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PRIMARY ESTIMATES OF THE CANNEL SWITCHED TELECOMMUNICATIONS NETWORK TIME CHARACTERISTICS

This article continues the cycle of works on the primary assessment of the time characteristics of telecommunication systems in different modes of their operation and using different methods of switching and data transmission. Based on the analysis of the functioning diagrams, analytical expressions for calculating the main time parameters of information exchange in a telecommunication network with circuit switching were obtained. The considered parameters are key in solving the problem of the user service quality. These parameters include the data delay time in the in the cannel switched network, the time of data delivery to the end user, the duration of the information exchange session, and the usage efficiency coefficients of the channels through which information exchange is carried out. The materials of the article can be used by specialists, developers and network administrators, as well as for educational purposes.

Keywords: computer network, methods of switching and data transmission, channel switching, quality of service time characteristic, information exchange, network time parameters.

Introduction

This article continues the cycle of works on the primary estimates of the time characteristics of telecommunication systems in different modes of their operation and using different methods of switching and data transmission [1]. In works [2]-[9] the main tasks of designing and improving telecommunication networks are defined, which provide high key indicators of productivity and efficiency of network functioning. The solution of these tasks consists primarily in reducing the time of information exchange between network nodes and delivery to the final destination to achieve high indicators of user quality of service (QoS). In works [1], [10]-[13] the importance and relevance of the task of primary estimates of the main time parameters at the starting stage of designing a telecommunication network are emphasized.

Research problem statement

In the telecommunication networks theory as basic message switching (MSM), packet switching (PSM) and channel switching (CSM) methods are considered. In modern networks for information exchange the compatible appliance of these methods are widely used [10]-[14]. This emphasizes the importance of solving the problems of primary estimation of time parameters during network design and deployment [1], [15], [16]. In the works [3]-[5], [17]-[21] the main requirements for providing users with reliable access to resources and services of the telecommunication system are formulated: productivity, reliability and data security, information and technical compatibility, manageability, scalability. The main indicators for implementing the specified requirements and assessing the efficiency of network operation are determined. Among them for the QoS provision an important place is occupied by the time parameters of network operation. That are information delay time in the net-

work, data delivery time to the end user, the duration of the user data exchange session including control information, the efficiency of using communication channels as the ratio the time transfer of user data to the full occupation of channels (including keeping channels unused), etc [2], [4], [9], [19], [22].

In [1, 15, 16] the issues of primary estimation of time parameters of telecommunication systems using MSM and PSM methods are considered.

The purpose of our article is to analyze and develop analytical expressions for primary estimation of time parameters of CSM networks. A characteristic feature of the CSM method is the need to use all channels with the same data rate for an information transfer session. When using the MSM and PSM methods, communication lines between end subscribers may have different data rates.

Analyze of CSM networks time diagrams

The basis of CSM is the formation of a direct physical channel for the duration of the communication session from the sending node (SNS – Switching Node Sender) to the receiving node (SNR – Switching Node Receiver) through a telecommunication data transmission network. A communication session is the time interval from the moment when the SNS initiated the exchange to the moment when all switching nodes (SN), that are involved in the session, have completed the exchange. A communication session in CSM consists of three phases: formation of a data transmission path (physical channel), data transmission over the formed path and the disconnection phase – disbanding the transmission path [4], [5], [7], [19].

The data transmission path formation phase in the following way is carried out. The sending node SNS, based on the analysis of the address of the final SNR, solves the routing task – the selection of the next SN to which the user data (UD) will be transmitted, and sends it a connection request (CR). If the selected SN is the final, the data transmission path is formed and consists of one transmission link without SN transit (SNT).

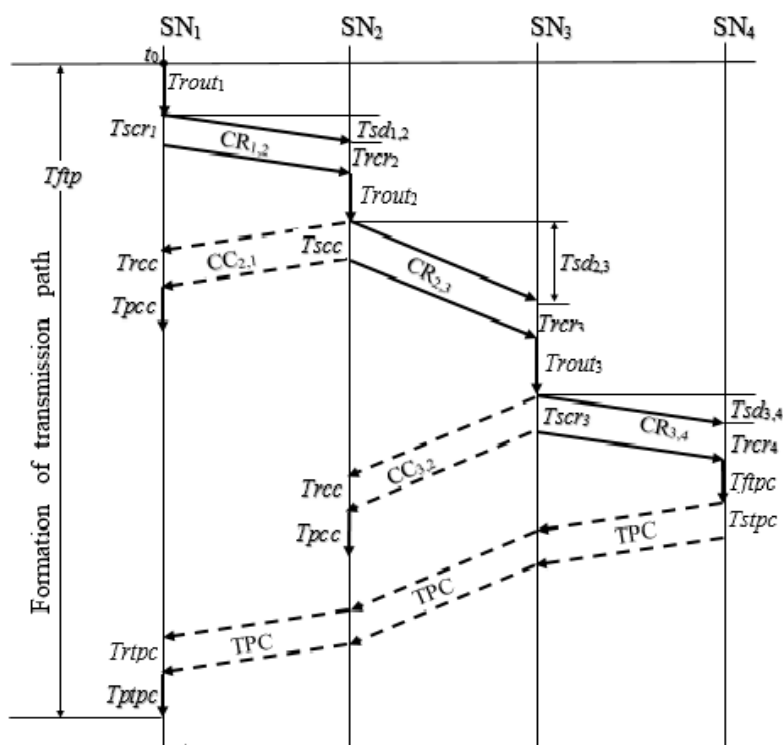


Fig. 1. Formation of the data transmission path phase

- In fig. 1 the following notations are adopted:
- SN is a switching node;
 - CR is a connection request;
 - CC is a connection confirmation;
 - TPC is a confirmation of transmission path;
 - T_{rout} is a routing time interval;

Otherwise, the selected SN is transitive, and the formation of the data transmission path continues. The next SN is searched for, to which the corresponding CR is sent. The channel on which the request was received and the channel on which the request was sent are combined, creating a two-link part of the path. This procedure is repeated until the final SNR is reached. Thus, if the information exchange is carried out through k nodes, including the SNS and SNR, we obtain a $(k - 1)$ -link data transmission path, which contains $(k - 2)$ SNT. All CR requests contain the address of the final SNR.

The time diagram of the data transmission path formation from node SN1 (data sender node) to node SN4 (receiver node) through two transit nodes SN2 and SN3 is shown in fig. 1.

- T_{scr} is a sending time of connection request;
- T_{rcr} is a reception time of connection request;
- T_{scc} is a sending time of connection confirmation;
- T_{rcc} is a reception time of connection confirmation;
- T_{pcc} is a processing time of the connection confirmation;
- T_{ftpc} is a forming time of transmission path confirmation;
- T_{stpc} is a sending time of transmission path confirmation;
- T_{rtpc} is a reception time of transmission path confirmation;
- T_{ptpc} is a processing time of the confirmation of transmission path;
- T_{sd} is a signal delay in the channel.

In the initial state (the moment time t_0) the sending node SN_1 contains user data (UD), that must be transmitted to the receiving node SN_4 , as well as the address of this node. The moment time t_0 is the exchange session beginning.

In the T_{rout_1} time interval the SN_1 node, based on the analysis of the address of the receiving node SN_4 , determines the transmission route (in our case this is the transit node SN_2) and sends a service message (SM) to this node – a request for connection $CR_{1,2}$ (interval T_{scr_1}). The value of this interval is determined according to the expression:

$$T_{scr_1} = NCR \times \frac{1}{f}, \quad (1)$$

where NCR is a size of the CR service message for a given network protocol (bits); f is a clock synchronization frequency of the transmission system (bits/sec).

After receiving the $CR_{1,2}$ service message (interval $T_{rcr_2} = T_{scr_1}$), node SN_2 solves the routing task (interval T_{rout_1}) – the selection of the next NS and link of the path. In our example, this is the transit node SN_3 , to which the service message $CR_{2,3}$ is sent. The selection of all subsequent links and nodes is carried out in the same way until the final receiving node is reached. In our example, this is node SN_4 , which along the formed path transmits to the sending node SN_1 the TPC service message, which for the SN_1 is permission to transmit UD. TPC service message signals the beginning of the data transmission phase.

Note that when forming each link of the data transmission path the CC service messages to the sender for each CR request are sent.

Analyzing the time diagram in fig. 1 for a CSM network, we obtain the following expressions for determining the implementation time of the information exchange session first phase – the formation of a data transmission path. The transmission path passes through k SN, including the sender and receiver nodes. All nodes are numbered in the order of the route and have numbers $i = 1, 2, \dots, k$ (for the SNS node $i = 1$, for the SNR node $i = k$). In other words, the data transmission path consists of $(k - 1)$ communication links.

For the example shown in fig. 1 ($k = 4$), the time for forming the data transmission path $T_{ftp(k=4)}$ is defined as:

$$T_{ftp(k=4)} = (T_{rout_1} + T_{rout_2} + T_{rout_3}) + 2(T_{sd_{1,2}} + T_{sd_{2,3}} + T_{sd_{3,4}}) + (T_{rcr_2} + T_{rcr_3} + T_{rcr_4}) + [T_{ftpc} + T_{stpc} + T_{rtpc} + T_{ptpc}]. \quad (2)$$

In the general case for any k the value of T_{ftp} will be:

$$T_{ftp} = \sum_{i=1}^{k-1} T_{rout_i} + 2 \sum_{i=1}^{k-1} T_{sd_{i,i+1}} + \sum_{i=2}^k T_{rcr_i} + [T_{ftpc} + T_{stpc} + T_{rtpc} + T_{ptpc}]. \quad (3)$$

Note that the time of sending the service message TPC is defined as:

$$T_{stpc} = NTPC \times \frac{1}{f}, \quad (4)$$

where $NTPC$ is a size of the TPC service message for a given network protocol (bits).

Taking into account (1) and (4) we obtain the final expression for determining the formation time of the data transmission path in the CSM telecommunication systems:

$$T_{ftp} = \sum_{i=1}^{k-1} T_{rout_i} + 2 \sum_{i=1}^{k-1} T_{sd_{i,i=1}} + \sum_{i=2}^k \left(NCR_i \times \frac{1}{f} \right) + [T_{fipc} + (NTPC \times \frac{1}{f}) + T_{rtpc} + T_{ptpc}]. \quad (5)$$

In formulas (2, 3, 5), the expression enclosed in square brackets determines the total time for forming, sending, and processing a SM confirming the creation of a data transmission path.

The data transmission phase is shown in fig. 2.

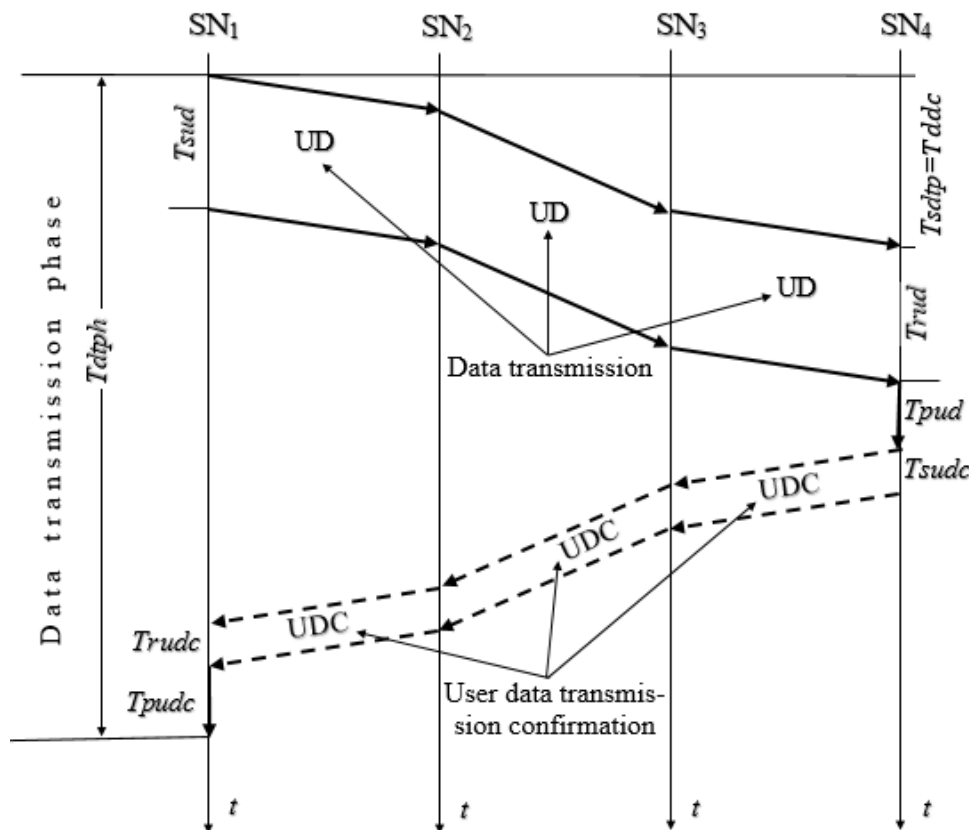


Fig. 2. Data transmission phase

In fig. 2 the following notations are introduced:

- UD is a user data;
- UDC is a user data confirmation;
- T_{sdtp} is a signal delay time in the transmission path;
- T_{sud} is a sending time of user data;
- T_{rud} is a received time of user data;
- T_{puud} is a processing time of received user;
- T_{sudc} is a sending time of user data confirmation;
- T_{rudc} is a received time of user data confirmation;
- T_{puudc} is a processing time of user data confirmation;
- T_{ddc} is a data delay time in the CSM network;
- T_{dtph} is a data transmission phase time.

The node SN₁ send user data UD to the channel of the formed path – the time interval T_{sud}, which is determined as follows:

$$Tsud = NUD \times 1/f, \tag{6}$$

where NUD is a user data volume (bits).

With a delay of $Tspd$ the user data UD are transmitted to the final receiving node SN_4 – the time interval $Trud$. On the receiving node side the received data are processed – the time interval $Tpud$, which consists of the following: checking the received data for errors during transmission and generating the SM UDC. Note that the article considers the case of error-free information transmission.

The formed message is issued to the transmission path channel – time interval $Tsudc$ – and with a delay $Tsdtp$ will be received by the sending node SN_1 . Here, at the time interval $Tpudc$ it is processed. At this interval the data transmission phase ends.

The time interval $Tsudc$ is defined as:

$$Tsudc = NUDC \times 1/f,$$

where $NUDC$ is the size of the UDC service message for a given network protocol (bits).

Based on the analysis of the time diagram in fig. 2, we obtain the following expressions for determining the duration of the data transmission phase at $k = 4$ (three-link transmission path):

$$Tdtph_{(k=4)} = 2(Tsd_{1,2} + Tsd_{2,3} + Tsd_{3,4}) + Trud + Tpud + Tsudc + Tpudc.$$

Here $Tsdtp = Tsd_{1,2} + Tsd_{2,3} + Tsd_{3,4}$, $Trud = Tsud$.

In the general case, for any k the analytical expression for determining the duration of the data transmission phase will be:

$$Tdtph = 2 \sum_{i=1}^{k-1} Tsd_{i,i+1} + Trud + Tpud + Tsudc + Tpudc. \tag{7}$$

Here it is worth noting the main advantage of the CSM over MSM and PSM. This is the smallest data delay time $Tddc$ in a CSM network, which is determined only by the delays of information signals in the channels of the created transmission path. As can be seen from the time diagram in fig. 2, data passes through transit nodes SN_2 and SN_3 without delays, i.e. without intermediate storage.

After receiving the UDC service message the sending node can start transmitting the next data block (continue the data transfer phase) or initiate the disconnection phase.

Disconnection phase. The execution of the disconnection phase consists in disbanding the data transmission path, thereby completing the information exchange session. The time diagram of this phase for the transmission path between the sending node SN_1 and the receiving node SN_4 through two transit nodes SN_2 and SN_3 is shown in fig. 3.

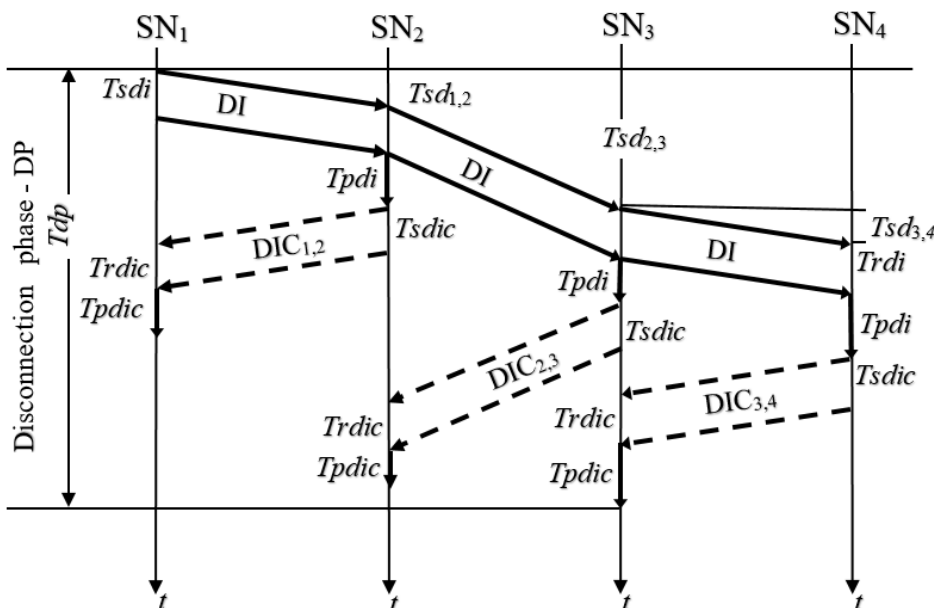


Fig. 3. Disconnection phase

In fig. 3 the following notations are introduced:

- DP is a disconnection phase;
- DI is a disconnect instruction;
- DIC is a disconnect instruction confirmation;
- Tdp is a time of the disconnection phase execution;
- $Tsdi$ is a time of sending disconnect instruction;
- $Trdi$ is a time of reception disconnect instruction;
- $Tpdi$ is a time of processing disconnect instruction;
- $Tsdic$ is a time of sending disconnect instruction confirmation;
- $Trdic$ is a time of reception disconnect instruction confirmation;
- $Tpdic$ is a time of processing disconnect instruction confirmation.

The sender node SN_1 issues over the data path channel the DI SM, which is sent to all nodes of the transmission path with the corresponding delays Tsd . After receiving this SM all nodes SN_i disconnect the channel, through which the command was received from the transmission path. At the interval $Tpdi$ a DIC SM is generated, which is sent to the previous node of the path SN_{i-1} . Thus, each node SN_{i-1} after processing this SM receives information about the disconnection of channels from the transmission path and their release for further use.

The time interval $Trdi$ is defined as follows:

$$Trdi = Tsdi = NDI \times 1/f, \quad - NDI \text{ is a command size (bits)}$$

Taking into account the above and based on the analysis of the time diagram in Fig. 3, we obtain the following expressions for determining the duration of the disconnection phase for an $(k - 1)$ -link data transmission path:

$$Tdp = 2 \sum_{i=1}^{k-1} Tsdi_{i,i=1} + Trdi + Tpdi + Tsdic + Tpdic. \quad (8)$$

Calculation of the main time parameters of the CSM network

In the works [2], [4], [9], [19], [22] the main requirements and time characteristics of telecommunication networks, which provide the required quality of service to users, are defined. Detailed analysis and analytical expressions for estimating the time parameters of MSM and PSM telecommunication systems are presented in the works [9, 15, 16]. Let us consider in more detail and give analytical expressions for determining the time parameters in a CSM network. We will assume that the transmission is carried out through k communication nodes, including the transmitter and receiver nodes. All nodes are numbered in the order of the route and have numbers $i = 1, 2, \dots, k$ (for the sender node $i = 1$, for the receiver node $i = k$).

Data delay time in the network $Tddc$ is defined as the transmission time in the physical medium of each i -th data bit from the sending node SN_1 to the receiving node SN_k . For a CSM network this is the delay time of the information signal in the data transmission path channels (fig. 2):

$$Tddc = Tsstp + \sum_{i=1}^{k-1} Tsdi_{i,i+1}. \quad (9)$$

Data portage time to the user $Tdpu$ is determined from the beginning of the initiation of the exchange session by the node SN_1 (time interval $Trout_1$ in Fig. 1) to the reception and processing of the message by the final receiving node SN_k (time interval $Tpud$ in Fig. 2). Note that this time parameter fully includes the duration of the data transmission path formation phase:

$$Tdpu = Tstp + \sum_{i=1}^{k-1} Tsdi_{i,i+1} + (NUD \times 1/f) + Tpud. \quad (10)$$

The duration of the information exchange session T_{sesc} is determined by the total duration of three phases: the data transmission path formation phase T_{ftp} (5), the data transmission phase T_{dtph} (7) and the disconnection phase T_{dp} (8):

$$T_{sesc} = T_{ftp} + T_{dtph} + T_{dp}. \quad (11)$$

In practice, all service messages (SM) – CR, CC, TPC, UDC, DI and DIC (fig. 1-3) – have approximately the same sizes. Also, the processing times of all SPs – T_{rout} , T_{rcc} , T_{rptc} , T_{rudc} , T_{rpd} and T_{pdic} (fig.1-3) – have approximately the same values. Taking into account the above, based on (11) we obtain a working formula for the initial estimate of the duration of an information exchange session in a CSM network:

$$T_{sesc} = \left(NUD \times 1/f\right) + 7 \sum_{i=1}^{k-1} T_{sd_{i,i+1}} + (K + 5)SM + (K + 2) \left(Nsm \times 1/f\right), \quad (12)$$

where $\left(Nsm \times 1/f\right)$ is a time of SM issuing/receiving, Nsm is a SM size (bits).

The efficiency of communication channel usage $Kefc$ is defined as the ratio between the channel occupancy time for transmitting user data UD and the total channel occupancy time during the exchange session. The channel occupancy time between nodes SN_i and SN_{i+1} for transmitting UD, taking into account (6), is defined as:

$$T_{cud_{i,i+1}} = T_{sd_{i,i+1}} + T_{sud} = T_{sd_{i,i+1}} + \left(NUD \times 1/f\right). \quad (13)$$

The total channel occupation time between nodes SN_i and SN_{i+1} $T_{Sm_{i,i+1}}$ is defined as the duration of the exchange session excluding some time intervals in the transmission path formation phase and the disconnection phase (fig. 1-3):

$$T_{Sm_{i,i+1}} = T_{sesc} - \left[(i \times T_{rout}) + \left(\sum_i^{k-1} T_{sd_{i,i+1}} + T_{rdi} + T_{pdi} + T_{sdic} + T_{pdic} \right) \right], \quad (14)$$

In (14), the first term in square brackets reflects the excluded time intervals of the transmission path formation phase, the second term reflects the separation phase.

Taking into account the assumptions made for expression (12), we obtain:

$$T_{Sm_{i,i+1}} = T_{sesc} - \left[(i \times T_{sm}) + \left(\sum_i^{k-1} T_{sd_{i,i+1}} + 2 \left(Nsm \times 1/f \right) + 2T_{sm} \right) \right], \quad (15)$$

Then, taking into account (13) and (15), the channel efficiency coefficient between nodes SN_i and SN_{i+1} for the CSM method is determined by the expression:

$$Kefc_{i,i+1} = \frac{T_{sd_{i,i+1}} + \left(NUD \times 1/f\right)}{T_{sesc} - \left[(i \times T_{sm}) + \left(\sum_i^{k-1} T_{sd_{i,i+1}} + 2 \left(Nsm \times 1/f \right) + 2T_{sm} \right) \right]}. \quad (16)$$

Expression (16) is suitable for assessing the efficiency of using any of the $k - 1$ channels of the data transmission path when organizing information exchange in the CSM network.

Conclusion

As mentioned above, the primary estimates task of the telecommunication systems time parameters is of great importance at the stages of designing and deploying data transmission networks. The importance of solving this problem is due to the widespread use of the basic methods CSM, MSM and PSM in modern telecommunication networks [1], [7], [10], [21], [22].

This approach ensures better fulfillment of the basic requirements for resources and services of the telecommunications system: productivity, reliability and data security, information and technical compatibility, manageability, scalability. The main indicators of assessing the efficiency of network operation are analyzed: information delay time in the network, data delivery time to the end user, du-

ration of the user data exchange session including control information, efficiency of communication channel use. The efficiency coefficient is defined as the ratio of the time of direct transfer of user data to the full occupancy of the channels (including keeping channels unused).

Transmission time diagrams in the CSM network were analyzed. That are the phase of data transmission path formation, the phase of data transmission and the phase of disconnection (disbandment of the transmission path). This analyze allows us to assess the advantages and disadvantages of the CSM method in comparison with other methods considered in the works of this direction [9, 15, 16]. It is shown that the main advantage of the CSM method over the MSM and PSM methods is the smallest data delay time T_{ddc} in the network, which is determined only by the delays of information signals in the channels of the created transmission path. As can be seen from the timing diagram in fig.2 data passes through transit nodes SN_2 and SN_3 without delays, i.e. without intermediate storage. This determines the effectiveness of using the CSM method in real-time systems with a significant duration of the information exchange session T_{sesc} , for example, broadcasting various public events (sports competitions, reports from the scene of real events, etc.).

As follows from the analytical expression (16), the channel utilization factor depends little on the unproductive use and occupation of channels in the phases of formation and disbandment of the data transmission path and increases significantly with increasing duration of the information exchange session. Here it should be emphasized the low efficiency of the CSM method when transmitting individual messages of small volume.

Analytical expressions (9) and (10) 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, transmission speed, number of transit nodes, and other parameters of CSM networks.

Expressions (12) and (16) provide an important estimate for administrators and providers of the exchange session time and the channel efficiency coefficient for the CSM method. The materials of the article can be used by specialists, developers and network administrators, as well as in the educational process.

Внесок авторів

Ярослав ТОРОШАНКО – концептуалізація дослідження, формалізація задачі, розробка часових діаграм; Микола ПРОЦЕНКО – аналіз літературних джерел, методологія дослідження; Олександр ТОРОШАНКО – аналітичні розрахунки, виведення математичних виразів, аналіз результатів; Ігор БУЧЕНКО – перевірка результатів, підготовка тексту статті, редагування та узагальнення висновків.

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ПЕРВИННІ ОЦІНКИ ЧАСОВИХ ХАРАКТЕРИСТИК ТЕЛЕКОМУНІКАЦІЙНОЇ МЕРЕЖІ З КОМУТАЦІЄЮ КАНАЛІВ

Цією статтею продовжується цикл робіт з первинного оцінювання часових характеристик телекомунікаційних систем в різних режимах їх функціонування і з використанням різних методів комутації і передачі даних. На основі проведеного аналізу часових діаграм функціонування комп'ютерної мережі з комутацією каналів отримано аналітичні вирази для розраху-

нку основних часових параметрів інформаційного обміну, які в основному визначають якість обслуговування користувачів. Аналітичні вирази отримані на основі розроблених часових діаграм інформаційного обміну, де враховані ключові часові параметри систем передачі даних: пропускна спроможність каналів передачі, затримка передачі даних в каналах, час обробки даних на транзитних і кінцевому вузлах, час передачі і обробки інформації зворотного зв'язку (квитанцій). Для користувача з точки зору QoS найважливіше значення мають такі часові параметри як час затримки інформації в мережі, час доставки інформації до отримувача, тривалість сеансу обміну інформацією, а також деякі інші параметри, які носять більше експлуатаційний характер і визначаються використовуваними протоколами, адміністрацією мережі тощо. Це час непродуктивного зайняття каналів (інформаційна надлишковість), ефективність використання каналів зв'язку, через які здійснюється інформаційний обмін, тощо.

Первинне оцінювання перерахованих параметрів на етапі проектування і розгортання мережі дозволяє покращити такі показники як витрати на створення і експлуатацію системи, час проектування та розгортання мережі, характеристики надійності, прогнозованість та захист від перенавантаження, завантаженість мережі. Матеріали статті можуть бути використані розробниками та адміністраторами мереж, а також у навчальному процесі.

Ключові слова: комп'ютерна мережа, методи комутації і передавання даних, комутація каналів, якість обслуговування, часова характеристика, інформаційний обмін, часові параметри мережі.

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