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MODELS AND METHODS FOR CALCULATING PROBABILITY-TIME CHARACTERISTICS OF SWITCHING NODES OF TELECOMMUNICATION NETWORKS

Abstract

The principle of activity of the switching node in telecom-munication networks is considered. Models of this node are developed based on classical mass service systems, which include Poisson input request flow, exponential service time, limited and unlimited queuing, and the transition graph of the ‘Death and Reproduction’ scheme, and based on them, the methods of calculating the probability-time characteristics of the considered node are proposed.

Keywords: *telecommunication networks, switching node, memory buffer of the input port of the switching node, mass service system, transition graph of the “Death and Reproduction” scheme, probability-time characteristics*

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Telekommunikasiya şəbəkələrinin kommutasiya qovşağının ehtimal-zaman xarakteristikalarının hesablanması modelləri və metodları

Xülasə

Telekommunikasiya şəbəkələrində kommutasiya qovşağının iş prinsipinə baxıl-mışdır. Özündə Puasson giriş sorğu axınını, eksponensial xidmət vaxtını, məhdud və qeyri məhdud növbəni ehtiva edən klassik kütləvi xidmət sistemləri, eləcə də "ölüm və çoxalma" sxeminin keçid qrafı əsasında bu qovşağın modellələri işlənmiş və onların əsasında baxılan qovşağın ehtimal-zaman xarakteristikalarının hesablanması metodları təklif olunmuşdur.

Açar sözlər: *telekommunikasiya şəbəkələri, kommutasiya qovşagı, kommutasiya qovşağının giriş portunun yaddaş buferi, kütləvi xidmət sistemi, "ölüm və çoxalma" sxeminin keçid qrafı, ehtimal-zaman xarakteristikaları*

Introduction

One of the important elements of telecommunication networks is the switching node, which transfers requests between two remote network nodes through physical channels (Kornienko, 2018:113). The length of requests at this node may be from a thousand bytes to several thousand bytes, depending on the standard used. If the length of a request is greater than its maximum length, then data is transmitted by dividing the request into several requests. Each request has data, a header, and other service areas, which are placed either at the beginning or at the end of the request. The data area contains own service information necessary for the switching node to direct (route) requests to the required channel. In this case, it is also possible to buffer requests in the switching node.

In telecommunication networks, requests at the entrance of the switching node are transmitted in two stages. In the first stage, requests are placed in the memory buffer of the node, their destination address is read, the routing table is viewed, and the output port number of the node is determined. In the second stage, the transmis-sion of requests from the memory buffer of the input port of the node to the output port of requests is ensured. According to these stages, the input and output ports of the switching node may be divided into two groups, the request address analysis block (RAAB) and the request transport block (RTB). As the request address analysis block is made in the form of a combined scheme, it has a constant delay and a constant average transmission speed (Tatarnikova, Miklush, Kraeva, 2020:84). The number of this block is equal to the number of ports of the switching node. As for the request transport block, it is single and contains the transport resources.

Transmission of requests at the switching node of telecommunication networks is carried out in the following order. The sequence of queries transmitted from the switching node of any remote network first falls on the switching node of its nearest neighboring network. Each of these requests, along with data, also has management and control information, in particular, the address of the destination node or route identifier. This switching node receives requests, determines their route direction through the control information and sends the received requests to the output port of the appropriate channel based on it. If the channel between the nodes is not busy and is operable, the requests are forwarded to another neighboring switching node and all requests move sequentially to their destination points on the network along their respective designated route. If the request to be transmitted on a specified channel has a set of requests greater than the capacity of this channel, then this set of requests is placed in the memory buffer of the input port of the switching node and the order of their transmission is created.

Currently, various types of mass service systems are widely used to study the switching node of telecommunication networks (Sychev, Umnov, Neznamov, 2014:27-31; Mirzakulova, 2017:195). According to these systems, the switching node of the considered networks is described as a single-channel mass service system with limited or unlimited capacity, that is, the memory buffer of the input port of this node has a limited or unlimited capacity for placing requests. The capacity of the memory buffer of the input port of the switching node of the telecom-munication networks is estimated by the classical formulas of the Teletraffic Theory, which allow to calculate the probability-time characteristics of the switching node of the considered networks.

Problem statement. When studying the switching node of telecom-munication networks, it becomes necessary to determine its probability-time charac-teristics (average query delay time, loss probability, etc.), that is, to adequately evalu-ate these characteristics. Thus, in this Thesis presented, the issue of developing mod-els for the switching node and proposing methods for calculating its probability-time characte-ristics based on these models using classical models of the mass service system and the transition graph of the ‘Death and Reproduction’ scheme is set.

Goal of the thesis. To develop models of the switching node of the considered networks and to propose methods for calculating the final proba-bilities of its cor-responding probability-time characteristics and activity based on these models using single-channel classical mass service systems (MSS) of type M/M/1, which in-clude a Poisson request flow, an exponential service time, limited or unlimited que-uing, and the transition graph of the ‘Death and Repro-duction’ scheme based on them.

Problem solution. In order to determine the probability-time char-acteristics of the switching node of telecommunication networks, let’s describe it in the form of a single-channel classical mass service system MSS of type M/M/1, which includes a Poisson input request flow, an exponential service time, and an unlimited queue (Figure 1).

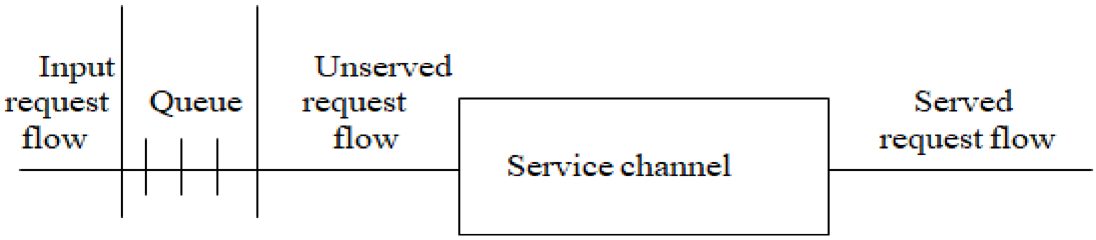

Figure 1. Description of the switching node of telecommunication networks in the form of a mass service system.

As seen from the Figure, this system includes an input request flow, a queue, an unserved request flow, a service channel and a served request flow. The probability-time characteristics of the considered mass service system include the absolute release capacity M_{rc}, relative release capacity N_{rc} , the probability of service refusal of requests per system $P_{ref.}$, the average number of requests in the system $\overline{N}_r$, and the average number of requests in the queue $\bar{n}_r$ (Tumanbaeva, 2012:81; Eremenko, 2019:244; Serviceman, 2017:36).

The absolute release capacity of the system A_{rc} is determined by the average number of requests to this system and served at the same time, that is:

$$M_{rc} = \bar{n}_{sr}, \quad (1)$$

where $\bar{n}_{sr}$ is the average number of requests per system and served at the same time.

The relative release capacity of the system N_{rc} may be determined by the following formula:

$$N_{rc} = M_{rc}/\lambda, \quad (2)$$

where M_{rc} is determined by Formula (1), and λ is the intensity of the flow of requests to the system.
The probability of service rejection of requests per system $P_{ref.}$ is equal to:

$$P_{ref.} = 1 - N_{rc}.$$

where N_{rc} is determined by Formula (2).
The average number of requests in the system, $\overline{\mathrm{N}}$ is determined by the sum of the number of requests served in this system and queued in the memory buf-fer of its input port:

$$\overline{\mathrm{N}} = s_{sr} + s_{rq}, \quad (3)$$

where s_{sr} and s_{rq} are the number of requests served in the system and queued in the memory buffer of its input port, respectively.

The average number of requests queued in the memory buffer of the system's input port, $\bar{n}_s$ is determined by the average number of requests waiting in the queue for service time in the memory buffer of the input port of this system, i.e.:

$$\bar{n}_{st}= \bar{n}_{rwst}, (4)$$

where $\bar{n}_{rwst}$ is the average number of packets waiting for service time in the memory buffer of the system input port.

The probability-time characteristics of the considered mass service system may also include the average stay time of requests per system stay in the system $\bar{T}_{st}$, their average waiting time in the queue $\bar{T}_W$ and the average number of busy channels $\bar{k}_b$ (Tumanbaeva, 2012:81; Eremenko, 2019:244; Serviceman, 2017:36).

The average stay time of requests in the system is determined by the sum of their stay and service times in the system, i.e.:

$$\bar{T}_{st}= t_{st} + t_s.$$

where t_{st} and t_x are the stay and service times of requests in the system, respectively.

The average waiting time in the queue of requests per system is determined by the waiting time in the queue in the memory buffer of the input port of the system, i.e.:

$$\bar{T}_w = t_{rw},$$

where t_{rw} is the waiting time of requests in the queue in the memory buffer of the input port of the system.

Average number of busy channels in the system, $\bar{k}_b$ is equal to the number of channels serving requests per system, i.e.:

$$\bar{k}_b= k_{sr}, (5)$$

where k_{sr} is the number of channels serving requests per system, which is determined by the following formula at the known values of the absolute release capacity of the system and the intensity of serving requests per system:

$$k_{sr}= M_{rc}/\mu_r, (6)$$

where μ_r is the intensity of serving requests per system.

If we consider and solve Formula (6) in (5), we will get the final calculation formula for the average number of busy channels in the system:

$$\bar{k}_b= M_{rc}/\mu_r,$$

There is dependency between the average stay time of requests in the system, $\bar{T}_{st}$ and the average number of requests in the system, $\bar{N}$, and the average waiting time of requests in the queue, $\bar{T}_w$ and the average number of requests in the queue, $\bar{n}_r$, which are dtetermined as follows according to Littla's formula:

$$\bar{T}_{st}= \bar{N}/\lambda, \bar{T}_w = \bar{n}_r /\lambda. (7)$$

If we consider and solve Formulas (3) and (4) in (7), we will get the following final formulas for calculating the average stay time of requests in the queue and the average waiting time of requests in the queue:

$$\bar{T}_{st}= (s_{sr} + s_{rq})/\lambda, \bar{T}_w = \bar{n}_{rwst}/\lambda.$$

And now let's consider the calculation of the final probabilities of the ope-ration of the switching node of telecommunication networks. For this purpose, let's describe the description of the packet switching node as a mass service system given in Figure 1 in the form of the transition graph of the 'Death and Reproduction'scheme (figure 2).

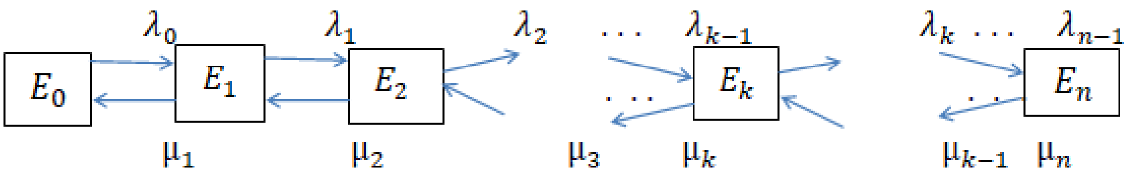

Figure 2. Transition graph of the 'Death and Reproduction'scheme of the switching node of telecommunication networks

Based on this transition graph, the final probabilities of the operation of the switching node of telecommunication networks may be written by the following formulas (Bely, 2014:76; Solnyshkina, 2015:76; Cherusheva, 2021:224):

$$p_0 = \{1 + (\lambda_0/\mu_1) + (\lambda_0\lambda_1/\mu_1\mu_2) + \ldots + (\lambda_0\lambda_1 \ldots \lambda_{k-1})/(\mu_1\mu_2 \ldots \mu_k) + \cdots +$$
$$+ (\lambda_0\lambda_1 \ldots \lambda_{n-1})/(\mu_1\mu_{2.} \ldots \mu_n)\}^{-1};\ p_1 = (\lambda_0/\mu_1)p_0;$$
$$p_2 = (\lambda_0\lambda_1/\mu_1\mu_2)p_0; \ldots;\ p_k = ((\lambda_0\lambda \ldots \lambda_{k-1})/(\mu_1\mu_2 \ldots \mu_k))p_0;$$
$$p_n = ((\lambda_0\lambda \ldots \lambda_{n-1})/(\mu_1\mu_2 \ldots \mu_n))p_0,$$

where $E, E_1, E_2, \ldots, E_n$ are corresponding states of the switching node, p_0,p_1,p_2,...,p_n are corresponding probabilities of transition of the switching node to states $E_0, E, E, \ldots, E_n$, λ_0, λ_1, λ_2,..., λ_n-1 are the corresponding intensities of the transition of the request flow from the lowest state to the highest state of the switching node; and μ_1,μ_2,..., $\mu_n - 1$, $\mu_n$are the corresponding intensities of the transition of the request flow from the high state to the lower state of the switching node.

Calculation of the average delay time of requests at the switching node. For calculating the delay time at the swit-ching node of telecommunication networks, let's describe this node as a single-channel classical mass service system of unlimited queue M/G/1 type, with a Poisson flow entering the input of this node, where the service time is distributed by any law. The average length of the queue in the memory buffer of the input port of the switching node may be determined by the following formula using Khinchin-Polyachek's formula based on the methodology given in (Goldstein, 2014:400) in this system database:

$$\bar{q} = \rho + \rho^2((1 + S_r^2)/2(1 - \rho)),\ \rho < 1, (8)$$

where $\rho = \lambda/\mu_r$ is the load of the considered system and S_r^2 is the quadratic coefficient of change of the service time of requests in the system, which are determined by the following formula:

$$S_r^2 = D(t_r)/(\bar{t}_r)^2, (9)$$

where t_s is the service time of requests in the system, $\bar{t}_r$ is the average service time of the requests in the system, and $D(t_r)$ is the variance of service time of the requests.

The average length of the queue in the considered system may be written in the following order based on Littla's formula (Goldstein, 2014:400):

$$\bar{q} = \lambda\bar{t}_{st}\ , (10)$$

where $\bar{t}_{st}$ is the average delay time of requests at the node in the considered system, which according to formula (10) is equal to:

$$\bar{t}_{st} = \bar{q}/\lambda\ (11)$$

If we consider and solve formula (8) in (11), as a result, we will get the final formula for calculating the average delay time at the switching node of telecom-munication networks:

$$\bar{t}_{st} = \bar{t}_r\ [1 + (\rho(1 + S_r^2)/2(1 - \rho))].$$

where S_r^2 is determined by formula (9).

Calculation of the probability of loss at the switching node. The probability of request loss is one of the most important characte-ristics of a switching node. The following are the reasons why requests transmitted on a considered node cannot reach their destination on time (Nemestnikov, 2016:154):

- distortion of requests during transmission on the node, the stay time of requests on the node extremely exceeds the allotted time; and
- the limited memory capacity of the memory buffer of the switch node's input port.

If the memory buffer of a switching node has a limited capacity, the probability of a request loss is equal to the probability of overflowing of the node's memory buffer (Solnyshkina, 2015:76). In order to calculate the request loss at the switching node of the considered networks, let's describe this node as a classical one-channel mass service system of M/M/1/N type, which includes Poisson flow, exponential service time, and limited queuing. In this system database, we can write the probability of request loss at the switching node of the considered networks with the following formula according to the transition graph of the 'Death and Reproduction' scheme (Nemestnikov, 2016:154):

$$P_{mm} = ((1-\rho)/(1-\rho^{N+1}))\rho^N, \quad (12)$$

where ρ is the system load, N is the capacity of the memory buffer of the input port of the switching node.

Formula (12) takes the following form under the condition $\rho \ll 1$ of the system load:

$$P_{mm} = \rho^N, \text{ N} = \ln P_{mm} / \ln \rho \quad (13)$$

where N is the capacity of the memory buffer of the input port of the switching node.

Conclusion

1. A model of a telecommunication network switching node as a single-channel mass service system containing a Poisson query flow, an exponential service time, and unlimited queuing is developed and on the basis of this model, the methods of calculating probability-time characteristics of the considered system, such as the absolute release capacity, relative release capacity, service rejection probability of requests per system, the average number of requests in the system, the average number of requests in the queue and the average number of busy channels in the system are proposed.

2. Appropriate calculation methods are developed to determine the dependences between the average stay time of requests in the system and the average number of requests in the system, and between the average waiting time of requests in the queue and the average number of requests in the queue using Littla's formula based on the developed model of the switching node of telecommunication networks in the form of a single-channel mass service system containing a Poisson request flow, an exponential service time and unlimited queuing.

3. The transition graph of the ‘Death and Reproduction’ scheme is developed on the basis of a single-channel classical mass service system, which includes a Poisson request flow, an exponential service time, and unlimited queuing, and based on it, a method of calculating the final probabilities of the operation of the switching node of telecommunication networks is proposed.

4. A method of calculating the average delay time at the switching node of telecommunication networks is developed using the Khinchin-Polyachek formula based on a one-channel mass service system with unlimited queues, with a Poisson flow at the input, where the service time is distributed by any law.

5. A method for calculating the probability of request loss at the switching node of telecommunication networks is proposed using the transition graph of the ‘Death and Reproduction’ scheme on the basis of a single-channel mass service system conta-ining Poisson input flow, exponential service time and limited queuing.

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