The object of the current research is the process of routing data packets in a telecommunications network. It was established that the state and parameters of data transmission channels and routers could have a negative impact and need to be taken into account in the process of modeling the routing of data packets in telecommunication networks.

A model of simulated dynamic modeling of data packet routing in telecommunication networks has been devised and proposed. The suggested model makes it possible to establish quantitative values of the delay time of processing data packets during their routing along a separate segment of the telecommunications network, taking into account the state and parameters of the data transmission channel and routers.

It has been established that the achievement of the minimum delay time of data packets during routing is achieved by choosing the path of their transmission under the condition of minimum transmission time by communication lines and the capabilities of routers in terms of their accumulation and service speed. At the same time, the reduction of packet transmission delay time relative to the average for the time network segment can reach from 21 to 38 percent. It is shown that the main factor affecting the value of the delay time is the speed of data processing along the selected path of packet transmission. The number of routing nodes in a separate data transmission path can affect the delay time only if the parameters of the routers are equal compared to others that are included in alternative routes.

The model of simulated dynamic modeling of data packet routing reported in this work, unlike the existing ones, takes into account the state and parameters of data transmission channels and routers. It can be used in practical improvement of existing and development of new multi-service telecommunication communication networks

Keywords: multi-service telecommunication network, simulation dynamic modeling, data packet transmission delay time

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CONSTRUCTION OF A SIMULATED DYNAMIC MODEL OF DATA PACKET ROUTING ON A TELECOMMUNICATION NETWORK FRAGMENT

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1. Introduction

A multi-service telecommunications network is a fairly complex system of digital data processing and transmission. It serves a large number of users and plays an important role in the information and technical support of various aspects of society. Quality of Service (QoS) methods are used to ensure high network performance, which support the stable operation of all the variety of telecommunication networks. QoS methods are aimed at improving operational characteristics, network reliability, reducing delays and packet losses during periods of network congestion. The selection and justification of the way of routing data packets in the telecommunications network is a rather important and relevant task [1, 2].

The primary task in the organization of route selection is a clear definition of factors that must be taken into account in the process of substantiating priorities or route selection criteria.

The process of routing data packets can be based on simple, analytical, and adaptive routing methods. Simple methods do not take into account network congestion. The analytical model of routing does not allow taking into account obstacles in the communication network.

Simulation modeling allows the description of individual channels of the communication network both by modeling various known distribution laws and by using experimental error statistics. That is, to perform a check and estimate the probability of delivery of data packets under conditions close to actual ones [2, 3].

To carry out simulation simulation, it is necessary to devise a model that takes into account the conditions on the path of the data packet, that is, the state of the data transmission channels and the state and parameters of the routers in the structure of the network or its individual fragment. The choice of the route is determined by certain routing criteria.

One of the problems of routing is taking into account the state and parameters of packet transmission channels and the state and parameters of routers in the network construction scheme. The possibilities of such consideration and timely response to negative changes in the specified states and parameters predetermine the dynamic nature of packet routing. The dynamic nature of the routing of data packets makes it possible to specify the state of channels and routers at certain intervals and take it into account during the next cycle of simulation modeling of the routing of data packets through the network [2, 3].

It is obvious that the construction of a complete simulated dynamic model of data packet routing in a telecommunications network, which would take into account the delay time of packets, changes in the states of the transmission route and routers, forms a new, urgent scientific task. And this requires the search for new theoretical and practical approaches to the development of new ways of solving it.

2. Literature review and problem statement

A number of studies [2–11] address the development of new and improvement of existing dynamic models of data packet routing in telecommunication networks.

General issues of developing and improving the functioning of existing data packet routing models in telecommunication networks are covered in [2, 3]. In these works, the main theoretical provisions regarding the development of packet routing models based on simulation and analytical modeling are outlined. It is noted that the routing models, which can be dynamic in nature, are more effective in ensuring the high-quality functioning of telecommunication networks. This provision in the cited papers is based on the possibilities of such models to reduce the time of packet routing, taking into account the time of their processing, the states of the network route and the equipment from its composition. These works have a generally theoretical, fundamental nature of the presented material. Based on this, the immediate issues of forming a complete outline of a simulated dynamic model of data packet routing and consideration and evaluation of finished versions of such models relative to a real version of a fragment of a telecommunications network were not considered in them.

In [4], the issue of designing multi-level telecommunications networks, the functioning of which should take into account the relationship between physical and logical ways of routing data in telecommunications, is considered. In the development of the issue of data routing in telecommunications, the cited work defines and substantiates a number of principles and modeling methods that should establish all connections at all levels that form the main physical path of data traffic. In the work, the relevance of achieving the minimum processing time of data packets is substantiated as the main criterion for evaluating routing efficiency. Consideration of general methods and ways to achieve the minimum processing time of data packets, methods of finding optimal data transmission routes based on the criterion of minimum time, and direct construction of simulated dynamic routing models were not considered in the cited paper. This is explained by the limitation of the research to the construction of interconnected physical and logical paths of data routing in telecommunications.

Solving the task of ensuring effective design of the telecommunications network and organization of traffic circulating in optical telecommunications networks, which are based on multiplexing of signals by wavelength, was considered in [5]. The paper proposes a mathematical statement, as well as a hybrid algorithm capable of finding high-quality solutions depending only on the network load. The immediate state of network channels and routers is not taken into account in this algorithm. This is explained by the methodical approach to the solution of the problem specified in the work, the selected limitations and assumptions adopted in the study.

Work [6] gives the review of existing state-of-the-art routing protocols for fixed telecommunication networks. Increasing the routing efficiency of such networks is solved in the cited work through routing algorithms based on internal agents. The task of network agents is to ensure adaptive and efficient use of network resources in response to changes in the network, providing load balancing and fault management. The method of simulated dynamic modeling of routing and the development of a promising algorithm based on it also involves the development of new and corresponding improvement of existing routing protocols. The algorithm reported in the work is actually tied to existing routing protocols and is aimed at increasing their efficiency within the limits of previously solved scientific tasks to improve the routing process. Accordingly, the specified work and the algorithm presented in it against the background of solving the task of increasing the efficiency of the routing process have limitations in taking into account the state of channels and network equipment when searching for optimal ways of transmitting data packets.

Deterioration of the state of the data transmission channel under the influence of a denial-of-service cyberattack, the formation of a malicious (illegitimate) data flow, and the optimization of the data routing model under such conditions are discussed in [7]. It was established that due to slicing of the 5G network, the network operator does not know the exact routing of illegitimate traffic in the network. This creates the problem of network congestion and the search for optimal data transmission paths in such conditions. In order to solve the problem of network overload, the cited paper proposes an appropriate algorithm, the purpose of which is to minimize the time of data transmission in the conditions of cyber attacks. The algorithm reported in the work, based on the adaptive routing method, takes into account only channel overload with redundant information. The state of the channel and the state of the network equipment in operation are taken out of the scope of the study, assuming that cyber attacks do not affect their state and efficiency of operation. Accordingly, in the work, for the solved problem of the deterioration of the data transmission channel under the influence of a cyber attack, the methods of simulated dynamic modeling were not applied.

In [8], the issue of data routing optimization is proposed to be solved through the use of the developed two-level model of adaptive network data flow circulating in the network under the influence of interference. The paper considers only those obstacles that affect the state of the data transmission channel of the telecommunications network. According to the results and their evaluation, the model reported in the article is generally able to optimize the routing of data flows under conditions of interference. In turn, the state of data transmission channels and internal routers was not considered in the cited work. Accordingly, the presented model of adaptive network data flow does not take this state into account. In general, it can be noted that this model has limitations in terms of improving the efficiency of the telecommunications network and is aimed only at eliminating the effects of interference and associated overloads.

It is proposed to solve the issue of optimization of data routing according to the criterion of route length minimization considered in work [9] with the help of the algorithm reported in this work. The essence of the algorithm is to solve problems created by the presence of potential long ties and the existence of cross ties in the system. The work of the proposed algorithms is also aimed at ensuring the energy efficiency of the network and additionally ensures a low percentage of data packet losses. The result of the application of the specified algorithm is the fixation of the steady state of the network fragment for the formation of optimal data transmission routes. Subsequently, the specified steady state can be the basis for further simulated dynamic modeling of packet routing relative to the given network fragment. But the development of the presented algorithm in the direction of dynamic routing was not carried out in the cited work.

The issues of overloading the telecommunications network and their elimination using the development of a suitable routing scheme are discussed in [10, 11]. Deterioration of the state of data transmission channels in work [10] is proposed to be eliminated using the proposed model of optimal routing based on the state of communication with low delay. The specified model proactively tracks the established path and connects the source to the destination with minimal cost and optimal energy consumption. In [11], a separate algorithm is also given, which in the process of implementation finds a broken connection, maximizes the packet delivery rate, and minimizes the packet processing delay. Owing to it, one can avoid overloading. In general, the cited work contains elements of a partially solved task of simulated dynamic modeling of packet routing taking into account the state of network channels, but it requires improvement and development of the reported algorithm in the direction of assessing the state of network elements and their impact on packet processing time.

Our review of the literature [2–11] that tackles the task of investigating packet routing process issues revealed inconsistencies related to the lack of assessment of the serviceability of channels and network elements, which is not taken into account in the process of routing data packets through a segment of the telecommunications network. Identified inconsistencies significantly affect the effectiveness of the functioning of telecommunication networks and require the solution of a number of scientific tasks related to the assessment of the state of channels and network elements and taking into account their state in the process of routing data packets.

One of such important scientific studies is the solution of the scientific task regarding the construction of a complete simulation dynamic model of data packet routing in the telecommunications network. The specified model should ensure the minimization of packet routing by choosing a route from a node to a network node in a defined area. The choice of the route, in turn, should take into account the packet delay time and the quality of the data transmission channel, which is determined by changes in the states of the transmission route and the routers from its composition.

3. The aim and objectives of the study

The purpose of this study is to build a simulation dynamic model of data packet routing on a segment of the telecommunications network. This could improve the quality of service of data packets due to the minimization of the delay time of their transmission during routing by means of dynamic route selection taking into account the state of channels and network equipment on a certain segment of the telecommunications network.

To achieve the goal, the following tasks were set:

– to formalize the task of building a data packet routing model on a segment of the telecommunications network;

– to evaluate the model for ensuring the maximum quality of service of data packets in the process of their routing on a certain segment of the telecommunications network.

4. The study materials and methods

The object of our research is the process of routing data packets in the telecommunications network.

The research hypothesis assumes the influence of the state of data transmission channels and network elements of the telecommunications network on the routing time of packets transmitted on a separate segment of the telecommunications network.

The classical structure of a fragment of a multi-service telecommunication network was chosen for research. A typical overview structural diagram of its construction is shown in Fig. 1.

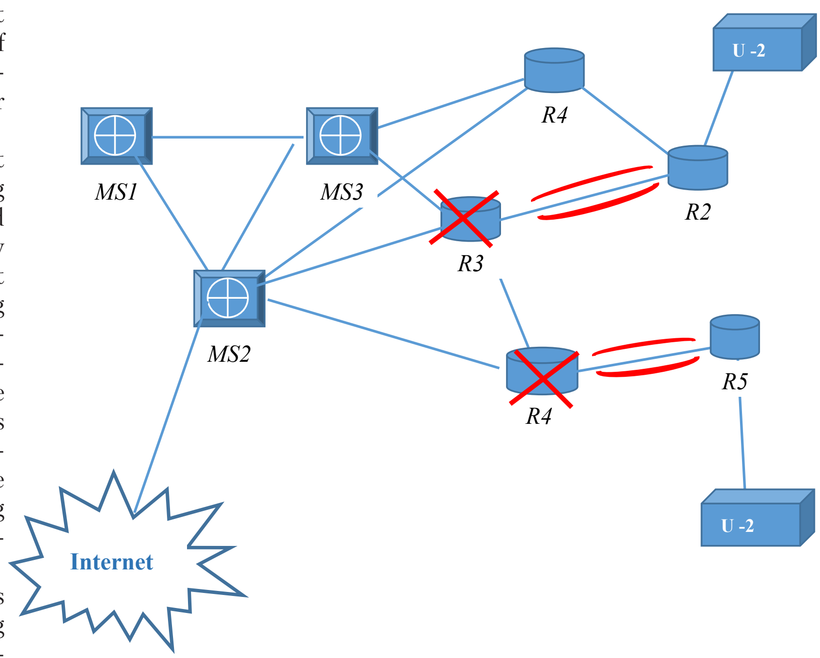

Fig. 1. A typical structural diagram of a fragment of a multi-service telecommunications data transmission network

The research uses the methods of simulation dynamic modeling of the state of the telecommunications network.

The simulation cycles are limited to one step of routing calculation at each node of the network element, which is justified by the rapid changes in time of the characteristics of the channels and the formation of a new state of the network fragment.

The following was adopted as an assumption and simplification during the research. The telecommunications network considered in the current paper works on the basis of the link state protocol, which is based on LSA (*link state algorithm*). The level of self-similarity of the traffic, in relation to which the research was conducted, is determined by the Hurst parameter (H) in the value of H=0.9. With such values of parameter H, it was assumed that packet losses are no more than 5–10 %. At the input of the data link scheduler, the "weighted fair queuing" (WFQ) algorithm is applied. The state of the data link is determined by the usable state of the link between the routers and the operational state of the routers themselves. The issue of maintaining the specified reliability of channels and routers, as well as the reasons for its deterioration in operation, are not considered.

The MATLAB application software package from The MathWorks developer company was used for simulation modeling and working with algorithms.

The fragment of the network, which contains 10 vertices, accepted for research is shown in Fig. 2.

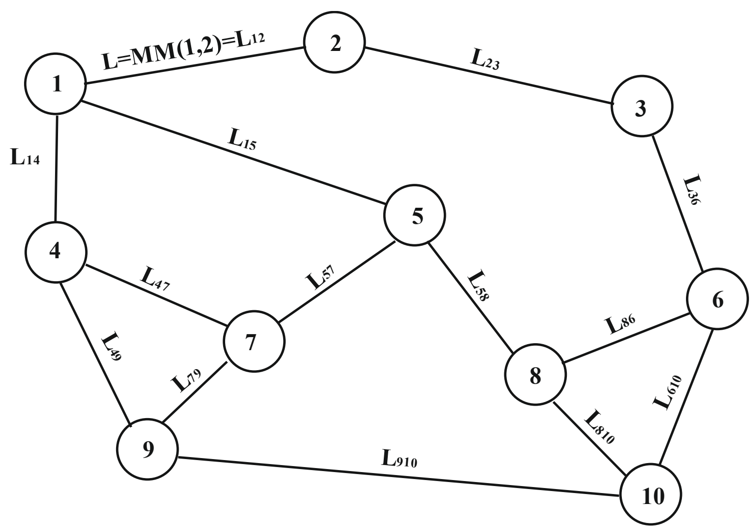

Fig. 2. Structure of a fragment of a telecommunication network

5. Simulation dynamic model of data packet routing in the telecommunications network

5. 1. Formalization of the task of building a data packet routing model on a segment of a telecommunications network

The structure of the network is described by the graph $G=(R, E)$, in which R $\{R_i;\ i=1,\ m\}$ is a set of vertices (nodes) simulating routers, and E $\{E_{ij};\ i,\ j=1,\ m,\ j\neq i\}$ is a set of arcs representing communication channels in the telecommunications network [12, 13].

Each arc $E_{i,j}\epsilon E$ can be assigned some characteristic of the channel on the given arc. For example, its throughput φ_{ij}, probability of packet loss or delay time. Each node can be assigned a certain characteristic of this node, for example, the volume of the buffer, the length of the queue at its input.

At the beginning of work, the initial and final vertices of the transfer are selected. The movement of data packets is carried out from the initial vertex to the final one. The movement of data packets in the reverse direction is excluded, the creation of cycles is also excluded. In hardware modeling, this is taken into account by including appropriate conditions in the transmission path selection subroutine. In each separate branch, the packet transmission process is simulated taking into account the delay in the network transmission line and the presence of queues in the transmission and reception buffers.

The network traffic route is chosen after evaluating the situation (total delay) in each branch leaving the current node. The transmission of packets takes place on the branch in which the total delay is minimal. The routing model is built under the condition of assessing the possibility of delivering data packets over the communication line, taking into account the delay of packets in it and in the routers' drives.

To describe the structure of the network, a version of the matrix of nodes and branches of the network was constructed for all nodes, which is defined as the routing matrix. The routing matrix can be used to determine the vector of values of branches coming from a given vertex, the matrix of numbers of nodes in which these branches of the network end, and so on.

To take into account the dynamics of changes in the state of the network, it is necessary to use a series of structures of a fragment of the communication network. That is, it is necessary to change the descriptions and change the routing matrix. The change in the state of branches and nodes of the network is simulated in separate subroutines. This increases the adequacy of the model because the models of individual nodes and branches can be chosen independently and there is no need to impose restrictions on their choice. A change in the state of the network occurs periodically, at certain discrete moments of time. This principle of describing the dynamic nature of the telecommunications network is implemented in a simple model that shows the effect of a change in the network structure on the choice of a transmission route [13, 14].

According to the structure of the fragment of the telecommunications network adopted for the study (Fig. 2), on the diagram of the structure, the nodes of the network, which are numbered accordingly, are marked with circles. Branches of the network connecting nodes are denoted by letters L_{ij}, where i, j are the numbers of the nodes connected by the branch [3, 14].

To formalize data processing, information about the structure of a network fragment is grouped in the form of a routing table (RT), which is given in Table 1.

The rows numbered in the first column of the table are the node numbers of the scheme. Number 1 in Table 1 indicates the available branches between nodes, the number 0 indicates the absence of a corresponding branch. The separate columns of Table 1 show the number of paths from the node and the numbers of the transition nodes.

The modeling algorithm involves a sequential review of the network vertices to choose a route for the transmission of data packets, taking into account the delay time in the nodes and in the branches. The matrix (RM) makes it possible to determine the output branches and the numbers of transition nodes, which makes it possible to organize a review cycle on all output branches. The vertex to which the incoming data packet will fall is determined by the value of the delay on the corresponding branch, taking into account the delays at the nodes. The structural diagram of the modeling algorithm is shown in Fig. 3.

Table 1

Routing matrix (RM)

Node numbers	Node numbers 1	2	3	4	5	6	7	8	9	10	Number of paths per node	Transition node numbers
1	0	1	0	1	1	0	0	0	0	0	3	2,4,5
2	1	0	1	0	0	0	0	0	0	0	2	1,3
3	0	1	0	0	0	1	0	0	0	0	2	2,4
4	1	0	0	0	0	0	1	0	1	0	3	1,7,9
5	1	0	0	0	0	0	1	1	0	0	3	1,7,8
6	0	0	1	0	0	0	0	1	1	0	3	3,8,10
7	0	0	0	1	1	0	0	0	1	0	3	4,5,9
8	0	0	0	0	1	1	0	0	0	1	3	5,6,10
9	0	0	0	1	0	0	1	0	0	1	3	4,7,10
10	0	0	0	0	0	1	0	1	1	0	3	6,8,9

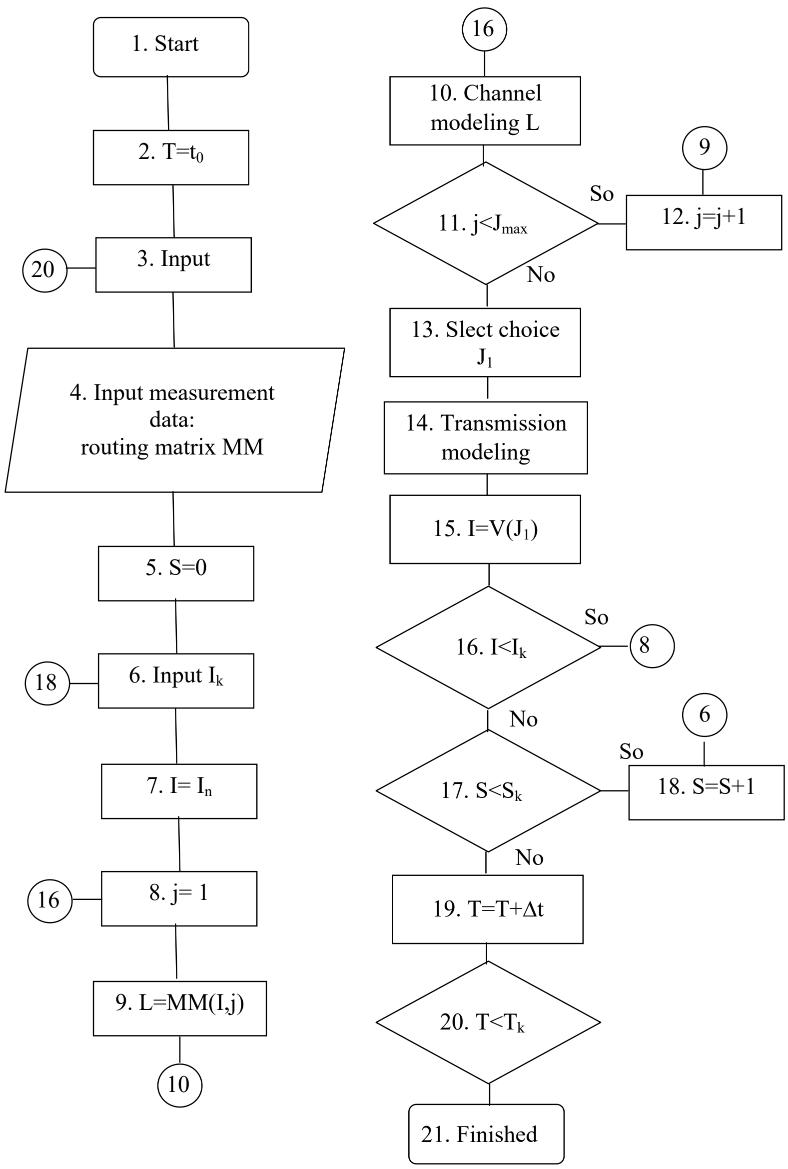

Fig. 3. Block diagram of the data packet routing algorithm

The data packet routing algorithm contains the following units:

– channel simulation unit for evaluating the state of the data transmission channel (simulation of the L_{ij}-branch);

– the branch (path) number selection unit for further transmission (selection of the channel number at the output);

– data transmission simulation unit on a separate branch (path) (transmission simulation).

5. 2. Simulation dynamic modeling of routing of data flows in a telecommunication network

The procedure for modeling and obtaining data based on it includes the following steps.

The first step is the simulated transfer of S_k data packets, the current packet number is S. The number of the current vertex is I; the numbers of the initial and final vertices are I_n, I_k; j denotes the branch number of the graph. The value J_t denotes the branch through which the data is transferred; $V(J_t)$ is the number of the next (selected) node.

At the beginning of the algorithm, the value of the initial time t_0, the value of the number of data packets N, and the value of the elements of the routing matrix (RM) are entered.

The second step is to enter the numbers of the initial and final message transmission nodes.

The following cycles are organized in the above algorithm:

– viewing branches from the current node and choosing the optimal branch for packet transmission;

– transition from one node to another until reaching the final node;

– transmission of a sequence of messages; time change (change of routing matrix parameters).

Table 2 gives a variant of the results of simulation of ten network states during the transmission of data packets between two pairs of nodes.

Table 2

Simulation results

Variant No.	Route node numbers					Relative transmission time
1	1	5	8	10	–	0.865
2	1	2	3	6	10	0.962
3	1	4	9	10	–	1.154
4	1	4	9	10	–	1.250
5	1	5	8	10	–	0.789
6	3	2	1	4	7	1.214
7	3	6	8	5	7	1.012
8	3	6	10	9	7	1.368
9	3	2	1	5	7	0.617
10	3	2	1	5	7	0.790

In Table 2, the numbers of vertices through which messages are transmitted in each of the simulated states are given. The delay time for the transmission of data packets is given relative to the average delay value for a given pair of nodes between which the transmission is conducted (inter-terminal delay).

During the simulation, the values of the parameters of the data flows were used, which correspond to the data generated by the terminal equipment of the standard structure. Their values are given in Table 3. The bandwidth of the channels is 100 Mbit/s.

Table 3

Values of the parameters of data streams of information transmission channels of a fragment of a telecommunication network

Data streams from the terminal	Value of traffic parameters					
	Video telephony			IP telephony		
	p, Mbit/s	r, Mbit/s	L, Byte	p, Mbit/s	r, Mbit/s	L, Byte
	2.2	0.89	1358	0.115	0.01	219

The data given in Table 3 include traffic parameters defined separately for Video and IP telephony.

6. Discussion of results of assessing the impact of channel resource on the criterion of the quality of service of a data transmission channel

The proposed formalization of the data packet routing model on a segment of the telecommunications network has made it possible to obtain the evaluation data given in Table 2. The values of the presented data unambiguously link the determined routes and ways of transmitting data packets through a fragment of the telecommunications network and the criterion of packet service quality.

Given in Table 2, the results showed that routes 9 and 10 are optimal according to the criterion of minimizing packet transmission delay time for the selected research scheme (Fig. 2). At the same time, the reduction of packet transmission delay time relative to the average for the network segment can reach from 21 to 38 percent. The main factor affecting the value of the delay time is the speed of data processing along the selected path of packet transmission. The number of routing nodes in a separate data transmission path can affect the delay time only if the parameters of the routers are equal compared to others that are included in alternative routes.

This is due to two main factors.

The first factor concerns the capabilities of the communication channels included in the data routes to ensure minimal delays in the time of data packets being sent to the routers.

The second factor is the capabilities of the routers from the specified routes. Namely, the capabilities of routers' input buffers for receiving and temporarily storing volumes of data packets, and the high, compared to others, speed of data packet service in routers from the data routes [13–15].

Analysis of the simulation results reveals that even with a small number of attempts to estimate packet routing, the proposed algorithm selects some identical routes that are more stable than others. When analyzing specific networks, it will help find the most reliable routes that provide the maximum quality of service according to the criterion of minimizing the delay time of packet transmission.

An additional factor that can contribute to the minimization of packet transmission delay time is the channel resource allocated for processing data packets, the values of which are determined by the telecommunications network management system [14, 15].

Thus, our work establishes and substantiates the interrelationships and mutual influences of the state parameters of communication lines and routers when data packet routing is ensured according to the criterion of the minimum delay time for the transmission of data packets.

The studies were conducted in relation to the multi-service communication network, taking into account the state of the data transmission paths in the network and its parameters regarding the quality of service of data packets.

In order to establish the specified relationships and assess the influence of the states of the routing paths of data packets in the network on the time of data transmission, a corresponding model and an algorithm based on its procedures were built and presented in the current work. Our model takes into account the state of communication lines on the paths of data packet transmission and their ability to transmit packets, the state of routers, and their ability to ensure the appropriate quality of service. It provides an estimate of the time of transmission of data packets by different paths and makes it possible to choose the paths that ensure their minimum delay in the process of passing from the input to the output point of the network. This, in aggregate, on the basis of simulated dynamic modeling of the routing of data packets, makes it possible to choose routing paths with the minimum delay time. This improves the quality of functioning of the protected corporate multi-service communication network.

It is also necessary to take into account the impact of targeted intentional attacks on data transmission channels and the performance of routers in the given values of the parameters set for them by law [16–19]. Given the established conditions for the impact of such attacks on the telecommunications network, it is necessary to ensure a timely and effective assessment of the state of the affected routers and channels. Later, when forming optimal routing paths, the presence of affected channels and routers on data packet transmission paths is taken into account.

The results reported in our work related to the development of a complete model of simulated dynamic modeling of packet routing make it possible to estimate the quantitative values of the delay time of packets along individual paths of their transmission. This is implemented in the presented model in accordance with the states and parameters of data transmission channels and routers on individual paths. The model provides results that, in general, make it possible to form and substantiate recommendations for ensuring a given value of data transmission delay time in accordance with the states and parameters of data transmission channels and routers.

The model of simulated dynamic modeling of routing of data packets presented in our work could be used in practical improvement of existing and development of new multi-service telecommunication communication networks.

The scope of modeling the state of the network was limited by the assumption that the characteristics of the channels can change quickly enough over time. This ensured that only one routing step was simulated at each node of the network element.

The limitations inherent in this study include the fact that the presented model and evaluation algorithm were developed without taking into account the condition of applying the "weighted fair queuing" (WFQ) algorithm at the input of the network planner [3, 14]. This allows formally taking into account the load characteristics of variable-rate flows but does not take into account the conditions of losing a certain number of data packets that do not match the declared profile and do not pass through the WFQ "token basket". The algorithm reported in our paper works under the assumption that such losses of part of the data packets are not observed. That is, exactly those packets that have passed through the WFQ algorithm are processed. At the same time, the work introduced a limitation in which the level of self-similarity of the traffic, in relation to which the research was conducted, was determined by the Hurst parameter (H) at a value of H=0.9. Losses of packets passing through the data channel were no more than 5–10 %.

Limitations also include the accepted condition in which the state of the data transmission channel is determined by the reliable performance of the communication line between the routers and the reliable performance of the routers themselves. Ensuring the established reliability and operability of channels and routers, as well as the reasons for their deterioration in operation, are not considered.

The shortcomings of the model proposed in the current work include the lack of devised procedures for taking into account the volume of data packets and the channel resources allocated for their service, corresponding to all packet routing paths.

An additional scientific task when devising such procedures is taking into account the buffer lengths of incoming routers and their physical limitations. These buffer limitations can be especially important when processing data packets based on various variants of building code structures [19, 20].

It is also necessary to take into account that all results and the conclusions based on them are limited to the calculation of a fragment of the network containing 10 vertices.

The simulated dynamic model of data routing on a segment of the telecommunications network, its description, and the algorithm reported in this paper provide a coherent procedure for the construction of similar models that may contain a different number of vertices on the segment of the network under investigation.

As further area of research and development of this work towards increasing the efficiency of the operation of the multi-service telecommunication network, it is proposed to conduct new study into dynamic reservation of the channel resource for the selected routing path. This will ensure the achievement of a higher quality of data packet service along the selected routing paths during peak loads.

7. Conclusions

1. The proposed formalization of the model makes it possible to choose from all possible options and establish a data transmission path taking into account the state and parameters of data transmission channels and routers. The data routing process is implemented according to the criterion of minimizing the delay time of data packets by transmitting them in accordance with the states and parameters of data transmission channels and routers from their composition.

2. It is established that the achievement of the minimum delay time of packets during routing is achieved by choosing the path of their transmission under the condition of the minimum time of data transmission by communication lines and the capabilities of routers in terms of their accumulation and service speed. At the same time, the reduction of packet transmission delay time relative to the average for the time network segment can reach from 21 to 38 percent.

It is shown that the main factor affecting the value of the delay time is the speed of data processing along the selected path of packet transmission. The number of routing nodes in a separate data transmission path can affect the delay time only if the parameters of the routers are equal compared to others that are included in alternative routes.

Increasing the speed of accumulation and processing of data packets in telecommunication network routers exerts a significant impact on reducing the delay time of data packets during their routing.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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