}, P^{(M)}, P^{(S)}\right)$; coefficient of readiness $K_h(t_a) = f_4\left(P^{(T)}, P^{(M)}, P^{(S)}\right)$; coefficient of operational readiness $P_g(t, t_a) = f_5\left(P^{(T)}, P^{(M)}, P^{(S)}\right)$.

Limitations and assumptions: TE is considered, the structural diagram of the reliability of which can be represented in the form of a reducible structure; the functioning of individual communication paths and directions is carried out independently; repair time of failed elements is significantly less than the mean time between failures; in the repair body, the complete restoration of the performance of the failed elements is carried out.

2 General approach to solving the problem

This approach is based on the decomposition principle, the practical implementation of which in the study of the reliability of TE of communication networks became possible due to the presence of an important feature of this class of complex systems – the possibility of splitting the hierarchy of the structure into a finite number of mutually independent subsystems, and each subsystem into a finite number of simpler subsystems etc. The formalization of the study of the formed scientific and technical problem led to the need for “vertical” and “horizontal” decomposition of this process [19].

The analysis showed that with a “vertical” decomposition, it is advisable to select a set of TE hardware as subsystems of the network structure that form the communication information lines. It is advisable to carry out the “horizontal” decomposition in stages at three interconnected levels:

the first stage – at the level of individual items of equipment (such typical devices as routers, switches, servers, workstations, IP encryption equipment, etc.), in which different types of redundancy can be provided separately or jointly: structural, load, temporary;

the second stage a at the TLCO level of information paths (routes), each of which consists of a combination of various equipment elements, interconnected in a certain way;

the third stage is at the TE level of information areas, which are a set of equipment of various paths. The feasibility of this approach is that it allows the reliability analysis of TE with varying degrees of detailization and depth at each stage of the study.

3 Methodology for solving the problem

This technique is intended for a comprehensive assessment of the reliability of TE communication networks (individual standard devices, as well as the totality of such devices, connected in a certain way and forming TE communication paths and directions) taking into account failures, stable failures and various types of redundancy, which are used individually and jointly. It is based on the above general approach to solving the problem, the formalized formulation of which, the initial data, limitations and assumptions were given earlier.

The technique includes a set of interrelated stages, the consistent implementation of which leads to the achievement of the goal (Fig. 1).

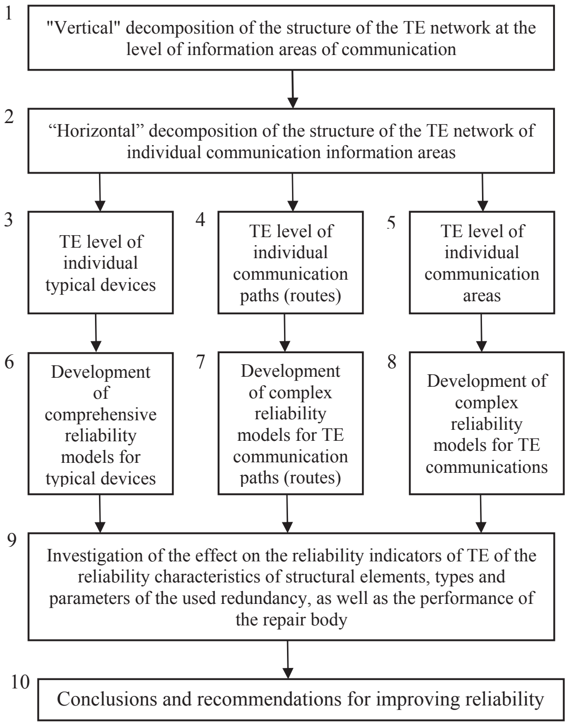

Fig. 1. Integrated block diagram of the integrated assessment methodology reliability of TE communication networks

Consider the main stages of the proposed methodology. Can be assumed that as a result of the operations of the first stage (“vertical” decomposition), a set of mutually independent subsystems is obtained, each of which contains TE communication directions (the solution to this issue is not the task of this article). Here are the results obtained by performing the subsequent steps of the methodology.

3.1 Level of individual typical TE devices

Let us consider the TE kit, which provides sharing of structural, load and temporary redundancy and which will be called the system in the future. Suppose that in the general case the system consists of n main (working) ($n \geqslant 1$) and m backup ($m \geqslant 1$) elements, which for simplicity will be considered identical. In the system, along with structural and temporary redundancy, load redundancy can be used, while the elements of the structural reserve are in unloaded mode.

In each main element, along with stable failures (intensity λ), malfunctions with intensity $\lambda_{\text{з}}$ can occur, stimulating the connection of one of the workable backup elements to the main (working) mode. We denote by $\lambda_i^{(\text{з})}$ the total failure rate and failure, and by λ_i the total failure rate, provided that the i elements are currently inoperative. The value of λ_i is determined by the number of main and backup elements, as well as the failure rate of a separate backup and failure of the main elements, i.e.

$$\lambda_i^{(r)} = n\left(\lambda + \lambda_r\right) + \left(m - i\right)\alpha\lambda, \quad i = 0, 1, 2, \ldots, m; \tag{1}$$

$$\lambda_i = \left[n + \left(m - i\right)\alpha\right]\lambda, \quad i = 0, 1, 2, \ldots, m. \tag{2}$$

At $\alpha = 0$ we get unloaded, and at $\alpha = 1$ – the loaded mode of structural reserve.

In case of failure of one of the main elements, one of the working backup elements is connected instead of it; connection duration t_c – random variable with arbitrary distribution function $F_c(t) = P\{t_c < t\}$. The system has a time reserve – allowable connection time t_a, which setting limits on the duration of each connection. The probability q that the refusals (failures) of one of the main elements and the further connection of the reserve will lead to the failure (disruption of operation) of the system (due to the long-term connection $t_c > t_a$) is determined by the formula:

$$q = P\left\{t_c > t_a\right\} = 1 - F_c\left(t_a\right). \tag{3}$$

Repair of failed elements (primary or backup) begins immediately.

The repair body l includes $(1 \leqslant l \leqslant m+1)$ repair crews with the same distribution of the duration of recovery $F_R(t) = P\{t_R < t\}$. Upon completion of the repair of one of the $m+1$ inoperative elements of the functioning of the system, the functioning resumes. To the previously accepted limitations and assumptions, can be assumed that

$$\bar{t}_R << 1/(\lambda + \lambda_c); \quad \bar{t}_R << 1/(\lambda + \lambda_R);$$

$$t_a << 1/(\lambda + \lambda_f); \quad \bar{t}_c << \bar{t}_R; \; t_a << \bar{t}_R.$$

For the accepted initial conditions in [20, 21], calculated ratios for the main reliability indicators (reliability models) of the system (TE set of a typical device) were obtained and have the form:

$$T_0\left(t_a\right) = \frac{1}{n\lambda}\left[\frac{x(n\rho)^m}{m!}\prod_{i-1}^{m}\left(n + i\alpha\right) + q\left(1 + k_f\right)\right]^{-1}; \tag{4}$$

$$P\left(t, t_a\right) = \exp\left[-n\lambda t\left(\frac{x(n\rho)^m}{m!}\prod_{i-1}^{m}\left(n + i\alpha\right) + q\left(1 + k_f\right)\right)\right]; \tag{5}$$

$$T_R\left(t_a\right) = \frac{1}{q_0}\left[q_1 T_R^* + q_2 T_c^*\left(t_f\right)\right], \tag{6}$$

where

$$q_0 = q_1 + q_2 = q_1 = \begin{cases} \frac{\beta_m}{m!}\prod\limits_{i=1}^{m}\lambda_i + \frac{qn(\lambda+\lambda_f)}{\lambda_0^{(f)}}, \; l = 1, \\ \frac{\beta_1^m}{m!}\prod\limits_{i=1}^{m}\lambda_i + \frac{qn(\lambda+\lambda_f)}{\lambda_0^{(f)}}, \; l \geqslant m; \end{cases} \tag{7}$$

$$T_R^* = \begin{cases} \frac{\beta_{m+1}}{(m+1)\beta_m}, \; l = 1, \\ \frac{\beta_1}{m+1}, \; l = m+1; \end{cases} \quad x = \begin{cases} \frac{\beta_m}{\beta_1^m}, \; l = 1, \\ 1, \; l \geqslant m; \end{cases} \tag{8}$$

$$T_c^*\left(t_a\right) = \int\limits_{t_a}^{\infty}\frac{\left(t - t_a\right)dF_c\left(t\right)}{1 - F_c\left(t_a\right)} = \frac{1}{1 - F_c\left(t_a\right)}\int\limits_{t_a}^{\infty}x\,dF_c\left(x\right) - t_a; \tag{9}$$

λ_i – formula (2); $\lambda_0^{(f)}$ – formula (1) when i=0; q – formula (3); $k_f = \lambda_f/\lambda$; $\rho = \lambda\bar{t}_R$; $\bar{t}_R = \beta_1$; $\beta_m = \int\limits_0^{\infty} x^m dF_R(x)$;

$$K_h\left(t_a\right) = \left[1 + \frac{T_R\left(t_a\right)}{T_0\left(t_a\right)}\right]^{-1}; \quad P_g\left(t, t_a\right) = K_h\left(t_a\right)P\left(t, t_a\right). \tag{10}$$

Let us now consider another typical TE kit, in which only temporary reservation is used (there is no structural reserve). For this device [22, 23], the following reliability models were obtained in

$$T_0\left(t_a\right) = \frac{1}{\lambda + \lambda_f q} = \frac{1}{\lambda\left(1 + k_f q\right)}; \tag{11}$$

$$P\left(t, t_a\right) = \exp\left[-\frac{t}{T_0\left(t_a\right)}\right] = \exp\left[-\lambda t\left(1 + k_f q\right)\right]; \tag{12}$$

$$T_R\left(t_a\right) = \frac{\bar{t}_R + k_f q T_f^*\left(t_a\right)}{1 + k_f q}; \tag{13}$$

$$K_h\left(t_a\right) = \left[1 + \frac{T_R\left(t_a\right)}{T_0\left(t_a\right)}\right]^{-1} = \left[1 + \lambda\left(\bar{t}_R + k_f q T_f^*\left(t_a\right)\right)\right]^{-1}; \tag{14}$$

$$P_g\left(t, t_a\right) = K_h\left(t_a\right)\exp\left[-\lambda t\left(1 + k_f q\right)\right], \tag{15}$$

where

$$T_f^*\left(t_a\right) = \int\limits_{t_a}^{\infty}\frac{\left(t - t_a\right)dF_f\left(t\right)}{1 - F_f\left(t_a\right)} = \frac{1}{1 - F_f\left(t_a\right)}\int\limits_{t_a}^{\infty}x\,dF_f\left(x\right) - t_a, \tag{16}$$

$F_f^*(t) = P\{t_f \leqslant t\}$, $q = P\{t_f \leqslant t\} = 1 - F_f(t_a)$, $k_f = \lambda_f/\lambda$.

3.2 The TE level of information paths (routes) and communication directions, consisting of individual communication directions

Fig. 2 shows a fragment of a communication network consisting of separate communication directions, each of which includes a set of independent paths.

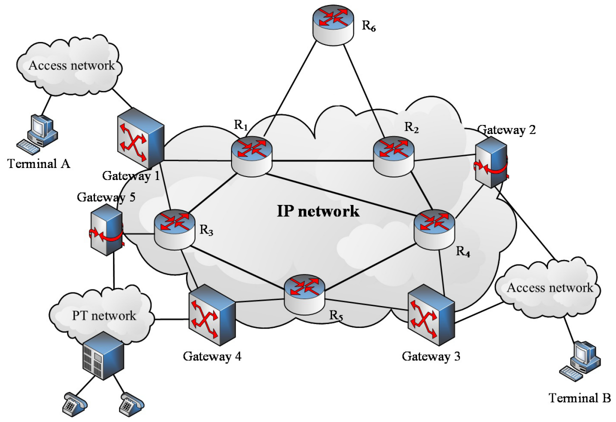

Fig. 2. A fragment of a communication network

Consider one of these paths, for example, I_{14}, containing routers, channel forming and switching equipment and other devices as standard equipment. The structural diagram of the reliability of path I_{14} is shown in Fig. 3 (can be assumed that in elements 1, 3, 4 temporary reservation is provided, and in elements 2, 5 – temporary, structural and load). As a result of two successive transformations of this scheme, we arrive at a single equivalent element $(1-5)^e$, the reliability indicators of which can be expressed by the formulas:

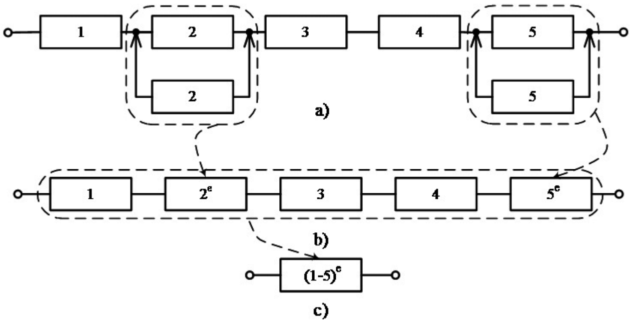

Fig. 3. The structural diagram of the reliability of the TE communication path: a – before conversion; b – after the first conversion step; c – after the second conversion step

$$T_0^{(e)}(t_a) = \frac{1}{\sum\limits_{i=1}^{5} \Lambda_{0i}^{(1)}(t_a)} = \frac{1}{\Lambda_0^{(e)}(t_a)}; \qquad (17)$$

$$P^{(e)}(t,t_a) = \prod_{i=1}^{5} P_i^{(1)}(t,t_a) =$$
$$= \prod_{i=1}^{5} \exp\left[-t\Lambda_{0i}^{(1)}(t_a)\right] = \exp\left[-t\Lambda^{(e)}(t_a)\right]; \qquad (18)$$

$$T_R^{(e)}(t_a) = \sum_{i=1}^{5} \frac{\Lambda_{0i}^{(1)}(t_a)}{\Lambda_0^{(e)}(t_a)} T_{Ri}^{(1)}(t_a); \qquad (19)$$

$$K_h^{(e)}(t_a) = \prod_{i=1}^{5} K_{hi}^{(1)}(t_a) =$$
$$= \prod_{i=1}^{5} \frac{T_{0i}^{(1)}(t_a)}{T_{0i}^{(1)}(t_a) + T_R^{(1)}(t_a)} =$$
$$= \frac{T_0^{(e)}(t_a)}{T_0^{(e)}(t_a) + T_R^{(e)}(t_a)}; \qquad (20)$$

$$P_g^{(e)}(t_a) = K_h^{(e)}(t_a) P^{(e)}(t,t_a) =$$
$$= \frac{T_0^{(e)}(t_a)}{T_0^{(e)}(t_a) + T_R^{(e)}(t_a)} \exp\left[-t\Lambda_0^{(e)}(t_a)\right], \qquad (21)$$

where $T_{0i}^{(1)}(t_a) = 1\Big/\Lambda_{0i}^{(1)}(t_a)$; $P_i^{(1)}(t,t_a)$; $T_{\mathrm{B}i}^{(1)}(t_{\text{Д}})$; $K_{hi}^{(1)}(t_a)$; $P_{gi}^{(e)}(t,t_a)$, $i = \overline{1,5}$ – TE indicators after the first step of the circuit transformation (Fig. 3 b) obtained using formulas (4) – (16).

Let us construct a structural diagram of the reliability of the TE communication direction I_{14} (Fig. 4), using the network fragment shown in Fig. 2.

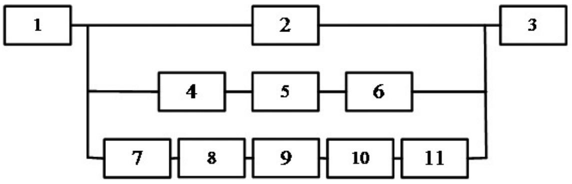

Fig. 4. The structural diagram of the reliability of TE information direction I_{14}

In fig. 4 marked: 1 – router R_1, 2 – communication line m_{14}, 3 – router R_4, 4 – communication line m_{12}, 5 – router R_2, 6 – communication line m_{24}, 7 – communication line m_{13}, 8 – router R_3, 9 – communication line m_{35}, 10 – router R_5, 11 – communication line m_{45}.

Let us use the procedure of sequential conversion of this structural diagram. At the first step of section 4 – 6 and 7 – 11, we replace with equivalent elements $3^{(e)}$ and $4^{(e)}$, for which we obtain a set of reliability indicators $T_0(t_a)$, $P(t,t_a)$, $T_R(t_a)$, $K_h(t_a)$, $P_g(t,t_a)$ using formulas similar to (17) – (21) (indices $3^{(e)}$ and $4^{(e)}$ can be omitted for simplification of the record) (Fig. 5 a).

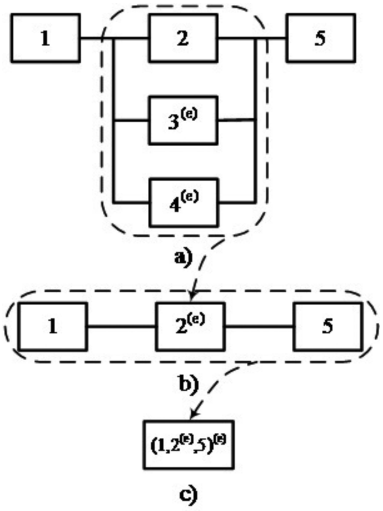

Fig. 5. The structural diagram of the reliability of TE information direction I_{14}: a – after the first conversion; b – after the second conversion; c – after the third conversion

At the second step, we replace the parallel section of circuit 2, $3^{(e)}$, $4^{(e)}$ with one equivalent element $2^{(e)}$ (Fig. 5 b), the reliability of which is determined by the formulas:

$$P^{(2^e)}(t,t_a) = 1 - \left(1 - P^{(2)}(t,t_a)\right) \times \times \left(1 - P^{(3^e)}(t,t_a)\right)\left(1 - P^{(4^e)}(t,t_a)\right); \quad (22)$$

$$K_h^{(2^e)}(t_a) = 1 - \left(1 - K_h^{(2)}(t_a)\right) \times \times \left(1 - K_h^{(3)}(t_a)\right)\left(1 - K_h^{(4)}(t_a)\right); \quad (23)$$

$$P_g^{(2^e)}(t,t_a) = 1 - \left(1 - P_g^{(2)}(t,t_a)\right) \times \times \left(1 - P_g^{(3)}(t,t_a)\right)\left(1 - P_g^{(4)}(t,t_a)\right). \quad (24)$$

At the third step, a section of the structural diagram of three series-connected elements 1, $2^{(e)}$, 5 is replaced by one equivalent element $6^{(e)}$ (Fig. 5 c) and these formulas can be used to evaluate it's reliability (the index $6^{(e)}$ can be omitted):

$$P(t,t_a) = P^{(1)}(t,t_a)\,P^{(2^e)}(t,t_a)\,P^{(5)}(t,t_a); \quad (25)$$

$$K(t_a) = K_h^{(1)}(t_a)\,K_h^{(2^e)}(t_a)\,K_h^{(5)}(t_a); \quad (26)$$

$$P_g(t,t_a) = P_g^{(1)}(t,t_a)\,P_g^{(2^e)}(t,t_a)\,P_g^{(5)}(t,t_a), \quad (27)$$

where $P^{(1)}(t,t_a)$; $P^{(5)}(t,t_a)$; $K_h^{(1)}(t_a)$; $K_h^{(5)}(t_a)$; $P_g^{(1)}(t,t_a)$ and $P_g^{(5)}(t,t_a)$ expressed by appropriate formulas (12), (14) and (15). $P^{(2e)}(t,t_a)$; $K_h^{(2e)}(t_a)$ and $P_g^{(2e)}(t,t_a)$ – by formulas (22), (23) and (24).

Thus, the reliability indicators (formulas (25) – (27)) of a single equivalent element $6^{(e)}$ (Fig. 5 c), to which we brought the initial structural reliability diagram (Fig. 4). As a result of three successive transformations the indicators reflect the reliability of the TE under consideration communication directions I_{14}.

4 Example

Consider a numerical example that will allow us to quantify the influence of the main factors affecting the reliability of the TE information path and communication direction I_{14} (Fig. 3 and 4). Can be assumed that the information area and their communication paths contain typical TE kits, one of which provides for the use of structural, load and temporary redundancy [20, 21], and in the other – the usage of temporary redundancy only [22, 23]. Let the first set of equipment be characterized by the following parameters: single-use structural reserve (duplication); failure rate of the main (working) device $\lambda = 1,25 \cdot 10^{-4}$ 1/h; the backup device is in unloaded state ($\alpha = 0$); there is one team in the repair department ($l = 1$); average recovery time $\bar{t}_R = 24$ h; $k_f = \lambda_f/\lambda = 0,\ 1,\ 5$; average backup device connection time $\bar{t}_c = 10$ min.; connection time is distributed according to Erlang law of the 2nd order; allowable connection time (time reserve value) $\bar{t}_a = 0$; 4 min.; 8 min.; 12 min. In the calculation, formulas (4) – (10) were used when $n = m = 1$.

When calculating the reliability indicators of the second standard set of equipment, the following initial data was used: $m = 0$ (no structural reserve); $\lambda = 1,25 \cdot 10^{-4}$ 1/h; $\bar{t}_R = 24$ h; $k_f = \lambda_f/\lambda = 0,\ 1,\ 5$; the duration of failures and the elimination of their consequences - a random variable distributed according to Erlang law of the 2nd order with an average value $\bar{t} = 10$min.; $\bar{t}_a = 0$; 4 min.; 8 min.; 12 min. In the calculation, formulas (11) – (16) were used.

The table 1 shows the results of calculating the reliability indicators of the TE information path (Fig. 3) and the direction of communication I_{14} (Fig. 4). In the calculation, formulas (17) – (27) were used.

An analysis of the data in the table 1 reveals some new features of the reliability of the operation of TE communication networks, caused, in particular, by taking into account the reliability models not only of steady failures, but also of failures leading to short-term interruptions in operation.

1. Failures significantly affect the reliability indicators of the TE, especially the reliability indicators ($T_0(t_a)$, $P(t,t_a)$) and the integrated indicator – the coefficient of operational readiness $P_g(t,t_a)$. It should be noted that the availability factor $K_h(t_a)$ is not very sensitive to failures.

2. An important factor (effective way) to neutralize (reduce) the harmful effect of failures on the reliability

Table 1 The results of calculating the reliability indicators of TE information paths and communication directions I_{14}

TE	Indicator	Time reserve $t_a = 4$ min			Time reserve $t_a = 12$ min		
		$k_f = 0$	$k_f = 1$	$k_f = 5$	$k_f = 0$	$k_f = 1$	$k_f = 5$
Communication path	$P(t, t_a)$	0,9862	0,9740	0,9279	0,9866	0,9846	0,9664
	$K_h(t_a)$	0,99098	0,99095	0,99067	0,9910	0,99099	0,99086
	$P_g(t, t_a)$	0,9773	0,9651	0,9192	0,9807	0,9757	0,9574
Directions of communication I_{14}	$P(t, t_a)$	0,952	0,9902	0,9708	0,9986	0,9962	0,9888
	$K_h(t_a)$	0,99995	0,99993	0,99982	0,99997	0,99996	0,99993
	$P_g(t, t_a)$	0,99515	0,9901	0,9703	0,9985	0,9961	0,9886

of a TE is temporary reservation – usage of allowable time t_a equipment functioning interruption.

If this parameter t_a is present, part of the failures, the duration of which does not exceed the permissible value of t_a, does not affect the reliability of the TE operation – there is a ”rarefaction” (decrease in intensity) of the input failure flow, which leads to a decrease in the number of failures (interruptions in operation) of the equipment due to failures.

Conclusions

To obtain more reliable calculated values of the reliability indicators of TE communication networks, it is necessary to use methods based on an integrated approach to assessing reliability, which allows you to take into account all the main factors affecting the reliability of operation, in particular, failures, various types of equipment redundancy and repair body performance.

One of the promising areas for further research is selection and justification of ways and methods of reducing the recovery time of a failed TE based on an increase in the productivity of the repair body.

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Методика комплексної оцінки надійності телекомунікаційного обладнання мереж зв'язку зі звідною структурою

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Вступ. Ефективність функціонування телекомунікаційних систем, які відносяться до класу складних технічних систем, залежить від надійності складових її підсистем і елементів, а також складності зв'язків між ними. Метою статті є обґрунтування загального підходу до комплексної оцінки надійності телекомунікаційного обладнання телекомунікаційної мережі зі звідною структурою з розробкою методики розрахунку показників надійності обладнання.

Основний матеріал. Формалізована постановка задачі. У розділі представлено опис проблеми в формалізованому вигляді, а також обмеження та допущення, що використовуються в наведеному дослідженні.

Загальний підхід до вирішення задачі. Загальний підхід до вирішення задачі базується на використанні принципу декомпозиції, який дозволяє поетапно проводити оцінку надійності телекомунікаційної мережі на трьох взаємопов'язаних рівнях: перший етап – на рівні окремих елементів обладнання (таких типових пристроїв, як маршрутизатори, комутатори, сервера, робочі станції, апаратура IP-шифрування і т.д.), в яких можуть бути передбачені окремо або спільно різні види резервування: структурного, навантажувального, часового; другий етап – на рівні телекомунікаційного обладнання інформаційних шляхів (маршрутів); третій етап – на рівні телекомунікаційного обладнання інформаційних напрямків, які представляють собою сукупність обладнання різних шляхів.

Методика вирішення задачі. Запропоновано методику комплексної оцінки надійності телекомунікаційного обладнання мереж зв'язку зі звідною структурою, що враховує сукупність факторів, одні з яких є агресивними і призводять до зниження надійності (збої, що викликають короткочасні перериви у функціонуванні; стійкі відмови обладнання, які потребують відновлення працездатності пристроїв, що відмовили у ремонтному органі; недостатня кваліфікація обслуговуючого персоналу), а інші – підтримують нормальне функціонування телекомунікаційного обладнання на заданому рівні (використання окремо або спільно різних видів резервування – структурного, часового, навантажувального, що призводить до підвищення ефективності використання надлишковості).

Пример. Наведений числовий приклад дозволяє виявити деякі нові особливості надійності функціонування телекомунікаційного обладнання телекомунікаційної мережі обумовлені, зокрема, урахуванням в моделях надійності не тільки стійких відмов, але і збоїв, що призводять до короткочасних перерв у функціонуванні.

Висновки. Перспективним напрямком подальших досліджень є обґрунтування шляхів та методів зменшення інтенсивності збоїв в існуючому і обладнанні, що розробляється, а також розробка ефективних способів нейтралізації (зменшення) їх впливу на процес функціонування телекомунікаційного обладнання телекомунікаційних мереж.

Ключові слова: надійність; телекомунікаційне обладнання; відмови; збої; резервування

Методика комплексной оценки надежности телекоммуникационного оборудования сетей связи с приводимой структурой

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Введение. Эффективность функционирования телекоммуникационных систем, которые относятся к классу сложных технических систем, зависит от надежности составляющих ее подсистем и элементов, а также сложности связей между ними. Целью статьи является обоснование общего подхода к комплексной оценке надежности телекоммуникационного оборудования телекоммуникационной сети с приводимой структурой с разработкой методики расчета показателей надежности оборудования.

Основной материал. Формализованная постановка задачи. В разделе представлено описание проблемы в формализованном виде, а также ограничения и допущения, используемые в приведенном исследовании.

Общий подход к решению задачи. Общий подход решения задачи базируется на использовании принципа декомпозиции, который позволяет поэтапно проводить оценку надежности телекоммуникационной сети на трех взаимосвязанных уровнях: первый этап – на уровне отдельных элементов оборудования (таких типовых устройств, как маршрутизаторы, коммутаторы, сервера, рабочие станции, аппаратура IP-шифрования и т.д.), в которых могут быть предусмотрены отдельно или совместно различные виды резервирования: структурного, нагрузочного, временного; второй этап – на уровне телекоммуникационного оборудования информационных путей (маршрутов); третий этап – на уровне телекоммуникационного оборудования информационных направлений, представляющих собой совокупность оборудования различных путей.

Методика решения задачи. Предложена методика комплексной оценки надежности телекоммуникационного оборудования сетей связи с приводимой структурой, учитывающая совокупность факторов, одни из которых являются агрессивными и приводят к снижению надежности (сбои, вызывающие кратковременные перерывы в функционировании; устойчивые отказы оборудования, которые нуждаются в восстановлении работоспособности отказавших устройств в ремонтном органе; недостаточная квалификация обслуживающего персонала), а другие – поддерживают нормальное функционирование телекоммуникационного оборудования на заданном уровне (использование отдельно или совместно различных видов резервирования – структурного, временного, нагрузочного, что приводит к повышению эффективности использования избыточности).

Пример. Приведенный числовой пример позволяет выявить некоторые новые особенности надежности функционирования телекоммуникационного оборудования телекоммуникационной сети обусловленные, в частности, учетом в моделях надежности не только устойчивых отказов, но и сбоев, приводящих к кратковременным перерывам в функционировании.

Выводы. Перспективным направлением дальнейших исследований является обоснование путей и методов уменьшения интенсивности сбоев в существующем и разрабатываемом оборудовании, а также разработка эффективных способов нейтрализации (уменьшения) их влияния на процесс функционирования телекоммуникационного оборудования телекоммуникационных сетей.

Ключевые слова: надежность; телекоммуникационное оборудование; отказы; сбои; резервирование