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Y. TOROSHANKO[1], Ph.D. technical, associate professor;
ORCID: 0000-0002-9053-7156
O. TOROSHANKO[2], Ph.D. technical, associate professor;
ORCID: 0000-0002-2354-0187
S. R. KUFTERINA[1]**,** senior lecturer;
ORCID: 0009-0004-1696-5699
A. DUTCHYN[1], student,
ORCID: 0009-0006-7190-6063
[1]State University of Information and Communication Technologies, Kyiv
[2]Taras Shevchenko Kyiv National University

CALCULATED ESTIMATES OF THE COMPUTER NETWORK TIME PARAMETERS

Performed a detailed analysis of the time diagrams of the computer network functioning using the methods of message and packet switching. The article presents analytical expressions for calculating the main time parameters of information exchange, which have the greatest impact on the quality of user service. Some other parameters have been identified that have a significant impact on the quality of user service, but are more operational in nature and are defined by the protocols used. This includes the efficiency of communication channels use, the time spent on unproductive channel occupancy (information redundancy), etc. The materials of the article can be used by specialists, developers and network administrators, as well as for educational purposes.

Keywords: computer network, message switching method, packet switching method, quality of service, key performance indicators, information exchange, network time parameters.

Introduction

Ensuring high performance indicators and acceptable quality of service is a key task in the design and improvement of telecommunication networks. Solving this problem consists in achieving the most productive use of communication channels and ensuring the specified required time parameters of the network. One of the main such parameters is the minimum time of reliable information exchange between users [1-8]. The initial calculation determination of the main time parameters of the network at the stage of forming the technical task of the relevant research and design work contributes to a significant reduction in design time, financial and material costs. Taking into account the above, the development of appropriate recommendations and analytical expressions for a preliminary initial assessment of the basic time parameters of the network is an urgent and important task.

Research problem statement

Modern telecommunication systems and networks are used in almost all spheres of human activity, which determines a large number of scientific publications on this topic [9-14]. Both the basic principles of building telecommunication systems and networks and methods of their implementation are being developed and improved, issues of ensuring the reliability of functioning, the reliability of information exchange, improving key indicators of efficiency and productivity of networks are being addressed. In most cases, considerable attention is paid to considering conceptual issues of building networks, principles of building telecommunication systems and networks, routing methods, topologies, use and development of various protocols and technologies, etc. At the same time, studies of specific efficiency parameters, in particular time characteristics, on which the quality and efficiency of the network significantly depend, are considered in the context of a particular area of use. Analytical expressions for determining key indicators of network efficiency are often of a general descriptive nature, which complicates their practical application when designing new or improving existing telecommunication networks.

Information exchange between users is carried out by the transport network by forming routes – connections of nodes and communication lines. The main function of the transport network is to provide users with the potential for reliable access to all resources and services of the telecommunications system. The implementation of this main function consists in fulfilling the following requirements: productivity, data security, reliability, information and technical compatibility, manageability, scalability [3, 15-19].

To ensure the specified requirements and assess the quality and efficiency of data transmission systems, the following indicators are used [3, 4, 8, 9, 12]: costs for creating and operating the system; network design and deployment time; reliability characteristics; time parameters of network operation (network response time to a request, message transmission time, productive channel usage time, information residence time in the system when it is transferred between nodes); predictability and protection against overload; network load.

Although all these requirements and indicators are important, often such concepts as Grade of Service" (GoS) or Quality of Service" (QoS) of a telecommunication network are interpreted more narrowly – it includes only the two most important network characteristics – performance, which is determined by time parameters, and reliability [4, 7, 11].

For the user, from the view point of GoS and QoS, the most important time parameters are the data delay time in the network $Tddm$, the transmission time to the recipient Ttm, the information exchange session time $Tsesm$, the efficiency of communication channel usage $Kefm$, as well as certain other parameters that are more operational in nature and are determined by the protocols used, network administration, etc [1, 3, 5, 9, 18].

A large number of scientific publications are devoted to the issue of considering the principles of building telecommunication networks, methods, techniques, and protocols [1-12]. The basic methods of switching and data transmission in telecommunication networks are the methods of channel switching (CSM), message switching (MSM), and packet switching (PSM). Their comparative characteristics are given, and the advantages and disadvantages of each of them are analyzed. A significant drawback and limitation in using the CSM method is the need to ensure the same bandwidth of all communication channels, from which the entire data transmission path for a given information exchange session is formed. When using the MSM and PSM methods, communication lines between end subscribers may have different bandwidths.

Analyzing the time characteristics of a MSM network

To analyze the time parameters of message-switched networks (MSM), let us consider the time diagram of information transmission from the switching node SN1 to the node SN3 through one transit communication node SN2 (fig. 1).

Node SN_1 is the sender of the message – SNS (Switching Node Sender), SN_3 node is the recipient of the message – SNR (Switching Node Receive).

The message contains the header (MH) and the user data (MD). The message header MH is an additional service information that contains the address of the receiver node and other information that is used to control and manage the exchange.

This message is transmitted in the network from node to node as follows.

A message is generated and stored on the SNS node – header + user data (MH+MD). Based on the analysis of the endpoint (final) SNR address, the routing task is solved – the SN node to which the message is transmitted is determined. This can be either a transit SNT or the endpoint SNR node. After receiving the message the SNT transit node processes it – checks for errors during transmission and solves the routing task – determines the SN node to which the message is transmitted. After receiving a message, each node (transit and final) performs an error check. If no errors are detected, a Message Confirmation (MC) is sent to the switching node from which the message was received. The received message is transmitted to the next node according to the result of the routing task.

If an error is detected in the received message, an Message Error (ME) is transmitted to the corresponding switching node. This case is not considered in this article.

Thus, each transit node buffers the transmitted information: it receives the full message, processes it, and only then transmits it further. This procedure leads to a significant increase in the time it takes to deliver information from the sender to the recipient.

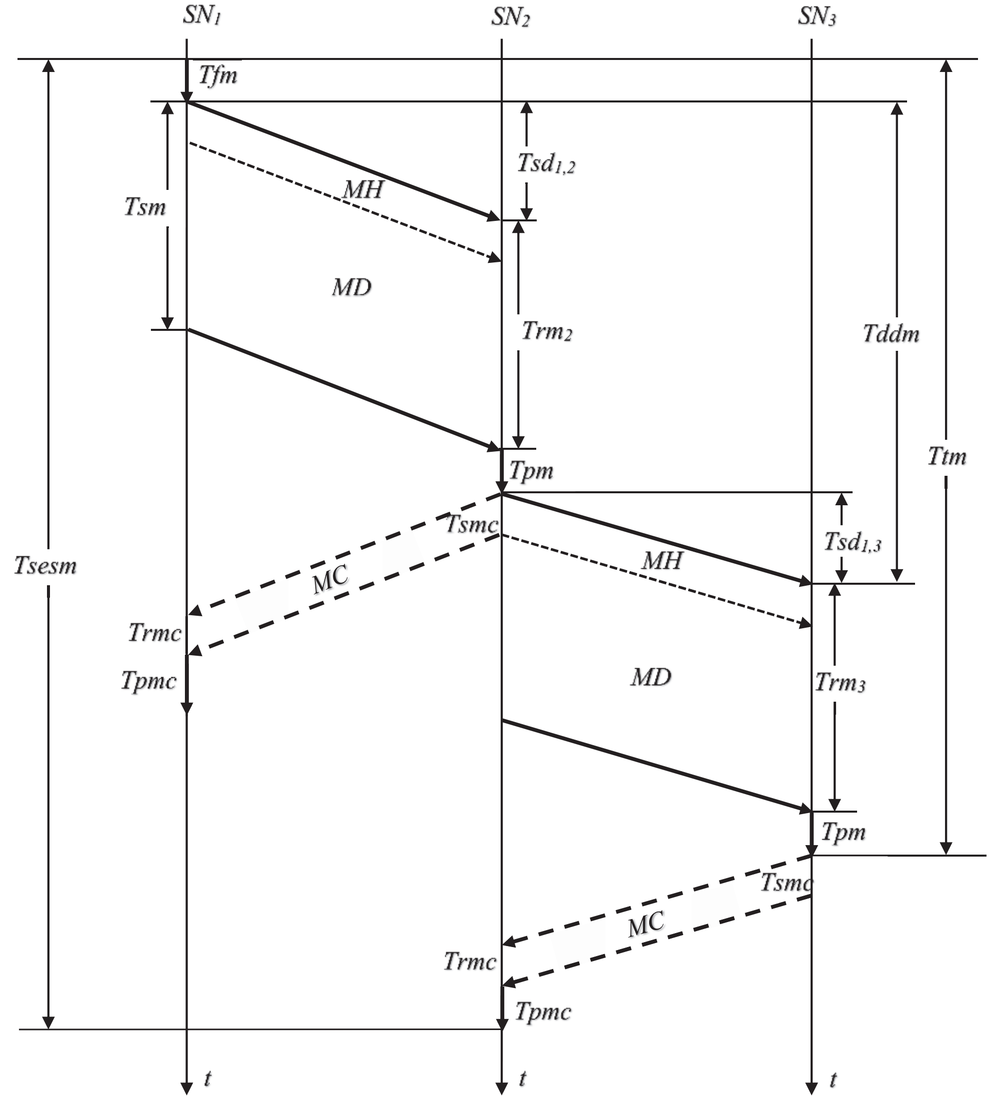

Fig. 1. The time diagram of information transmission of Message Switching Method (MSM)

In the initial state, the endpoint sending node SN_1 contains the user's data MD, which must be transmitted to the endpoint receiver node SN_k, as well as the address of this node (k is the number of nodes through which the message passes in this session: in Fig. 1 k=3). In the Tfm time interval, the sending node SN_1 processes this information as follows:

– based on the analysis of the address of the endpoint receiver node SN_k, the further transmission route is selected (routing task). This can be a transit node or a endpoint receiver node;

– forming a message header (MH);

– generating a message (MH+MD);

– sending the generated message to the selected channel - time interval Tsm. The size of this interval is determined by the transmission rate and the size of the generated message.

The communication node (transit or endpoint) receives the specified message – the time interval Trm_i $(i = 2 \dots k)$, stores it and processes the received message in the time interval Tpm_i.

If it is a transit node the following tasks are performed:

– control of the absence of errors in the received message;

– selection of the further transmission route;

– modification of the MH header (if necessary);

– transmission of the modified message via the further route.

If this is the endpoint receiver node only the following tasks are performed:

– control of the absence of errors in the received message;

– selection of the further transmission route.

Let's take a closer look and give analytical expressions for determining the time parameters in a MSM. Let's assume that the transmission is carried out through k communication nodes, including the sender and receiver nodes. All nodes are numbered in the order of the route sequence and numbered $i = 1, 2, \ldots, k$ (for the sender node $i = 1$, for the receiver node $i = k$).

Data delay time in the network $Tddm$ – is defined as the time of delivery of each *i-th* bit of data from the sender node SN_1 to the receiver node SN_k.

Then, according to Fig. 1, the data delay time in the network can be determined as follows:

$$Tddm = \sum_{i=1}^{k-1} Tsd_{i,i+1} + \sum_{i=2}^{k-1} (Trm_i + Tpm_i), \quad (1)$$

– $Tsd_{i,i+1}$ is a signal delay time in the channel between nodes SN_i and SN_{i+1};

– Trm_i is a time when node SN_i receives a message from the channel;

– Tpm_i is a processing time of the received message at node SN_i. The value of Tpm_i is determined mainly by the size of the message queue of exchange sessions between network nodes.

In (1), time of receiving the message Trm_i by node SN_i is defined as:

$$Trm_i = (NMD + NMH) \times \frac{1}{f_{i,i+1}}, \quad (2)$$

– NMD is an amount of useful data (user data) in the message (bit);

– NMH is a size of the header in the message (bit);

– $f_{i,i+1}$ is a rate of data transmission in the channel between nodes SN_i and SN_{i+1} (bit/sec). Note that in networks with MSM, channels with different data transmission rates can be used.

Taking into account (1) and (2), we obtain an analytical expression for estimating the data delay in the MSM network depending on the amount of data, the channel transmission rate, and the message processing time at the communication nodes:

$$Tddm = \sum_{i=1}^{k-1} Tsd_{i,i+1} + \sum_{i=2}^{k-1} \left[(NMD + NMH) \times \frac{1}{f_{i,i+1}} + Tpm_i \right]. \quad (3)$$

The message transmission time Ttm is determined from the beginning of the initiation of the exchange session by node SN_1 (time interval Tfm) to the reception and processing of the message by the endpoint receiver node SN_k.

$$Ttm = Tfm + \sum_{i=1}^{k-1} Tsd_{i,i+1} + \sum_{i=2}^{k} (Trm_i + Tpm_i)\,, \quad (4)$$

$-Tfm$ is a time of message formation.

Taking into account (2), we obtain an analytical expression for estimating the message transmission time in the MSM network depending on the amount of data, channel transmission rate, and message processing time at the communication nodes:

$$Ttm = Tfm + \sum_{i=1}^{k} Tsd_{i,i+1} + \sum_{i=2}^{k} \left\{ \left[(NMD + NMH) \times \frac{1}{f_{i,i+1}} \right] + Tpm_i \right\}. \quad (5)$$

The exchange session time $Tsesm$ is determined from the beginning of the initiation of the exchange session by the SN_1 node (time interval Tfm) to the reception and processing by the SN_{k-1} service node of the MC message confirming the delivery of data to the endpoint SN_k receiver node:

$$Tsesm = Ttm + Tsmc + Tsd_{k-1,k} + Tpmc = Ttm + \left(NMC \times \frac{1}{f_{i,i+1}} \right) + Tsd_{k-1,k} + Tpmc, \quad (6)$$

– NMC is a size of the MC service message (bit).

Effective use of communication channels Kef is defined as the ratio between the channel occupancy time for transmitting MD user information and the total channel occupancy time during the exchange session. For one channel, for example, between nodes SN_1 and SN_2 (Fig. 1), the total channel occupancy time for the MSM method is equal:

$$TSm_{1,2} = \left(2 \times Tsd_{1,2}\right) + \left[(NMH + NMD + NMC) \times \frac{1}{f_{1,2}}\right] + Tpm_2 + Tpmc_1. \quad (7)$$

Then, taking into account (7), the efficiency factor of using this channel for the MSM method is:

$$Kefm_{1,2} = \frac{NMD \times \frac{1}{f_{1,2}}}{(2 \times Tsd_{1,2}) + \left[(MH+MD+MC) \times \frac{1}{f_{1,2}}\right] + Tpm_2 + Tpmc_1}. \quad (8)$$

The efficiency factors for other channels usage are determined in the same way.

Analyzing the time characteristics of a PSM network

The time diagram of data transmission of PSM method from the sender node SN_1 to the receiver node SN_3 through one transit communication node SN_2 is shown in Fig. 2. The number of packets being transmitted equals 4. Each packet contains a header (PH1...PH4) and user data (PD1...PD4). In fig. 2 they are separated by a dashed line. The header contains control information, the address of the receiver node, the packet number and control information that is used to detect transmission errors [2, 3, 6, 10, 15]. Note that, unlike the MSM method, the packet number field is introduced here.

The session of information exchange is initiated by the sender node SN_1 at the time interval Tfp, where packets are formed bered and the routing task is solved based on the analysis of the address of the endpoint receiver node SN_k.

In the time intervals $Tsp_1 \ldots Tsp_u$ generated packets are sent to the selected channel (u is a number of packets in the exchange session). The size of these intervals is determined by the transmission rate $f_{i,i+1}$ in the channel between nodes SN_i and SN_{i+1} and the volume N_{Dp} of the corresponding packets. The packets received at the transit node are stored and queued for processing, after which the processed packets are transferred to another queue – the queue for delivering packet to the channel according to the selected route. The time intervals during which packets are queued and processed are labeled as $Tpp_1 \ldots Tpp_u$.

The processing of the received packet is as follows:
- control of the absence of errors in the received packet;
- solving the routing task;
- modification of the packet header (if necessary);
- transmitting a modified packet on a further route.

If it is the endpoint receiver node, the routing task and further transmission of packets is not performed. Only the following is performed::
- checking for errors in the received packet;
- transmission of the packet reception result – service message PC.

Note that in our case, we consider the case when there was no distortion in the channel during the transmission of the packet. After receiving and processing a positive acknowledgment PC, the corresponding packet on the sender node can be deleted. If an error is detected in the packet on the receiver node, a Packet Error (PE) message (negative acknowledgement) is sent to the transmitter node according to the used acknowledgement protocol [3, 4, 11, 12, 18].

As with the MSM method, the most important things in terms of QoS are the data delay time in the PSM network $Tddp$, transmission time Ttp, a session time $Tsesp$ [4, 6-8, 12]. The transmission is carried out through k number of communication nodes $SN_1 \ldots SN_k$.

The data delay time in the network $Tddp$ is defined as the time of delivery of each *i-th* bit of information from the sender node SN_1 to the receiver node SN_k (fig. 2):

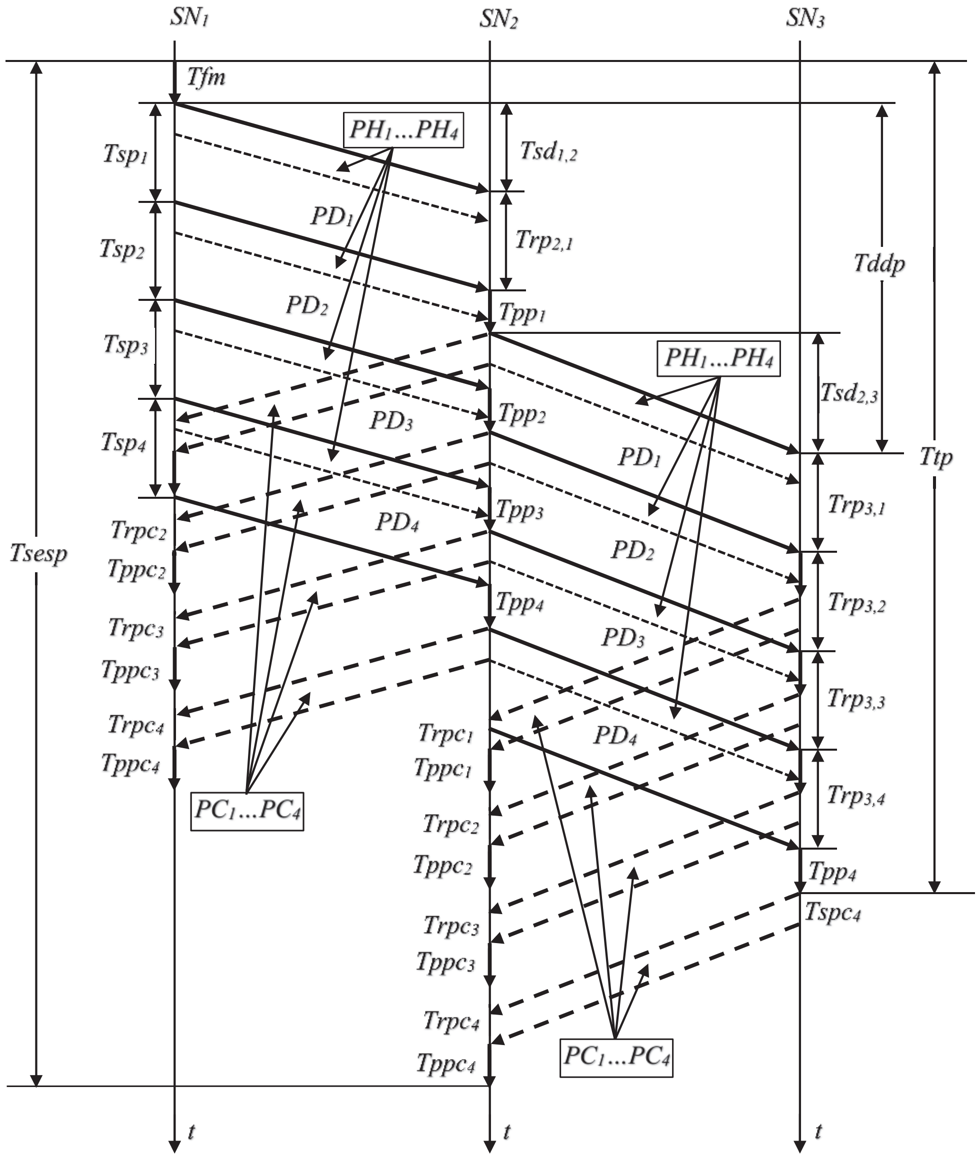

Fig. 2. Time diagram of information transmission using Packet Switching Method (PSM)

$$Tddp = \sum_{i=1}^{k-1} Tsd_{i,i+1} + \sum_{i=2}^{k-1}\left(Trp_{i,1} + Tpp_{i,1}\right), \quad (9)$$

– $Tsd_{i,i+1}$ is a signal delay time in the channel between nodes SN_i and SN_{i+1};

– $Trp_{i,1}$ is a time when the SN_i node receives the 1-st packet from the channel;

– $Tpp_{i,1}$ is a processing time on the SN_i node of the 1-st packet. The value of Tpp_i is determined mainly by the size of the packet queue in exchange sessions between other network nodes.

In (9), time of receiving the 1-st Trp packet by the SN_i node is defined as:

$$Trp_i = (NPD_1 + NPH_1) \times \frac{1}{f_{i,i+1}}, \quad (10)$$

– NPD_1 is an amount of useful data (user data) of the 1-st packet (bit);

– NPH_1 is a header size in the 1-st packet (bit);

– $f_{i,i+1}$ is a rate of data transmission in the channel between SN_i and SN_{i+1} nodes (bit/sec). Note that in PSM networks channels with different data transmission rates can be used.

Taking into account (9) and (10), we obtain an analytical expression for estimating the data delay in a packet network depending on the amount of data, the channel transmission rate, and the message processing time at the communication nodes:

$$Tddp = \sum_{i=1}^{k-1} Tsd_{i,i+1} + \sum_{i=2}^{k-1}\left\{\left[(NPD_1 + NPH_1) \times \frac{1}{f_{i,i+1}}\right] + Tpp_i\right\}. \qquad (11)$$

Transmission time Ttp is determined from the beginning of the initiation of the exchange session by node SN_1 (time interval Tfp) to the reception and processing of the last packet by the endpoint receiver node SN_k (in fig. 2 – SN_3):

$$Ttp = Tfp + Tddp + \sum_{j=1}^{u} Trp_{k,j} + Tpp_{k,u}, \qquad (12)$$

– Tfp is a time of formation of packet;
– $Tddp$ is a data delay time in the PSM network, defined in (11);
– $Trp_{k,j}$ is a time of receiving the *j*-th packet by node SN_k;
– $Tpp_{k,u}$ is a processing time of the *u*-th packet by the node SN_k.

Taking into account (10), we obtain an analytical expression for estimating the transmission time of all packets in the network, depending on the amount of data, transmission rate in the channel, and the packet processing time at the communication nodes:

$$Ttp = Tfp + Tddp + \sum_{j=1}^{u}\left[\left(NMD_j + NMH_j\right) \times \frac{1}{f_{k-1,k}}\right] + Tpp_{k,u}, \qquad (13)$$

– $f_{k-1,k}$ is a the rate of data transmission in the channel between nodes SN_{k-1} and SN_k (bit/sec).

The session time $Tsesp$ is the information transmission time defined in (13), plus the time of transmission and processing of the last acknowledgment (confirmation by the endpoint receiver node about receiving the last packet):

$$Tsesp = Ttp + \left(NPC \times \frac{1}{f_{k-1,k}}\right) + Tppc, \qquad (14)$$

– NPC is a size of the service message PC (bit);
– $Tppc$ is a processing time of the service message PC.

Communication channel utilization efficiency $Kefp$ for the PSM method is defined as the ratio between the channel occupancy time for user information transmission (TUp) and the total channel occupancy time (TSp) during the exchange session.

For the channel between nodes SN_1 and SN_2 (fig. 2):

$$Kefp_{1,2} = {TUp_{1,2}}/{TSp_{1,2}}, \quad TUp_{1,2} = \sum_{j=1}^{u} PD_j; \qquad (15)$$

$$TSp_{1,2} = \left(2 \times Tsd_{1,2}\right) + \sum_{j=1}^{u}\left[\left(NPH_j + NPD_j\right) \times \frac{1}{f_{1,2}}\right] + \left(NPC_u \times \frac{1}{f_{1,2}}\right) + Tpp_{2,u} + Tppc_{1,u}.$$

The efficiency coefficients of other channels are determined in the same way.

Conclusions

The obtained in the work analytical expressions make it possible to calculate initial quantitative estimates of the network's time characteristics at the design and modeling stage. Detailed time diagrams of information exchange in networks using the MSM and PSM methods are presented, which allows assessing the quality of service provision to users from the point of view of the main time requirements for the network.

Expressions (3-5) and (11-13) make it possible to estimate the delay time and data delivery time to the final receiving node of the network, taking into account the message volume, the number of transit nodes and other network parameters. For PSM networks expressions (11-13) also take into account the number of packets into which the message is divided.

Expressions (6-8) and (14-15) give the important estimate for administrators and providers of the exchange session time and the channel efficiency coefficient for the MSM and PSM methods. In addition, expressions (14-15) provide an opportunity to estimate for the PSM network the impact of packet size on the efficiency of communication channels and information delay, which is especially important for real-time systems.

The materials of the article can be used by specialists, developers and network administrators, as well as in the educational process.

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