Fault-tolerance model of the information systems

V I Potapov, A I Goleva, N R Storozhenko and O P Shafeeva, E I Pastuhova,
I V Chervenchuk

Omsk State Technical University, 11 Mira ave., Omsk, 644050, Russia
E-mail: frybkf07.93@mail.ru

Abstract. The article deals with the reliability problem of information systems and contains the developed method for assessing the fault-tolerance of data transmission systems and mathematical model that allows to obtain the probability of failure at different levels of information systems.

1. Introduction

By the present, modern possibilities in the field of information technologies are being introduced and used in all spheres of our life. The widespread use of new computer technologies makes relevant the task of ensuring the reliability, security and availability of network resources in modern information systems. The problem of analysis of the level of reliability and fault-tolerance of information systems is quite topical now. However, according to international statistics, despite the rapid development of information technology and great attention to the problems of reliability information systems — the level of intrusion into the network, the number of failures and the levels of loss data and devices performance are not reduced. According to research by Kaspersky Lab, more than 40% of computers of information systems were attacked in the first half of 2018, for this reason, information systems of organizations did not become less vulnerable to failures in 2018 in comparison with 2017.

This problem is considered in the works of many Russian and foreign authors [1-13]. Thus, the works [1-7] contain a description of the general methods and principles of mathematical models and approaches to the calculation and modeling of an arguments of the classical theory of reliability or of the parameters of typical data networks (without taking into account the levels of its functioning). The works [8-13] describe the reasons of application of systems for control and diagnostics of information systems, and also explain the basic principles of their work without application of the mathematical device.

A literature review of sources on the topic of improving the uninterrupted operation of information systems has allowed to do some conclusions. In the considered works for construction of mathematical models only the basic parameters of reliability information systems are taken into account, meanwhile some important functions of information systems are not taken into account. In this article an attempt is made to eliminate these disadvantages by modeling failures of information systems at each level of its functioning: local level, level of network environment, level of critical nodes.

2. Object of modelling

In general form, when considering information systems, it is necessary to take into account its structural, functional and system-technical properties.
In terms of structural features — information systems can have a various topology, with the several local networks. Information systems can unite branches, creating a single space for data storage and exchange.

From the point of functional characteristics of information systems, it is an environment for storage and transfer of information which is necessary for the solution of multipurpose tasks of data processing. In such environment it is possible to identify 3 levels:

- local level (the level of operation of a single node of information system);
- level of network environment (subnets and networks with interacting nodes);
- level of critical nodes (in particular, switching equipment and servers). Table 1 shows the functions for each such node.

From the point of system and technical specifics — information system represents the complete structure which includes the interconnected and interacting levels (figure 1). The most important components of information system are system and applied software, the system of databases management, functions and services of transfer, storage and processing of data.

| Critical important nodes | Purpose and functions |
|--------------------------|-----------------------|
| Switching equipment      | Switches and routers   |
|                          | transfer messages according to dedicated VLAN channels, storage of switching tables |
3. Setting of the task and model description

During the implementation the implementation of reliable and fault-tolerant systems for minimize the time and cost of restoration and replacement of failed units and blocks, various methods of modeling have been widely applied in recent years. The purpose of the simulation is to select the optimal strategy for the use of reserve elements, taking into account the failures of the relevant blocks.

Accordingly, the following task is especially actual: modeling and evaluation of the probability of failure in the information system for determining the blocks that need to be modernization or replacement [14].

One of the most visual and labor-intensive methods of mathematical modeling of many operations (including failures in the information system), developing in the form of a random process, is the mathematical apparatus of Markov chains. Markov chains are a well-known mathematical method for describing a variety of problems of probabilistic nature. The chain can be written as a graph with vertices — states of the system and edges — intensities of transition to this state. Having a marked graph, it is possible to find the probabilities of each of the states, in the conditions of changing the parameters in time and in the conditions of the limit, stationary mode of operation of the system [15].

Before starting the modeling, it is necessary to determine the input parameters: possible states of failure which are typical for investigated information system, and take into account various kinds of connections between states — the intensity of the flow of events that transfers the system from one state to another.

After determining the input parameters of the system, you can begin to building a model. In this instance, we propose the use of a graph model based on the theory of Markov chains.

Operation and failure in the information system are considered as a random process with a finite number of states. Meanwhile, events happen singly, and not in groups of several at once — its means the ordinariness of the described model. In addition, the model does not contain any aftereffects, because for any two non-overlapping segments of time, the number of events falling on one of them does not depend on how many events fell on the other.

To build a model and calculate the characteristics of fault-tolerance of the network, we suppose that in investigated information system at a random time the failure can be carried out at one of the levels of network operation: the local level, the level of the network environment and the level of critical nodes of the system.

At the stage of construction of the model, we assume that the system can move to the following states of failure at one of the levels of the network operation $S_{ij}$, where:

- $i$ — levels of network operation ($i=1,2,3$), in this example are considered:
  - local level;

| Servers | Function |
|---------|----------|
| File-server | storage of shared folders and data |
| Mail-server | sending, receiving and storing messages of corporate correspondence |
| Domain Controller | centralized management of workstations and network servers |
| Application Server | storage of information and management of life cycle of manufactured products |
| Accounting Server | storage of financial accountability |
| Security Server | protection against leakage of confidential information and differentiation of user access rights to external and internal devices, centralized management of a comprehensive anti-virus protection system |
level of network environment;
- level of critical nodes.

\( j \) — the types of failure \((i=1,2,3,4,5)\), to which it is possible to refer respectively:
- hardware failure;
- system-wide failure;
- application failure;
- network device failure;
- failure of the physical communication channels.

The initial state of the information system is the normal functioning of the system without failures, when all resources are operable. All subsequent states are different from the initial and are characterized by extraordinary operation in the implementation of failures.

Then, we construct a connected graph of states of the simulated system, which shows the connection of each of the \( j \)-th failure at each \( i \)-th level of functioning of the information system (state \( S_{i,j} \)) with a vertex in \( S_0 \) (the system state with no failures), and \( \lambda_{i,j1,j2} \) — intensity of the flow of events that takes the system from one state to another. For presentation, the constructed chain of events in the network can be represented as a graph, where the vertices are the possible states of the system, and the edges are the intensities of transition into them. Graphically, the proposed model of the system can be represented by figure 2.

![Graph of the information system failures](image)

**Figure 2.** Graph of the information system failures, where \( S_{i,j} \) — is the state of \( j \)-th failure on the \( i \)-th level of the system functioning, \( \lambda_{i,j1,j2} \) — is the intensity of the transition from a state of failure \( j1 \) to \( j2 \) on the \( i \)-th level of functioning

To assess the level of fault-tolerance and finding the probability of failure in the network, using the constructed graph we can make a mathematical model in the form of a system of differential or linear algebraic equations, according to the following rule: the left — the derivative of the probability of the state, and the right — the sum of the products of the probabilities of those states from which the arrows go to this state, the intensity of the corresponding flows of events, minus the total intensity of the flows leading from this state, multiplied by the probability of this state (1).
\begin{align}
\frac{dp_0}{dt} &= -p_0 (\lambda_{101}^1 + \lambda_{102}^1 + \lambda_{103}^1 + \lambda_{104}^1 + \lambda_{105}^1), \\
\frac{dp_{11}}{dt} &= p_0 \lambda_{101}^1 + p_{12} \lambda_{21}^1 - p_{11} (\lambda_{111}^1 + \lambda_{112}^1), \\
\frac{dp_{12}}{dt} &= p_0 \lambda_{102}^1 + p_{14} \lambda_{12}^1 - p_{12} (\lambda_{21}^1 + \lambda_{23}^1 + \lambda_{12}^1), \\
\frac{dp_{13}}{dt} &= p_0 \lambda_{103}^1 + p_{14} \lambda_{23}^1 - p_{13} \lambda_{33}^1, \\
\frac{dp_{14}}{dt} &= p_0 \lambda_{104}^1 + p_{15} \lambda_{34}^1 - p_{14} \lambda_{44}^1, \\
\frac{dp_{15}}{dt} &= p_0 \lambda_{105}^1 - p_{15} (\lambda_{34}^1 + \lambda_{55}^1), \\
\frac{dp_{21}}{dt} &= p_{11} \lambda_{11}^1 - p_{21} (\lambda_{112}^1 + \lambda_{11}^1), \\
\frac{dp_{22}}{dt} &= p_{12} \lambda_{22}^2 + p_{21} \lambda_{12}^1 + p_{23} \lambda_{22}^3 - p_{22} (\lambda_{23}^2 + \lambda_{22}^3), \\
\frac{dp_{23}}{dt} &= p_{13} \lambda_{33}^2 + p_{22} \lambda_{23}^2 + p_{24} \lambda_{43}^2 - p_{23} (\lambda_{34}^2 + \lambda_{32}^2 + \lambda_{33}^1), \\
\frac{dp_{24}}{dt} &= p_{14} \lambda_{44}^2 + p_{23} \lambda_{34}^2 + p_{25} \lambda_{54}^2 - p_{24} (\lambda_{43}^2 + \lambda_{45}^2 + \lambda_{43}^3 + \lambda_{34}^3), \\
\frac{dp_{25}}{dt} &= p_{24} \lambda_{45}^2 + p_{15} \lambda_{55}^3 - p_{25} (\lambda_{34}^3 + \lambda_{35}^3), \\
\frac{dp_{31}}{dt} &= p_{21} \lambda_{11}^3 + p_{33} \lambda_{31}^3 + p_{34} \lambda_{41}^3 - p_{31} (\lambda_{12}^3 + \lambda_{13}^3 + \lambda_{14}^3), \\
\frac{dp_{32}}{dt} &= p_{22} \lambda_{22}^1 + p_{31} \lambda_{12}^1 + p_{33} \lambda_{32}^1 - p_{32} \lambda_{32}^1, \\
\frac{dp_{33}}{dt} &= p_{23} \lambda_{33}^3 + p_{24} \lambda_{43}^3 + p_{31} \lambda_{13}^3 + p_{32} \lambda_{23}^3 + p_{34} \lambda_{43}^3 - p_{33} (\lambda_{32}^3 + \lambda_{31}^3), \\
\frac{dp_{34}}{dt} &= p_{24} \lambda_{44}^3 + p_{31} \lambda_{14}^3 + p_{35} \lambda_{54}^3 - p_{34} (\lambda_{41}^3 + \lambda_{45}^3), \\
\frac{dp_{35}}{dt} &= p_{25} \lambda_{55}^3 + p_{34} \lambda_{45}^3 - p_{35} \lambda_{54}^3.
\end{align}

Choosing numerical values of intensities, it is possible to solve the system of equations. Ultimately, the solution will be the desired values of the probabilities of standing the information system in each of the considered states: from the states of failure-free operation to failure of its various blocks. The output of the simulation can be used to make conclusions about the most critical blocks that require modernization.

Thus, in the work with the help of Markov chains in relation to the network with 3 levels of operation was designed a mathematical model of failure-free operation of the information system with the construction of a system of equations, solving which, you can get specific values of the
probabilities of failures different blocks of the system at each level of operation: local, network and critical nodes.

4. Conclusion
In the conditions of growth and variability of qualitative and quantitative characteristics of network anomalies in the operation of the information systems and failures, as well as various incidents, there is a need to improve the existing apparatus for modeling fault-tolerant systems, also systems and algorithms of fault detection. Because even unintentional accidental failures in the operation of services information systems can lead to undesirable results, which include a slowdown in the response of hardware or software until the complete discontinuance of the operation of critical services and programs.

To solve the problems in this field of research, the article provides a mathematical description of the process of fault tracing and equipment failures for a network with 3 levels of operation: local, network and critical nodes. It is important to perform such a modeling with an assessment of possible failures in order to understand the possible risks and be able to neutralize the consequences as quickly as possible.

The solution of differential equations allows us to track the dynamics of changes in the degree of fault-tolerance of the information system through tracking failure probabilities at certain time intervals. If you are interested in the probabilities of the states of network in the limit steady mode, you can go to a linear system of algebraic equations, equating all the left parts of the differential equations to zero.

As a result, the solution of the developed in this article mathematical model allows to obtain definite values of failure probabilities at each of the 3 levels of information systems functioning. If necessary, this method can be described by a large number of states for modeling the behavior of more complex difficult systems, and the creation of the algorithm and its software implementation will not only optimize the modeling process, but also provide an opportunity to monitor the behavior of the system under conditions changing parameters.

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