INCREASING EFFICIENCY OF ROUTING IN TRANSIENT MODES OF COMPUTER NETWORK OPERATION

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Abstract: Despite the rich theoretical and practical experience of research in computer networks, current trends in the development of network information technologies require new approaches to solving the problems of optimal management of large corporate computer networks. The analysis of existing routing and switching algorithms is carried out, future-leaning directions of increasing the efficiency of routing algorithms in transient network operation modes are determined. An algorithm for multi-parameter routing is created. It supports the TCP/IP family network protocols and provides efficient network management at a high intrinsic convergence rate by considering alternative shortest routes.

Key words: routing, TCP/IP protocols, switching algorithms, territorially connected systems.

1. INTRODUCTION

The rapid growth of the Internet and corporate information computer networks based on Intranet technology makes the problem of researching methods of distributed networks management [1, 2, 3] in transient operating conditions extremely relevant. Despite the rich theoretical and practical experience of research in this field, current trends in the development of network information technologies require new approaches to solving the problems of optimal management of large corporate computer networks. Under conditions of rapidly changing load intensity, the variable nature of traffic, failures of individual communication channels and network nodes, as well as the network transient mode cases, the problem of optimal network management is extremely complex, depending on a large number of factors with varying degree of influence.

One of the main problems in the management of distributed networks in the transient mode of operation is the problem of finding new optimal routes [4, 5, 6] for the delivery of information and the distribution of traffic over communication channels. Thus, in the routing protocols developed at present, such mechanisms of increasing the optimality of information flow as the use of multi-parameter routing, the formation of multi-route traffic with it's balancing among several alternative routes of data transmission paths, are not sufficiently implemented. In addition, the research of routing processes in distributed networks with the help of modeling systems, as well as the automatic identification of the configuration parameters of routing algorithms that are optimal for a given network and the conditions of its operation, are not sufficiently developed. Thus, the study of multi-parameter routing in transient modes of computer network operation is an urgent task [7, 8].

The purpose of the paper is the development of mathematical and software support for multi-parameter routing that supports network protocols for constructing optimal delivery routes for delivering information to the receiver and efficient distribution of traffic flows over communication channels online.

2. PROBLEMS OF DEVELOPING EFFECTIVE ALGORITHMS FOR CONTROL OF TOPOLOGICALLY UNSTABLE INFORMATION AND COMPUTER NETWORKS

The main requirement for the delivery of information during the operation of the network in transient mode is the delivery time optimisation [9, 10], which consists of at least two independent components: the time of delivery via communication channels and the sojourn time for a packet in transit nodes. In addition, due to the highly dynamic nature of the traffic, the bandwidth capacity reserve of communication channels with respect to their current congestion often has a strong influence on the packet delivery time. Therefore, it is necessary to add a third component – ideal delivery time, which considers the bandwidth of communication channels. However, the search for the extreme of the objective function of minimising the time of delivery of information in the network must be carried out for given boundary conditions of delivery reliability, quality of service requirements, etc. Thus, the routing subsystem should be based on the use of multi-parameter routing algorithms that provide the minimum time for information delivery to the receiver and the fulfilment of the associated delivery requirements.

A comparative analysis of the existing routing and switching algorithms showed that, despite the advantages of the existing routing and switching algorithms, they all have several disadvantages. There is a need to modify some of the most suitable algorithms and develop new algorithms. We note that a number of routing algorithms and, in fact, all switching algorithms are closed proprietary developments, or the standards for these algorithms have not yet been approved and are to be finalised. The last remark leads to the need to develop new algorithms or to modify open standards.

3. MATHEMATICAL MODELLING OF MULTI-PARAMETER ROUTING PROCESSES

The process of delivering a packet to a receiver along a single route in a network is the final Markov chain. The transition probability matrix P, together with the a priori distribution of nodes, determines the Markov process, which describes the procedure for delivering a packet to a specific destination node. For a particular network, we can construct the transition probability matrix P, which describes a discrete Markov process with two absorbing states, one of which is the desired node l, and the other is the loss of search. The remaining nodes form a set of non-recurrent states, the transition probabilities in which are represented by the matrix S. For a closed specification of flows in the network, the zero state of the finite Markov chain is introduced, from which the load enters the network nodes. The source data for specifying the initial distribution of flows is the intensity matrix $\lambda^{`} = \| \lambda^{`}_{ij} \|_{n,n}$, where $\lambda^{`}_{ij}$ is the intensity of the flow of requests (packets/s) coming from node i in the direction of node j. The probabilities of transitions to network nodes from the zero state are determined based on the intensity matrix

$$P^{l}_{0i} = \frac{\lambda^{`}_{il}}{\sum_{j=1}^{n} \lambda^{`}_{il}} \quad (1)$$

The matrix P itself has the following form:

$$P^{(l)} = \left[\frac{E \; O}{S \; Q} \right]_{n+2,n+2} \quad (2)$$

where E – identity matrix of dimension 2•2,

O – zero matrix of dimension 2•n,

S – matrix of dimension n•2, which displays the transitions from nonrecurrent states to ergodic (absorbing) ones,

Q – matrix of dimension n•n, which displays the behaviour of the process until it is out of the set of non-recurrent states,

l – index, which means that the matrix is constructed for the l-th desired node.

During the analysis of the operation of the entire network, when the requirements for packet transmission arise on a massive scale, it is necessary to consider the totality of finite Markov chains, where each destination node corresponds to one nested finite Markov chain. The states of the chain are identified with the nodes of the network, and all processes, as a rule, are determined on the same states. A complete description of routing processes in a network with n nodes implies the presence of n transition matrices of the form (2). Moreover, the system of equations (3), which describes the massive processes of routing in the network, is nonlinear.

$$\pi_{jk} = (\lambda_{jk} - C_{jk}) \cdot \mu / \lambda_{jk} \ \text{ for } \rho_{jk} \geq 1,$$
$$\pi_{jk} = (1-\rho_{jk})\rho_{jk}^{m_{jk}} \Big/ (1-\rho_{jk}^{m_{jk}+1}) \ \text{ for } \rho_{jk} < 1, \quad (3)$$
$$P^{(l)} = \| p_{ik}^{(l)} \|_{n-1,n-1},\ p_{ik}^{(l)} = \sum_{s=1}^{2^r} \Omega_i^{(s)} \xi_{ik}$$

where $1/\mu$ – the mean length of packets,

λ_{ij} – flow intensity in the edge j_k,

C_{jk} – bandwidth of the edge j_k,

$\Omega_i^{(s)}$ – probability of occurrence of a situation ($X_{i\Omega}$),

π_{ik} – probability of blocking the channel i_k,

ρ_{jk} – channel utilization index,

$P_{ik}^{(l)}$ – the probability of sending a packet from node i to node k for the desired node l.

The numerical solution of the system of nonlinear equations (3) for a given network, traffic, and operating conditions allows us to determine the probabilistic-temporal characteristics of the network, to evaluate the routing algorithms used, flow control methods, etc. As we can see from (4), the search for a solution to the system by a numerical method is iterative.

$$\pi^{(b)}{}_{jk} = (\lambda^{(b-1)}{}_{jk} - C_{jk}) \cdot \mu / \lambda^{(b-1)}{}_{jk},\ \rho^{(b-1)}{}_{jk} \geq 1,$$
$$\pi^{(b)}{}_{jk} = (1-\rho_{jk})\rho_{jk}^{m_{jk}} \Big/ (1-\rho_{jk}^{m_{jk}+1}),\ \rho^{(b-1)}{}_{jk} < 1,$$
$$P_l^{(b)} = \| p_{ik}^{(b)} \|_{n-1,n-1},\ p_{ik}^{(b)} = \sum_{s=1}^{2^r} \Omega_i^{(s)(b)} \xi^{(b)}{}_{ik}, \quad (4)$$
$$\lambda^{(b)}{}_{jk} = (\sum_{l}^{n} \sum_{i \neq l}^{n} \lambda_{il}^{(b)} \cdot f_{ij}^{(b)} \cdot q_{jk}^{(b)}) / (1 - \sigma_{jk}^{(b)}) + \lambda_s^{(b)}$$

where b – step number,

$f^{(b)}{}_{ij}$ – corresponding row of the fundamental matrix F in step b,

$q^{(b)}{}_{jk}$ – corresponding row of the fundamental matrix Q in step b,

$\sigma^{(b)}{}_{jk}$ – mean square deviation of the flow intensity in step b,

$\lambda^{(b)}{}_s$ – overhead flow in step b.

Identification of the routing process model parameters, which are close to optimal values, is possible during the iterative process of searching for a solution to the system of nonlinear equations (4). After introducing into the iterative process of searching for a solution to the system of flow equations a step-by-step procedure for correcting the configuration parameters of the routing algorithm, it becomes possible to find their optimal values for a given network and traffic. The algorithm for identifying the parameters of the routing process model is presented in Figure 1.

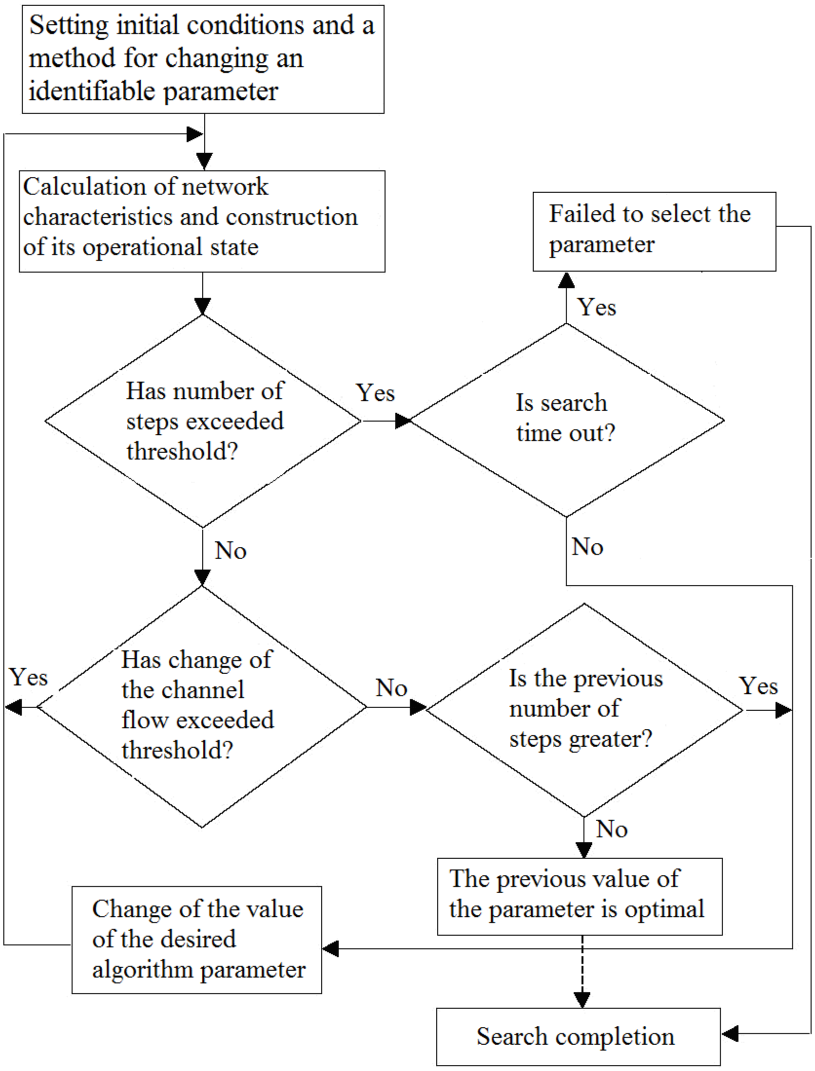

Fig. 1. Algorithm for identifying the parameters of the routing process model

4. NEW ALGORITHM FOR MULTI-PARAMETER ROUTING AND REAL-TIME SWITCHING

The algorithm for constructing route tables presented in Figure 2 is developed, the feature of which is the consideration of alternative shortest paths. According to the algorithm, the search for an alternative shortest path with the root not in the node that initiated this search, but in neighbouring nodes, is carried out. At the same time, there is no need to store the shortest path tree itself, but only the shortest distances themselves. This reduces the overhead in memory storing the shortest routes. It is appropriate to carry out a search for a modified network, in which there is no node that initiated the search. This allows us to obtain all alternative routes from neighbouring nodes that do not pass through the node that initiated the search, which ensures the absence of loops.

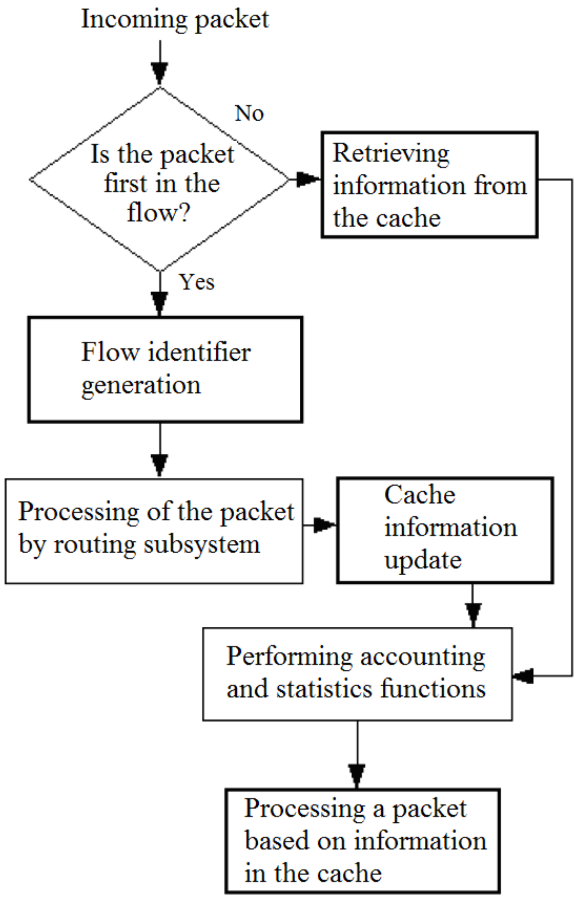

Fig. 2. Algorithm for constructing route tables

A switching algorithm is developed to reduce the time for processing a packet by a router, due to caching traffic information. Traffic in the router is split into separate flows and only the first packet of each flow is routed, and the results of processing the first packet are stored in the cache. The remaining packets of the flow are switched based on information in the cache. The traffic flows are identified by the following parameters: IP address of the sender and receiver; address of the next router of the path, inbound and outbound physical interfaces; number of packages; port numbers for TCP and UDP protocols for applications; types of protocols (TCP, UDP, etc.); type of service; TCP flags; numbers of autonomous systems of the sender and receiver; the sender and receiver subnet masks. This information allows us to fully identify each flow passing through the router. The algorithm for traffic processing by the switch subsystem is shown in Figure 3.

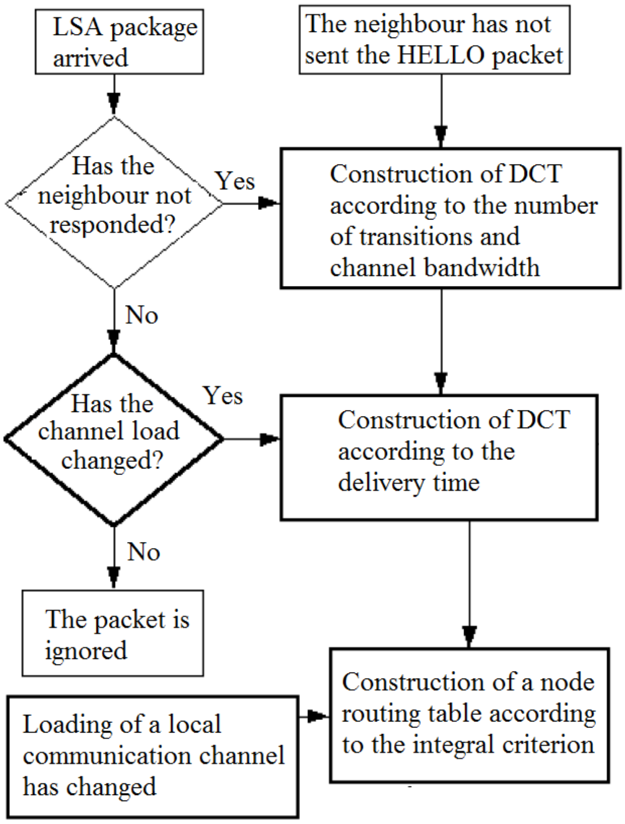

Fig. 3. Algorithm for packet processing by the switch subsystem

The integration of the switching protocol and the routing protocol allows us to organise a single effective routing system. Effective interaction of routing and switching subsystems is based on the traffic balancing algorithm. A feature of the algorithm shown in Figure 4 is not the switching of individual packets, but the switching of traffic flows among groups of channels, which determine alternative delivery routes, and which are called balancing groups.

The developed routing and switching algorithm optimizes the route according to several independent delivery time components that affect the efficiency of network management:

1) time of delivery over communication channels, which is determined by the current intensity of the traffic;

2) sojourn time of a packet in transit nodes, depending on the load on the network nodes and on the number of transit nodes in the route;

3) ideal delivery time due to the bandwidth of the communication channels.

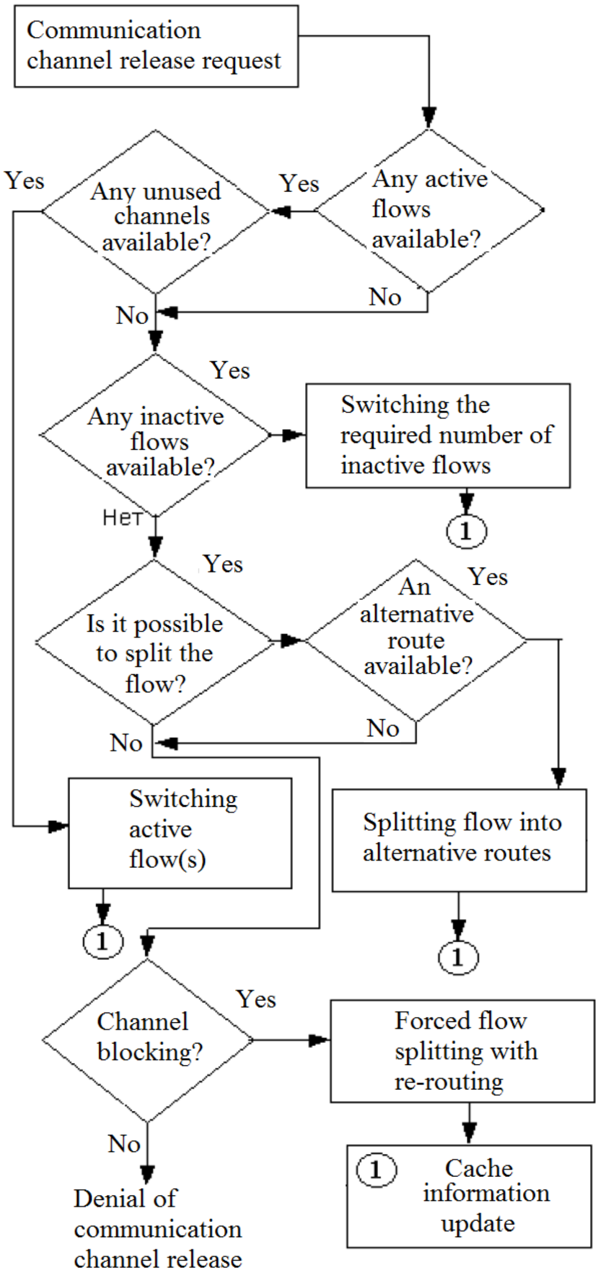

Fig. 4. Flow switching algorithm

An integral criterion for optimizing the route is developed:

$$Q = (K_1T+K_2D+K_3EL) / R \quad (5)$$

where T – packet delivery time for the current network load (s),

D – packet delivery time for an unloaded network (s),

E – mean sojourn time for a packet in the node (s),

L – number of transit nodes (pcs.),

R – fraction of successfully transmitted packets (in fractions),

$T = \frac{1}{S \cdot (1-B)}$ for each communication channel,

where S – bandwidth of the channel (Kbps),

B – channel congestion (in fractions).

Thus, this integral criterion makes it possible to consider not only the network topology and bandwidth of communication channels (parameters *L* and *D*), but also the current real state of the network (parameter *T*). The coefficients K_i allow us to prioritise route optimization parameters, which allows flexible control of the routing process. In addition, if the corresponding weighting factors K_i are equal to zero, it is possible to carry out one-parameter routing according to the selected parameter of the route.

5. SOFTWARE SYSTEM FOR ROUTING PROCESSES MODELLING

In order to analyse the developed algorithms and methods, a software system is created for modelling routing processes in distributed networks, which allows a comparative analysis of different routing algorithms for a specific network and type of traffic, and identification of their advantages and disadvantages. The analysis system is developed in the Inprise CBuilder 5.0 environment based on the C ++ language and registered in the State Fund of Algorithms and Programmes.

As a result of a comparative analysis of the routing algorithm based on the first shortest path found, and the new routing algorithm using alternative information transfer routes, a higher efficiency of the alternative path algorithm is revealed under the condition of the network operation for various types of traffic, cases of individual communication channels and network nodes as a whole. Figure 5 shows a graph of the dependence of packet delivery time on the inter-node load intensity, where OSPF is the Open Shortest Path First algorithm, ASPA is an Alternative Shortest Paths Algorithm developed by the author.

The parameters of routing algorithms are identified for a particular network and its operational conditions, and, as a result of this, the optimal values of the configuration parameters of the algorithms under study are determined. Figure 6 shows the dependence of the information delivery time on traffic in the event of a communication channel failure for a given interval of balancing group metrics (1 – 5%, 2 – 10%, 3 – 15%). As we can see from the graph, the optimal interval is 10%, which simultaneously provides acceptable delays at low loads and efficient traffic distribution at high network loads.

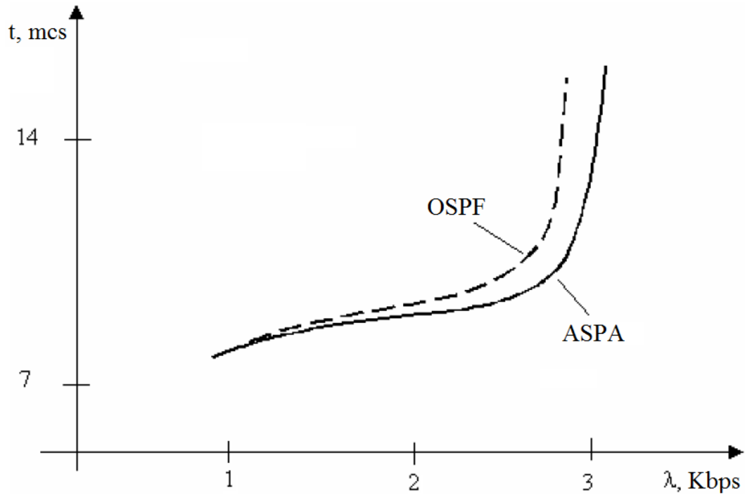

Fig. 5. Dependence of delivery time on inter-node traffic

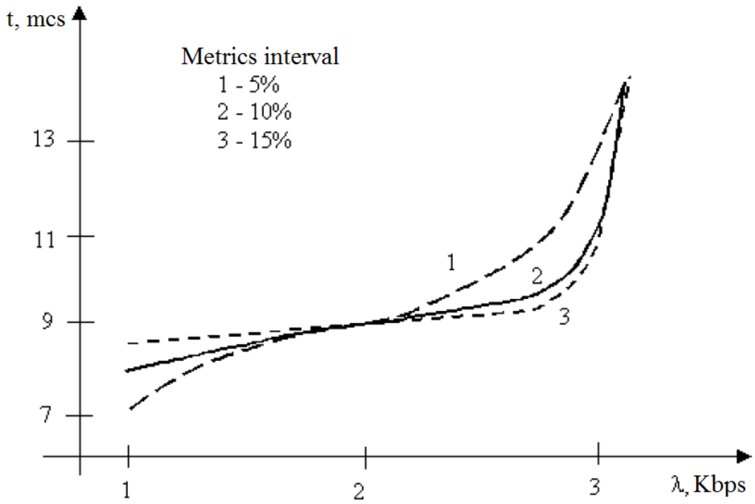

Fig. 6. Dependence of information delivery time on traffic in case of communication channel failure for a given interval of balancing group metrics

6. CONCLUSION

The analysis of existing routing and switching algorithms is carried out, future-leaning directions of increasing the efficiency of routing algorithms in transient network operation modes are determined. An algorithm for multi-parameter routing is created. It supports the TCP/IP family network protocols and provides efficient network management at a high intrinsic convergence rate by considering alternative shortest routes.

An analytical model of the processes of multi-parameter routing and flow control is constructed, which allows determining the probabilistic-temporal characteristics of the network and considering administrative traffic due to the routing algorithm used. A software system for modeling routing processes in distributed networks is developed, which allows a comparative analysis of various routing algorithms. The parameters of routing algorithms for a particular network and its operational conditions are identified, as a result of which the optimal values of the configuration parameters of the algorithms under study are determined.

The efficiency of using a routing algorithm that considers alternative shortest paths in a real-time routing system, as well as in transient network operation modes, is shown.

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