Reliability in the model of an information system with client-server architecture

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Abstract. Two mathematical models have been built to describe the behavior of an information system with a client-server architecture without and taking into account the ultimate reliability of the monitoring system and the restoration of the failed component of the system under consideration. The behavior of the information system in the presence of failures and the restoration of the performance of components is approximated by a Markov process and is described by a system of differential equations with variable coefficients. The solution of the obtained differential equations by numerical methods on computers allows the research of various characteristics of the reliability of information systems such as "client-server" in a wide range of changes in failure rates and restoration of system components.

1. Introduction
Currently, distributed information systems have been developed, in particular the client-server architecture. This is due to the modern development of information technologies and high-loaded computing systems. In this case, the term “client-server” is used to designate such an architecture of an information system in which its functional components interact in a “request-response” scheme [1-2]. In such systems, usually the database and software are located on the server, and the client component of the system is the corresponding hardware and software part and the client interface. Data processing is most often distributed between client and server components. The client initiates requests, and the server generates responses to requests. The development of models for research the reliability of the distributed information systems under consideration in stationary conditions and under the influence of external destabilizing effects on the system, leading to an increase in the failure rate of the system components is an important task [3-5]. The development of mathematical models for the research of reliability and protection of information in information systems of various configurations that are in different situations, in particular in the situation of deliberate impact on the system in order to destabilize its work and reduce the reliability of a large number of works authors [6-8].

2. Research
As an object for which mathematical models are being developed, we will consider a recoverable information system after failures consisting of a finite number n of hardware and software client systems connected via the appropriate interface to server C. Considering the probabilistic nature of the functioning of the considered information system both in a stationary mode, when the failure rates and recovery of system components are constant, and under external destabilizing effects on the system, leading to an increase in the failure rate of components and a decrease in their recovery, which leads to a decrease the reliability parameters of the information system, when developing its mathematical
model, we will approximate the behavior of the systems Markov process with a finite number of states. We will assume that the failure of any component of the information system is determined immediately after its occurrence and the restoration of the failed component immediately begins. To simplify the mathematical model, we will neglect the ultimate reliability of the system for monitoring and restoring the failed component, although, if necessary, this parameter is not difficult to consider.

We will also assume that in the information system simultaneous failures are possible in several client systems with a server. In this situation, failed client systems are restored, and efficient ones continue to operate in the "client-server" mode. When a server fails, the information system is interrupted until the server is restored to a healthy state. We believe that the information system under consideration may have states when one or more client systems and a server simultaneously fail. In this case, the information system stops functioning until the end of the recovery process of the server and the failed client systems. In this case, the recovery reserves of the failed components of the system are redistributed between the server and the failed client systems, which naturally leads to a decrease in the recovery rate of the server and the failed client systems.

After their recovery, the information system continues to operate in a stationary mode.

To build mathematical models of the considered information system, we introduce the following notation:

- $E_0$ – the state of the information system in the absence of failures in client systems and in the server;
- $E_i$, $i = 1, 2, ..., n$ – the state of the information system in the presence of failures in $i$-client systems;
- $\lambda_c$ – server failure rate;
- $\lambda_k$, $i = 1, 2, ..., n$ – failure rate of client $i$-system
- $\mu_c$, $i = 0, 1, 2, ..., n$ – the intensity of the restoration of the operational state of the server with the simultaneous presence of failures in $i$-client systems;
- $\mu_k$, $i = 1, 2, ..., n$ – The intensity of recovery after a failure of the client $i$-system.

2.1. First model of information system

By approximating the considered information behavior after the failures of an information system with a client-server architecture by a Markovian random process with a finite number of states [9,10] and considering the assumptions and notations made, it is not difficult to make a graph of its states Figure 1.

Denote $p_i(t), i = 0, 1, 2, ..., n$ the probability of finding the information system in states $E_0, E_1, ..., E_n$, respectively, and the probability $p^*_i(t), i = 0, 1, 2, ..., n$, of finding the information system in the corresponding states $E_0^*, E_1^*, ..., E_n^*$. Now, using the well-known technique [11], it is easy to obtain a system of Kolmogorov differential equations (1), describing the behavior of the information system under consideration.

\[
\begin{align*}
p_0'(t) &= \mu_c p_0^*(t) + \mu_k p_1(t) - (\lambda_c + \lambda_k) p_0(t) \\
p_i'(t) &= \mu_c p_i^*(t) + \mu_{k_{i+1}} p_{i+1}(t) + \lambda_k p_{i-1}(t) - (\lambda_c + \lambda_{k_{i+1}} + \mu_k) p_i(t), i = 1, 2, ..., n-1 \\
p_n'(t) &= \mu_c p_n^*(t) + \lambda_k p_{n-1}(t) - (\lambda_c + \mu_k) p_n(t) \\
p_i^*(t) &= \lambda_c p_i(t) - \mu_c p_i^*(t), i = 0, 1, 2, ..., n
\end{align*}
\]

with initial conditions

\[
\begin{align*}
p_0(0) &= 1 \\
p_i(0) &= 0, 1 \leq i \leq n \\
p_i^*(0) &= 0, 0 \leq i \leq n
\end{align*}
\]
The solution of the system of differential equations (1) by numerical methods is not difficult and can be easily obtained using computer programs. For small values of n, the solution of the system of equations can be obtained in an analytical form.

If the failure rates $\mu_i, \mu_k$ are functions of time $\lambda_c = \lambda_c(t), \lambda_k = \lambda_k(t), \mu_i = \mu_i(t), \mu_k = \mu_k(t)$, the solution of the system of equations (1) with coefficients variable in time can be obtained by the method of discretization and integer programming [12] using modern personal computers. The system of differential equations (1) allows calculating and investigating many characteristic of reliability [13] of the information system under consideration: probability of failure-free operation, probability of partial or complete failure, availability factor, recovery time after failure and others.

2.2. Second model of information system

When developing the second model of the information system with the client-server architecture that is restored after failures, unlike the first model, we will assume that the system for monitoring the operation and recovery of the failed component of the information system under consideration has ultimate reliability and can fail and recover after a failure. In some cases, the role of such a hardware-software system can be performed by the network operator, who can also fail to tolerate errors in the work, restore their operability and correct the errors made.

In this regard, we introduce the notation for the new states of the restored information system:

- $E_{ij}, i = 1, 2, \ldots, n; j = 1, 2, \ldots, n$ the state of the information system in which the restoration of the failed client systems occurs and the failure of the control and recovery system of the failed components occurred;
- $E_{ij}^*, i = 1, 2, \ldots, n; j = 1, 2, \ldots, n+1$ the state of the information system at which the failed server is restored and the monitoring and recovery system failed;
- $V_i, i = 1, 2, \ldots, n$ the failure rate of the control system and the recovery of the failed component of the information system;
- $\xi_i, i = 1, 2, \ldots, n$ the intensity of the restoration of the performance of the control system and the restoration of the failed component of the information system.

Taking into account the previously introduced and introduced new designations, we will compile a state graph taking into account the ultimate reliability of the operation control system and the restoration of the failed component (Fig. 2).
To denote $p_{ii}, i=1,2,...,n$ the probability of finding the information system in the states $E_{1,1}, E_{2,2},..., E_{n,n}$, respectively, and $-\lambda$ the probability of finding the information system $p_{0i}, i=0,1,2,...,n; j=1,2,...,n+1$ in the corresponding states $E_{0,1}, E_{1,2},..., E_{n,n+1}$.

Then, using the above technique [11], it is easy to create a system of Kolmogorov differential equations (3) describing the behavior of the information system under consideration with the ultimate reliability of the system for monitoring the operation and restoring the failed components of the system.

$$
\begin{align*}
\dot{p}_{00}(t) &= \mu_{c0} p_{00}(t) + \mu_{k1} p_{11}(t) - \left( \lambda_c + \lambda_{k1} \right) p_{00}(t) \\
\dot{p}_{ii}(t) &= \mu_{ci} p_{i-1,i}(t) + \mu_{ki} p_{i+1,i}(t) + \lambda_{ki} p_{i,i}(t) - \left( \lambda_c + \lambda_{ki+1} + \mu_{ki} \right) p_{i,i}(t) - \zeta_{i} p_{i,i}(t), i=1,2,...,n-1 \\
\dot{p}_{nn}(t) &= \mu_{cn} p_{n-1,n}(t) + \lambda_{kn} p_{n,n}(t) + \zeta_{n} p_{n,n}(t) - \left( \lambda_c + \mu_{cn} \right) p_{n,n}(t) - \zeta_{n} p_{n,n}(t) \\
\dot{p}_{0i}(t) &= \lambda_{c0} p_{0,i}(t) - \mu_{ci} p_{i,i}^{*}(t), i=0,1,2,...,n \\
\dot{p}_{ij}(t) &= \mu_{ij} p_{i,j}(t) - \zeta_{ij} p_{i,j}(t), i=1,2,...,n \\
\dot{p}_{ij}(t) &= \zeta_{ij} p_{i,j}(t) - \mu_{ij} p_{i,j}^{*}(t), i=0,1,2,...,n; j=1,2,...,n+1
\end{align*}
$$

with initial conditions
\[
\begin{align*}
& p_0(0) = 1 \\
& p_i(0) = 0, 0 \leq i \leq n \\
& p_i^*(0) = 0, 0 \leq i \leq n \\
& p_{i,i}(0) = 0, 1 \leq i \leq n \\
& p_{i,j}(0) = 0, 0 \leq i \leq n; 1 \leq j \leq n+1
\end{align*}
\] (4)

Solving the system of equations (2) by numerical methods for known values of \(k\) (constant or time-dependent variables) coefficients \(\lambda, \lambda_k, \nu_i, \mu_i, \zeta_i\), it is not difficult to obtain a solution in the form of probabilities of finding the considered information system from an architectural “client-server” in any of its states \(E_i, E_i^*, E_{i,j}, E_{i,j}^*\) taken into account when developing mathematical model, as well as almost any characteristics of the reliability of the information system.

3. Conclusion

Two variants of the functioning of client-server architecture systems are considered. The proposed model of reliability, each of which reflects the specifics of the architectural solution. Models can be used for use in various circuit solutions to increase the reliability of high-loaded information systems.

4. References

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