Methods for Assessing the impact of Bandwidth of Control Channels on the Quality of Telecommunications Networks in the Transmission of Data Packets of different types

Mohialdeen Mustafa Mohammed[1], Zaika Viktor[2], Khlaponin Yurii[3], Berkman Lyubov [2], Polonskyi Konstiantyn[2], Turovsky Oleksandr[4]

[1]Middle Technical University, Baghdad, Iraq
[2]State University of Telecommunications, Kyiv, Ukraine.
[3] Kyiv National University of Construction and Architecture, Kyiv, Ukraine
[4]National Aviation University, Kyiv, Ukraine

Abstract: It is known that since the early 2000s there has been a rapid increase in data traffic and a significant increase in the need for information flows in the process of providing new types of telecommunications services. This has led to the fact that the existing telecommunications networks have failed or approached the limit of their ability to serve subscribers with specified quality of service. The problem of improving the network architecture of such networks and improving the quality of their operation based on the use of modern methods and principles has arisen and needs constant solution. In this paper the requirements to the bandwidth of the channels of the telecommunication network management system in modern conditions are analyzed and their formalized description is given. In order to assess the bandwidth of the channel of the control network of the telecommunications network on the indicators of the quality of its work in the transmission of various types of data in the work developed and submitted an appropriate methodology. The method is based on mathematical dependences that describe the process of functioning of the telecommunication network management system based on the application of the laws and rules of queuing theory.

In the process of assessing the impact of the bandwidth of the control network on the quality of the telecommunications network when transmitting data packets of different types, it is established that the bandwidth requirements for a single network element are determined by the amount of information the network element exchanges with the operating system and the allowable delay of the management transaction. The paper considers the indicators that should be used to characterize the control system from the standpoint of queuing theory. The average packet delay time was investigated and analyzed using mathematical queuing models with a heterogeneous flow of applications, which allowed to assess the effect of channel bandwidth on quality indicators in the transmission of different types of packets, taking into account their priority in emergency management.

Keywords: packet, traffic, inhomogeneous, delay, bandwidth.

1. Introduction

Since the 2000s, there has been a rapid increase in data traffic and a significant increase in the need for information flows in the process of providing new types of services. This has led to the fact that the existing telecommunications networks have failed or approached the limit of their ability to serve subscribers with specified quality of service. Telecommunication operators are forced to make decisions on improving the network architecture of such networks and improving the quality of their operation based on the use of modern methods and principles. To effectively serve subscribers, taking into account the traffic they generate, it is necessary to have a margin of bandwidth at the transport level. Today, the need for high bandwidth arises at the lowest levels of telecommunications networks, and this primarily applies to the organization of a dedicated channel for Internet access. In this regard, recently the issue of building a network with the most rational hierarchy has become one of the most pressing. And the development of one of the main components of the telecommunications network - the control system is one of the main areas of improving the quality of telecommunications networks [1].

The telecommunication network management system (MS) is a complex system to which the most diverse and multifaceted requirements are put forward. These are the requirements for functionality, quality indicators, reliability and efficiency of the system along with the requirements for economic indicators [1,2]. There are currently no ready-made solutions for formalizing the requirements for the MS, even given the standards developed for them, such as the Common Management Information Protocol (CMIP) and Simple Network Management Protocol (SNMP), there is no guarantee that a particular management system will fully meet the formalized requirements for it [2,3]. That is why currently the tasks of optimization of telecommunication control systems come to the fore, which should be solved starting from a formal description of the requirements for it, the choice of optimization criteria, determining the structure and set of parameters of the control system [1, 4].

The need to design optimal control systems for telecommunications networks has caused an urgent need to choose a formal mathematical apparatus that adequately reflects the features of telecommunications networks and the nature of their behavior over time. One of the main methods of studying control systems is mathematical modeling. The process of building a model consists of several stages. At the first stage of modeling is the formation of abstract logical representations of the object by highlighting its most important properties and features, representation of these properties in a simplified form, as well as finding a suitable mathematical apparatus for formal description and study of model properties. In many previously developed MS in the subsystems of identification of the state of the controlled object and the development of control effects used deterministic mathematical models. Thus, MS are systems of parametric control, ie systems that control not the states of the object, but its parameters [1, 2, 5]. In this regard, for the analysis of network management systems are widely used some applications of information theory.

One of the most important problems in designing a control system for telecommunications networks is the choice of the optimal speed of transmission of control information [2, 3]. On the one hand, overestimating the required bandwidth leads to unproductive spending. On the other hand, if the channel is not able to provide the required speed and quality, the delay of control information in the network can be unacceptably large. Thus, determining the optimal values of network management bandwidth and information delay time in the MS is a task that is of great practical importance and requires the development of appropriate assessment methods.

2. Literature Survey and problem statement

A number of works are devoted to the issue of formalization of requirements to the MS by the telecommunication network and assessment of its parameters on the indicators of the quality of functioning of the specified network.

In [6] the model of MPLS (multiprotocol label switching) network operation in tunneling mode is presented. In order to assess the performance of this network, analytical expressions are proposed, which allow to describe the process of mutual influence in servicing applications of different communication directions on the same network elements, to determine service quality indicators and bandwidth of MPLS network communication directions, to compare them with normalized values and assess compliance with specified standards. Formalization of requirements for such a network was not carried out in the work, the bandwidth assessment presented in the work does not take into account the transmission of data packets of different types x taking into account their priority in the operation of the network in an emergency.

The work [7] is devoted to the issue related to the assessment of the required capacity of control channels to control the situation and control the modes of operation of the corporate satellite network with adjustable parameters in the conditions of interference. It is noted that the instantaneous rate of transmission of the reverse channel should be selected with the requirement of the response time to the impact. Calculations of such capacity depending on the number of earth stations, the speed of possible changes in the parameters of the interference and the number of possible states are given. The paper does not fully define the requirements for this type of MS and there is no assessment of network bandwidth, taking into account the priority.

The issue of synthesis of the control system of information and communication data transmission networks is considered in [8]. The paper shows that the application of the data supply principle based on data flow theory is one of the effective ways to increase the use of network resources in emergencies. In order to ensure dynamic flow distribution in the control system of the information transmission network, it is proposed to use a dynamic flow distribution control system. It is shown that dynamic routing is so effective only with average channel usage. The issues of assessing the impact of bandwidth on the efficiency of the considered information and communication network in the work were not considered.

The work [9] is devoted to the peculiarities of the synthesis of the management of the TMN (Telecommunication Management Network) type of the second level with the combined management principle. The paper deals in detail with intelligent control, taking into account perturbations and deviations. The issues of bandwidth estimation for a certain network were not considered in the work.

In [10] the issue of studying the architecture of the intelligent control network is considered, the development of methods for calculating the basic parameters of the network, the relationship between them and the synthesis of vector networks. At the same time, it is not shown which methods of vector synthesis should be used in network optimization and calculation of network bandwidth and its impact on the efficiency of the considered control network.

The optimal reception algorithm using a sequential method, which should be used in the management of channels of infocommunication networks, is proposed in [11]. The paper deals in detail with the improvement of control quality during signal reception and processing. In order to compensate for the influence of various noises and disturbances on the quality and reliability of the input signal in this paper, an algorithm is proposed to compensate for its losses. Bandwidth estimation issues are not considered in this paper.

The paper [12] is devoted to the development of algorithms for the operation of the network management system in the process of speed control and priority operation of input data packets. The proposed algorithm of the control system allows the method of regulating the speed of reception of data packets to maintain high dynamics of the entire network. Also in the work the scheme of estimation of speed of processing of packets of input data and algorithm of an estimation of availability of a bandwidth of a network is presented. The issues of bandwidth assessment were not directly considered in this paper.

In [13], the issues of a comprehensive review of bandwidth estimation methods in order to increase it for the streaming data network are considered. The paper proposes several methods for estimating bandwidth for modern wireless networks. The methods proposed in the work are of a general nature, algorithms for direct calculation of bandwidth for in this work are absent. The requirements for the network management system are also not considered.

The purpose of this work is to develop a method for estimating the impact of bandwidth of the control network channel on quality indicators in the transmission of packets of different types, taking

into account their priority in the operation of the MS in emergencies.
To achieve this goal it is necessary to solve the following tasks:
- to form in general requirements to the management system of telecommunication networks;
- choose and justify the feasibility of using a formal mathematical apparatus that adequately reflects the features of telecommunications networks and the nature of their behavior over time;
- to develop a mathematical model for estimating the impact of the bandwidth of the control network channel on the quality indicators of the telecommunications network;
- to develop a method for assessing the impact of the bandwidth of the control network channel on the performance indicators of the telecommunications network management system;
- evaluate and analyze the results of the calculation of the bandwidth of the control channel at different values of load parameters and packet delay constraints.

3. Proposed Methodology

3.1. Formalization of requirements to the telecommunication network management system

As is known, the maximum possible speed of information transmission over the channel is called the bandwidth of the channel, and is determined as follows [1, 4]:

$$C = R_{MAX} = \max\left[\lim_{T\to\infty} \frac{H(a)}{T}\right]$$

where H(a) is the entropy of the message a;
R – information transfer rate;
T – is the duration of the message.

It should be noted that the bandwidth as a criterion for optimal operation of the control system can be considered from two sides [1, 3, 4]:
1. MS channel bandwidth between the MS server and the client (workstation) of the control system.
2. MS bandwidth between the OS operating system (MS server) and the managed network element.
It is clear that the second type of bandwidth is of paramount importance when planning a network, because it provides interaction with many network elements.
The bandwidth requirements of the control network depend on the network traffic generated by the most typical and important operations of the control system.
With regard to the bandwidth requirements of the management system channels between the server and the MS client, it should be noted that the amount of data transmitted between the server and the MS client is approximately the same as between the server and network elements, except that that at the time of launching the client program, a large amount of data is transmitted, especially in the case of creating a remote client that requires additional bandwidth.
Consider in more detail the requirements for the bandwidth of the control system channels between the MS server and the managed network element.
The traffic generated by the interaction between these objects is determined by:
– the traffic received as a result of periodic interrogation of a condition of channels (link) – depends on the interrogation period and quantity of the managed network elements;
– the traffic received as a result of operations of management of a configuration of a network and network elements – frequency and size of this traffic size is casual, but as practice shows small enough;
– traffic obtained as a result of periodic collection of statistical data, quite significant in size, but predictable and depends on the period of the survey and the number of managed network elements;
– traffic received as a result of management operations in case of damage and accidents in the network – frequency and magnitude of this traffic is random, unpredictable, can be very significant and can lead to network congestion.
Thus, it is possible to determine the bandwidth C required to provide quality management services (QoS) [2, 4]:

$$C = \frac{H(E)\sum_{i=1}^{n} N_i k_{t_i}}{k_C T}$$

where *N* is the number of information flows with the same priority;
H(E) is the entropy or average amount of information that a network element exchanges with the operating control system, ie the amount of information required to control one network element;
k_c – a factor that characterizes the actual consumption of bandwidth, this factor is determined empirically and depends on the bandwidth of the channel;
k_t – normalized coefficient, which depends on the priority of the network element;
T – the average execution time of the management transaction.
The bandwidth requirements of a channel related to a single network element are determined by the amount of information that the network element exchanges with the operating control system and the allowable delay time of the control transaction.
Note that packet delay or latency consists of serialization delay, propagation delay, and switching delay.
Serialization delay is the time it takes for a device to transmit a packet at a given bandwidth (bandwidth). The serialization delay depends on both the bandwidth of the information channel and the size of the transmitted packet.
Propagation delay is the time required for the transmitted bit of information to reach the receiving device at the other end of the channel. This value is quite significant, because in the best case, the speed of information transfer is comparable to the speed of light. The propagation delay depends on the distance and the medium used, not on the bandwidth. For WAN lines, propagation delay is measured in milliseconds.
Switching delay is the time required for the receiving device to start transmitting to the next device. Typically, each of the packets belonging to the same traffic flow is transmitted with a different delay value. The packet transmission delay varies depending on the state of the intermediate networks.
If the network does not experience congestion, then packets are not queued in routers, and the total delay time when transmitting a packet consists of the sum of the serialization delay and the propagation delay at each intermediate transition. In this case, we

can talk about the minimum possible delay in the transmission of packets over a given network. If the network is congested, delays in queuing routers begin to affect the total packet transmission delay, and lead to a difference in latency when transmitting different packets of the same stream.

3.2. The choice and justify the mathematical apparatus that adequately reflects the features of telecommunications networks and the nature of their behavior over time

The mathematical apparatus of queuing theory allows to optimize the delay time of delivery of control information to the destination. Using the mathematical apparatus of queuing theory, it is possible to determine the dependence of the time of transmission of control information on the speed of the network without connection to real channels. Such calculations allow to answer many questions about the performance of the network and management system; thanks to them it becomes clear what is the average delay time of control information on the service device (bridges, routers, etc.), how can increase the magnitude of these delays increase the speed of the communication channel and under what conditions increase the speed of information exchange channels does not lead to a significant increase in the productivity of MS [14, 15].

The objects of research in the theory of queuing are queuing systems (QS) and queuing networks (QN).

Queuing systems are classified according to the following characteristics [15]:

– the nature of the receipt of claims (regular and random flow of claims);

– the number of claims received at one point in time (ordinary and non-ordinary flows of claims);

– connection between requirements (flows with aftereffect and without aftereffect);

– the nature of service requirements (QS with refusals and expectations);

– service disciplines (with priority, first come - first served, in reverse order, in random order);

– the nature of the lesson (with deterministic and random lesson time);

– number of resource units (single-channel and multi-channel QS);

– the number of stages of service requirements (single-phase and multiphase QS);

– nature of requirements (homogeneous and inhomogeneous);

– limited flow of requirements (closed and open QS).

As is known, queuing theory establishes a relationship between the characteristics of the flow of information, the number of devices that serve this flow, their performance and efficiency.

3.3. Methods for assessing the impact of bandwidth of the control network channel on the quality of the telecommunications network

To characterize the MS from the standpoint of queuing theory, the following indicators are considered [14, 16]:

1. The incoming flow of requirements or, in other words, the moments of receipt of requirements in the system - in most cases it is accepted to model the process of receipt of requirements using the Poisson process. The Poisson process is most often used in queuing theory to describe the input stream.

2. Maintenance system consisting of a drive and service devices. Requirements can be waiting for a free service device, forming one or more queues.

3. Request service time by each channel.

4. Discipline of expectation, ie a set of rules governing the number of requirements that are at the same time in the system.

5. Queue discipline, ie a set of rules according to which the requirement prefers one or another queue (if there are several) and is located in the selected queue.

6. Discipline of service, ie a set of rules according to which the requirement selects the device by which it will be serviced.

To develop a mathematical model of network operation for the transmission of control information, it is necessary to analyze which factors significantly affect the magnitude of delays, and which - to a lesser extent, which parameters may in reality vary.

The average delay of control information should not exceed the established norms and negatively affect the operation of the network properly.

In the theory of teletraffic the basic interrelations of parameters of information exchange where allocate some systems of service, including with losses of orders and with expectation, and also their combinations are established. Note that the SU is characterized only by a system with an expectation, because the system with losses leads to the loss of information about some negative process that occurred in the network that is managed. And as a consequence, failure to take measures to eliminate it. Therefore, for the calculation and evaluation of the parameters of the SU will use the apparatus of the theory of teletraffic in the case of servicing applications with expectations.

Interpret the management system in terms of transactions and resources. Transactions are active moving elements of the system, and resources are inactive. Transactions in the control system are, for example, control commands, and the resource is a communication channel in the control system. The functioning of the management system can be considered as the interaction of transactions and resources.

Consider a control system for which the intensity of the input flow of control information λ depends on the state of the system, and the source of the requirements is internal and generates a limited flow of applications.

The speed of receipt of control information depends on the number of control objects that change state over a period of time (for example, per day) and the frame size of the control information. The information received by the system at the moment when at least one service device is free is processed immediately. If all service devices at the time of receipt of information are busy processing other information, it does not leave the system, but queues and waits until one of the devices becomes free. Therefore, in a closed queuing system, the input flow of requirements is formed from the output.

Information in the control system can be initiated upon request from one of the devices of the control center (request from the workstation), and can be initiated by any network element due to a change in the status (or state) of one or more of its parameters. In the first embodiment, the transactions in the control system consist of four phases: request sub-response, response sub-operation, request acknowledgment sub-operation, and response acknowledgment sub-operation.

In the second and third embodiments, the transactions in the MS consist of the subation of the transfer of status change and the

subation of the confirmation of receipt of information, ie the complete transaction is formed of two phases.
Variants of different transactions are presented in Fig.1-Fig.3.
With the use of service-oriented architecture in the MS model, the complete transaction will consist of a significant number of phases, namely [1, 4, 14, 16]:
– subrouting the request to the integrating server;
– sub-requests to the register of services;
– sub-requests to remote servers - applications and / or databases;
– sub-confirmation of receipt of the request;
– sub-response;
– sub-confirmation of receipt of the answer.
The request subbaction consists of the request generation time, the transmission time, the delay time in the queue to the server to which the request was addressed, and the request processing time by the server.

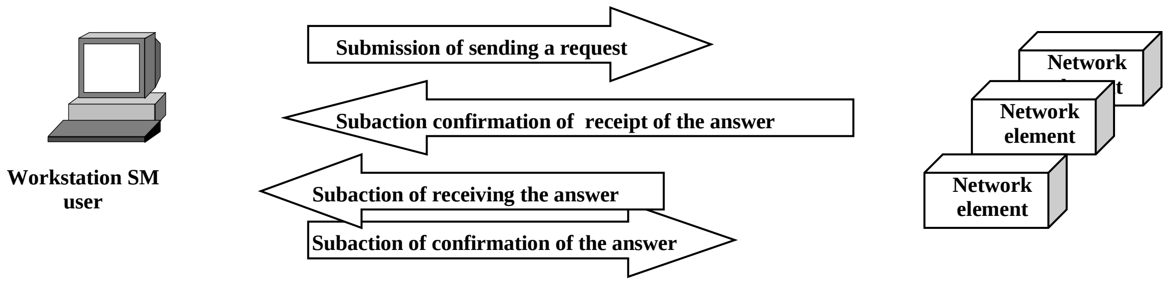

Figure 1. Phases of the transaction in the MS (option 1)

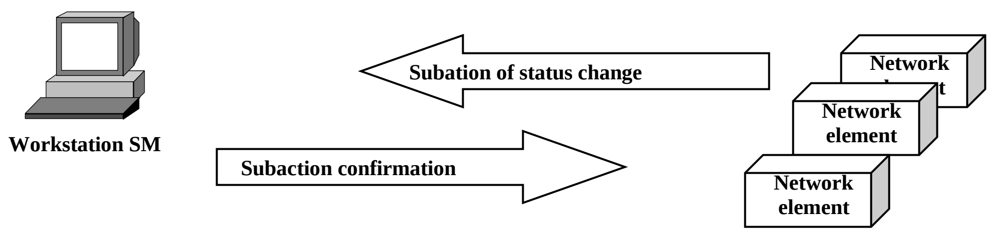

Figure 2. Phases of the transaction in the SU (option 2)

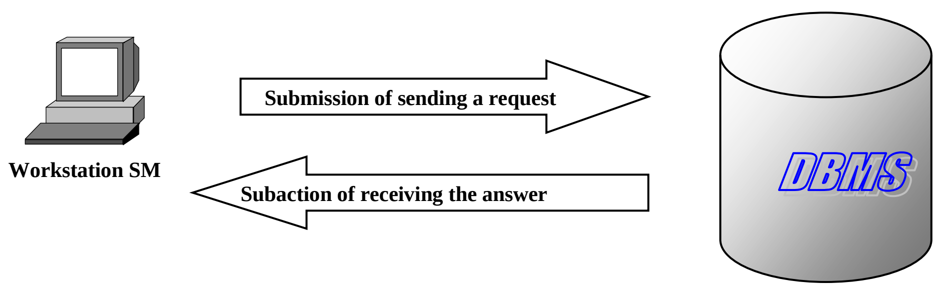

Figure 3. Phases of the transaction in the MS (option 3)

Other submissions are considered similarly.
Therefore, the total transaction time can be defined as [16]:

$$T = t_f + n t_n + nW + n t_{obr}$$

where t_f is the time of request formation;
t_n – transmission time on the communication channel;
W – delay time in the queue to the remote server;
t_{obr} - time of request processing by the remote server;
n – the number of phases in the transaction.
The state of the system is characterized by the total number of requirements that are in service and in the queue (equal to k, $k = 0, 1, ..., n$) and have the following interpretation:
S_0 - service device is free;
S_1 - the service device is busy, there is no queue;
S_2 - the service device is busy, one request in the queue;
S_n - service device is busy, n-1 application in the queue.

The number of control objects is equal to n, and the number of service devices - m. If λ is the intensity of control information, and μ is the intensity of the service flow, then the stationary process in this system will be described as follows [14, 16]:

$$p_n = \frac{(m\rho)^n}{n!} \qquad n < m;$$

$$p_n = \frac{m^m \rho^n}{m!} \qquad n. > m;$$

where

$$\rho = \frac{\lambda}{m\mu}$$

As a result of the decision of this system we find probability of the 0–th state:

$$P_0 = [\sum_{n=0}^{m-1} \frac{(m\rho)^n}{n!} + \sum \frac{(m\rho)^m}{m!}\ ]^{-1},$$

Probability that the request will be queued:

$$P_Q = \frac{P_0 (m\rho)^m}{m!(1-\rho)},$$

Thus, we determine the following characteristics of the probability of MS:

– the average length of the queue

$$N = T\lambda = \frac{\lambda}{\mu} + \frac{\lambda P_Q}{m\mu - \lambda} = m\rho + \frac{\rho P_Q}{1-\rho}$$

– average message delay time by remote server:

$$t_c = W + t_{обр} = \frac{1}{\mu} + \frac{P_Q}{m\mu - \lambda}$$

Currently, a characteristic feature of emergency management systems can be considered heterogeneity of traffic.

Heterogeneity of traffic is the transmission over the network of packets of several types, which have different requirements. These requirements are formulated in the form of restrictions on the delivery time of packages of different types. Basically, these are average constraints τ_i^*, that affect the average packet delay time $\overline{\tau_i}$ in the network under the condition $\overline{\tau_i} < \tau_i^* \left(i=\overline{1,n}\right)$, where n is the number of packet types in the network.

Research and analysis of the average packet delay time $\overline{\tau_i}$ can be performed using mathematical queuing models with a heterogeneous flow of applications, which will assess the effect of channel bandwidth on quality indicators in the transmission of packets of different types. At the same time, the task of selecting packet parameters critical to delays in the control network becomes relevant.

The solution of this problem will allow to analyze the properties of control systems and formulate recommendations for the design of control networks, in particular, to estimate the delay and the required bandwidth of the channels for the transmission of control information.

To assess the efficiency of traffic in the control network as a basic model of the channel, it is advisable to use a queuing system with a heterogeneous flow of packets of *n* types entering the control channel with intensities $\lambda_1, \ldots, \lambda_n$.

Let's mark:

V is the bandwidth of the channel,

L_i is the average length of the *i*-th type packet.

For the case when packets of one class have the same length, and packet flows are the simplest, the average packet delay of the *i*-th type when using the method of traffic management based on relative priorities is determined by expression (1) [4, 16]:

$$\tau_i = \left(\frac{\left(\sum_{j=1}^{n} \lambda_j \cdot L_j^2 \right)}{\left(V - \sum_{j=1}^{i-1} \lambda_i \cdot L_i \right) \cdot \left(V - \sum_{j=1}^{i} \lambda_i \cdot L_i \right)} \right) + \frac{L_i}{V},\ \left(i=\overline{1,n}\right) \quad (1)$$

One of the important tasks at the design stage of networks for the transmission of control information is to determine the requirements for channel bandwidth. Obviously, these requirements significantly depend on the load generated by the transmitted data packets and the restrictions imposed on the amount of packet delay, which is especially important in emergencies.

Consider the case when the restrictions are set on the average delay time of packets of a certain priority, in the form: $\overline{\tau_i} < \tau_i^*$. Suppose that the sizes of packets of all types are the same [L_i = L = 64 bytes for all], and the share of priority packets in the total load is $k(0 \le k \le 1)$, ie $\lambda_1 = k \cdot \Lambda$ .. Then, solving the inequality $\overline{\tau_i} < \tau_i^*$ taking into account (1), we obtain that the bandwidth of the control channel must be selected from the condition [17]:

$$V > \frac{L}{2} \left(\frac{1}{\tau_1^*} + k \cdot \Lambda + \left(\left(k \cdot \Lambda - \frac{1}{\tau_1^*} \right)^2 + \frac{4 \cdot \Lambda}{\tau_1^*} \right)^{\frac{1}{2}} \right) \quad (2)$$

The expression in the right part of inequality (2) is the lower limit of the bandwidth V_k of the control channel, which must be had to transmit *k* priority packets with a given high quality. In the process of designing control networks, it is usually quite difficult to specify k priority packets in the total load. At the same time, this share can vary considerably during the day. In this regard, it is proposed to estimate the required bandwidth for the entire range of change *k*. To do this, consider the limit cases when $k \to 0$ and $k \to 1$.

Then from (2) we obtain the lower (3) and upper (4) limit of the bandwidth of the control channel and the effect of using the bandwidth of the channel (5) [4, 17]:

$$V_{\min} = \frac{L}{2} \left(\frac{1}{\tau_1^*} + \left(\frac{1}{\tau_1^{2*}} + \frac{4 \cdot \Lambda}{\tau_1^*} \right)^{\frac{1}{2}} \right) \quad (3)$$

$$V_{\max} = L \left(\frac{1}{\tau_1^*} + \Lambda \right) \quad (4)$$

$$\delta = (Vmax - V_k) / V_k \quad (5)$$

4. Result and discussion

4.1. Estimating the impact of packet time delays when using channels with different bandwidths and discussing the results

In the table. 1 presents the results of calculating the time delays of packets for eight variants of values of intensities and lengths of packets when using channels with different bandwidths.

Analysis of the results presented in table. 1 and graphical data presented in Fig. 4 allows us to formulate the following conclusions:

1. To ensure a minimum packet transmission delay with a bandwidth of 128 kbit / s, it is advisable to use long packets, but with low intensity or short packets, but with higher intensity.
2. When the bandwidth of the communication channel is increased 1.5 times (from 128 to 192 kbit / s), the delays for packets of all types and variants are reduced more than twice.

Table 1

λ_i, c^{-1}	L_i, біт	Vk, kbit / s	
		128	192
		τ_i, c	
3	$1.3*10^4$	0.17	0.09
6	$8.1*10^3$	0.131	0.07
11	$4.1*10^3$	0.1	0.05
21	810	0.78	0.03
3	810	0.27	0.12
6	$4.1*10^3$	0.29	0.13
11	$8.1*10^3$	0.32	0.15
21	$1.3*10^4$	0.35	0.17

4.2. Estimation of influence of throughput of a control channel at various values of parameters of loading and restrictions on a delay of packets and discussion of results

In the table. 2 presents the results of calculating the bandwidth of the control channel at different values of load parameters and packet delay constraints.

Analysis of the results shows that reducing the bandwidth requirements of control channels allows:

– reduce the allowable delay several times with a minimum increase in channel bandwidth;

– with increasing load (intensity Λ) and the optimal choice of packet type increases the effect of using channel bandwidth;

– with decreasing share of k priority packets in the total load, the effect of using the bandwidth of the channels increases.

Thus, the proposed model and the methodology based on it allowed to study the channels of the telecommunication network control network, namely to determine the bandwidth of the channel and evaluate the effect achieved by the optimal choice of intensity and priority of the packet.

It should be noted that the reliability and efficiency of the control system of the telecommunications network depends on the quality and reliability of the reception of discrete input signals, which are influenced by both external and internal factors. The integrity and reliability of the discrete data packet is directly related to the assessment of the stability of the reference signals by the system of their reception, which is part of the telecommunications network. The estimate itself depends on the parameters of the carrier frequency of the input signals. Solving problems in estimating the carrier frequency of these signals involves the choice of evaluation parameter and methodology for their determination. As such a technique in the work to estimate the carrier frequency of signals transmitted in packet mode, it is proposed to use the rule of maximum likelihood using fast sliding Fourier transform [18].

In this case, the system of synchronization of the reference signal can be improved by the method of synthesis of open communication, which is described in detail in [19]. As a criterion for quantifying the minimum marginal variance of the carrier frequency of the packet input signals of the telecommunications network, it is advisable to use the lower Cramer-Rao lower bound (Cramer-Rao lower bound), the calculation of which for the telecommunications network is given in [20].

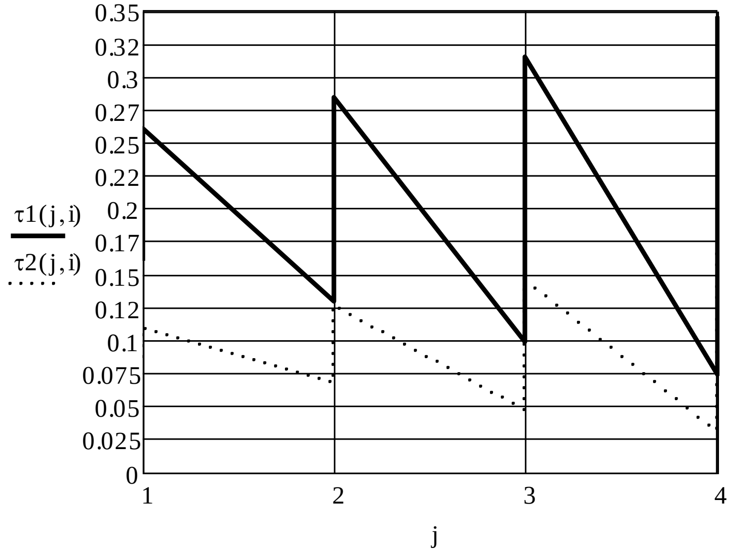

Figure 4. Dependence of packet time delays on changes in packet intensities and lengths when using communication channels with different bandwidths (τ_1 at V_k = 128 Kbps, τ_2 at V_k = 192 Kbps).

Table 2

Restriction delay, τ_1^*, mc	Intensity, c^{-1}	Share of priority packages, *k*	Bandwidth, kbit / s			Effect, %
			V_k	$V_{k\ min}$	$V_{k\ max}$	
150	10	0.1	$6.391*10^3$	$5.95*10^3$	$8.54*10^3$	34.01
	20	0.3	$9.11*10^3$	$7.73*10^3$	$1.37*10^4$	49.97
	30	0.5	$1.351*10^4$	$8.983*10^3$	$1.9*10^4$	44.451
	40	0.7	$1.9*10^4$	$1.01*10^4$	$2.4*10^4$	27.82
	50	0.9	$2.7*10^4$	$1.12*10^4$	$2.91*10^4$	9.3
300	10	0.1	$4.11*10^3$	$3.851*10^3$	$6.83*10^3$	66.322
	20	0.3	$6.572*10^3$	$5.07*10^3$	$1.2*10^4$	81.953
	30	0.5	$1.06*10^4$	$5.91*10^3$	$1.71*10^4$	62.457
	40	0.7	$1.651*10^4$	$6.791*10^3$	$2.223*10^4$	34.517
	50	0.9	$2.473*10^4$	$7.52*10^3$	$2.745*10^4$	10.625

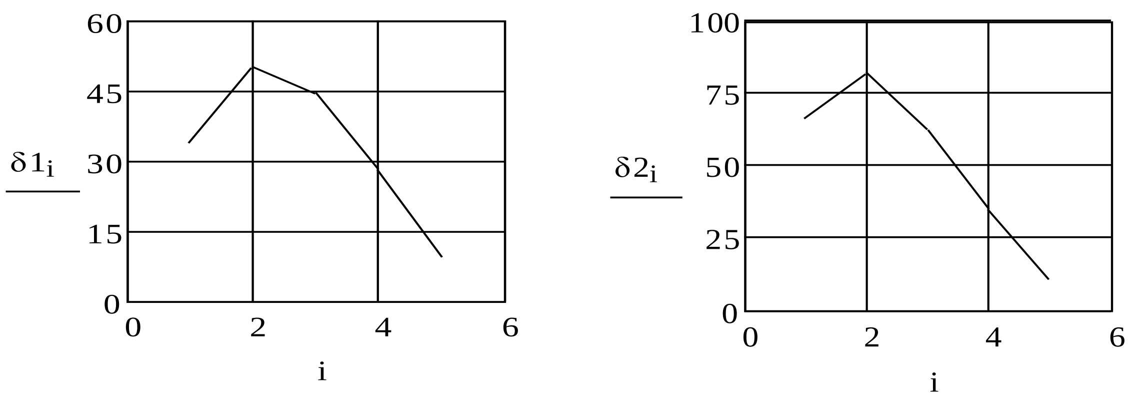

Figure 5. Dependence of the effect (%) of channel bandwidth utilization on the coefficient (k) with packet delay constraints of 150 ms (δ1) and 300 ms (δ2

To ensure the reliability and reliability of the input data package in high-speed control systems of telecommunications networks can be a method of improving the synchronization system of the input device of the telecommunications network, which is covered in [21,22].

5. Conclusion

The paper analyzes, generalizes and formalizes the requirements for the bandwidth of the control system channels.

Their formalization became the basis for determining the general approach, substantiation of the application of the mathematical apparatus and the development of mathematical dependencies that describe the process of modeling the bandwidth of the telecommunication network control channel.

The paper develops and presents a mathematical model based on the laws and rules of queuing theory and is the basis of the method of estimating the impact of bandwidth of the control network channel on performance indicators in the transmission of different types of packets taking into account their priority in the operation of MS in emergency situations.

In the process of assessing the impact of the bandwidth of the control network channel on the quality of the telecommunications network during the transmission of packets of different types, it is established that:

- the minimum delay in the transmission time of data packets at a given bandwidth depends on the length of the packet and the intensity of their transmission.
- the bandwidth requirements of the channel relating to one network element are determined by the amount of information that the network element exchanges with the operating system management and the allowable delay time of the management transaction;

The use of the proposed approach, mathematical dependences and the presented method allowed to assess the effect of channel bandwidth on quality indicators in the transmission of packets of different types, taking into account their priority in the operation of the MS in emergency situations.

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