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Mathematical Model of the Control System of the Priority Data Transmission Network

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ABSTRACT

In this paper, on the basis of the Laplace-Stieltjes transform, a mathematical model of the data transmission network control system is obtained with an absolute priority discipline of message (packet) servicing. Based on the approximate method, the probability distribution functions for the timely delivery of messages (packets) are obtained. The proposed mathematical model of the data transmission network control system with absolute priority discipline of message (packet) service allows to determine the pre- failure state of the data transmission network for its various parameters.

KEYWORDS: *network; data transmission; priority; message; packet; distribution function*

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I. INTRODUCTION

One of the most general requirements for data transmission networks is the requirement to ensure the efficient use of technical means of communication. The solution of this problem is possible while ensuring high reliability of the functioning of communication networks.

The data transmission network is a complex object implemented with the help of hardware and software. Due to the fact that the equipment of the data transmission network and its software are quite complex and operate in a real environment, the problem of ensuring the reliability of the functioning of the data transmission network arises.

II. The main types of priority service discipline messages(packets) in the data network

r message flows (packets) $\lambda_1, \lambda_2, \ldots, \lambda_r$ arrive in the data transmission network. Message flows (packets) λ_i will be called messages (packets) of priority *i*. Assume that message flows (packets) λ_i have a higher priority than message flows (packets) λ_j if $i<j$. Message flows (packets) of higher priority have an advantage over message flows (packets) of lower priority, which lies in the fact that among messages (packets) awaiting the start of service, messages of higher priority are served earlier than messages of lower priority, and messages (packets)) of the same priority are served in the order in which they arrive. If during the service of a certain stream of messages (packets) a stream of messages of a higher priority arrives, then there may be cases when the service of this message is interrupted and the service of the incoming message (packets) of a higher priority immediately begins, or the case when such an interruption does not occur. In this regard, we will distinguish the following disciplines for servicing messages (packets):

- absolute priority discipline of servicing messages (packets);

- relative priority discipline of message (packet) servicing;
- shifted priority discipline for servicing messages (packets).

The absolute priority discipline for servicing messages (packets) has two varieties:

1. absolute priority service discipline with post-service messages (packets);
2. absolute priority service discipline with repeated service of messages (packets).

If during the service of a stream of messages (packets) a message of a higher priority arrives, then the serviced message is interrupted and the service of the incoming message begins. After servicing a higher priority message, the interrupted message is re-serviced. Such a service discipline is called an absolute priority service discipline with post-service messages (packets).

If the interrupted message is serviced again, then there is an absolute priority service discipline with repeated service of messages (packets).

If during the service of a stream of messages (packets) a message of a higher priority arrives, then the message service will not be interrupted until the end of its service. After that, the service of the higher priority message begins. This service discipline is called the relative priority message (packet) service discipline.

To effectively use the priority discipline (absolute and relative) of message (packet) service, a service discipline with mixed priority is used.

With absolute priority service discipline, it is possible to interrupt almost completed service of lower priorities, and with relative priority, it is possible to force a message of higher priorities to wait, even if a message of lower priorities has just arrived for service. To avoid such situations, the service device has the ability to decide whether to continue or interrupt the service of lower priority messages. This assumption leads to the so-called mixed-priority discipline.

Consider a process with two priority classes. Whenever a high priority message arrives while transmitting low priority messages, the following solutions apply:

- if the time elapsed since the beginning of the service of the message of the lowest priority is less than some fixed number *Z*, then the received messages of the highest priorities are served with absolute priority;
- if the time elapsed since the beginning of message servicing is greater than or equal to some fixed value *Z*, then the received messages of higher priorities are served with relative priority.

III. Mathematical Model of the Data Transmission Network Control System with Absolute Priority Discipline of Message (Packet) Service

r independent Poisson message flows arrive in the data transmission network with intensity $\lambda_1, \lambda_2, \ldots, \lambda_r$. We will assume that the message of the thread λ_I has a higher priority than the messages λ_j if $i<j$. Then messages of priority *I* will be served before messages of priority *j*. As stated above, the message flow of priority *I* has no effect on the transmission of the message flow of priority *j* and above.

Since the arrival of a message flow of priority *I* interrupts the transmission of a message flow of priority *j*, the arrival of a message flow of priority *i* in the network during the transmission of a message flow of priority *j is* tantamount to a network failure for the message flow of priority *j*. Further reasoning will be substantiated by this assumption. Network failure rate δ for messages of the *k*-th priority is determined by the total intensity of the flow of messages of higher priorities λ_i, that is:

$$\delta_{k-1} = \sum_{i=1}^{k-1} \lambda_i \, . \qquad (1)$$

Thus, in the case under consideration, the failure is due to the arrival of messages of priority higher than *k*, in addition, failures can occur due to malfunctions of the elements of the data transmission network. Therefore, this factor must also be taken into account. Then the waiting time for the start of servicing messages of the *k*-th priority will be determined by the time of failure recovery of the network elements and the time the network is busy servicing messages of priority higher than *k*, i.e.:

$$t_{k\ W} = t_R + t_{S\ k-1} \, , \qquad (2)$$

where $t_{k\ W}$ – random waiting time to start servicing messages of the *k*-th priority, received at time *t*;

t_R – network recovery time;

$t_{S\ k-1}$ – random time spent on servicing a message of priority higher than *k*.

With ideal reliability of priority data transmission networks, the waiting time for the start of message servicing will be equal to the time the network is busy servicing messages of priority higher than *k*, i.e.:

$$t_W = t_{S\ k-1}. \qquad (3)$$

Therefore, since in the case under consideration the failure is due to the arrival of messages of priority higher than *k*, then the distribution function *F(t)* of the recovery time will be equal to the distribution function of the network busy period by $\pi_{k-1}(t)$ the transmission of messages of priority higher than *k*, i.e.:

$$F(t) = \pi_{k-1}(t). \qquad (4)$$

From this we can conclude that determining the probability of timely delivery of messages (packets) of the *k*-th priority is reduced to the task of determining the same characteristic for a non-priority data transmission network with real reliability.

We introduce the following restrictions:

$$A(t) = 1 - e^{-\lambda_k t},$$

$$B(t) = 1 - e^{-\mu_k t}, \qquad (5)$$

$$E(t) = C(t) = 1 - e^{-\delta_{k-1} t},$$

$$F(t) = D(t) = \pi_{k-1}(t),$$

where $\pi_{k-1}(t)$ is the distribution function of the network busy period by transmission of messages of priority *k* and higher;

A. *(t)* is the distribution function of the arrival time of the flow of messages (packets) of the *k*-thpriority in the data transmission network;

B. *(t)* is the distribution function of the service time of the message flow (packets) of the *k*-th priority of the data transmission network;

C. *(t)* is the distribution function of the uptime for a non-priority data transmission network;

D. *(t)* is the recovery time distribution function for a non-priority data transmission network;

E. *(t)* is the distribution function of the uptime for the priority data transmission network;

F. *(t)* is the recovery time distribution function for the priority data transmission network;

λ_k-intensity of receipt of messages of the *k*-th priority;

μ_k– service rates for messages of the *k*-th priority.

To determine the probability of timely delivery of a message (packets), we first determine the following values, taking into account (5):

$$e(\lambda) = \frac{\delta_{k-1}}{\lambda_k + \delta_{k-1}}, \qquad (6)$$

where *e(λ)* is the probability that no message of the *k*-th priority arrives in the network during the time of the correct operation of the network.

$$h_k(v) = \frac{\mu_k}{\mu_k + v + \delta_{k-1} - \delta_{k-1}\pi_{k-1}(v)}, \qquad (7)$$

where $h_k(v)$ - the probability that during the service of messages of priority *k* -1 and higher, the waiting time for messages of the *k* -th priority will not exceed the allowable value;

$\pi_{k-1}(v)$ - Laplace–Stieltjes transform of the distribution function of the network busy period by the transmission of messages of priority *k*-1 and higher, which is determined from the expression:

$$\delta_{k-1}\pi_{k-1}(v) = \sum_{i=1}^{k-1} \frac{\lambda_i \mu_i}{\mu_i + v + \delta_{k-1} - \delta_{k-1}\pi_{k-1}(v)}, \qquad (8)$$

$$h_{k1} = \frac{1 + \delta_{k-1}\pi_{k1}}{\mu_k}, \qquad (9)$$

where h_{k1} is the average service time for messages of the *k*-th priority;

π_{k1} - the average network busy time, due to the service of messages, the priority is higher than *k*, which is determined from the expression.

$$\delta_{k-1}\pi_{k1} = \frac{\sum_{i=1}^{k-1} \rho_i}{1 - \sum_{i=1}^{k-1} \rho_i}, \qquad (10)$$

where ρ_i– network load by the *i*-th priority message.

Taking into account expressions (5)-(10) and omitting intermediate transformations, we determine the probability of timely delivery of messages (packets) of the *k*-th priority of the data transmission network with ideal reliability, which is determined by

$$Q_k(v) = \left[\frac{e^{-v_{k_i}/\mu_k}\left(1 - \lambda_k/\mu_k\right)}{1 - \frac{\lambda_k}{v_{k_i}}\left(1 - e^{-v_{k_i}/\mu_k}\right)} \right]^n \qquad (11)$$

($v_{ki} > 0,\ \mu_k \ge \lambda_k$),

where

$$v_{k_i} = v_k \left[1 + \frac{\mu_k \left(1 - \sum_i^{k-1} \frac{\lambda_i}{\mu_i}\right) \cdot \left(1 - \left(1 - \sum_i^{k-1} \frac{\lambda_i}{\mu_i}\right)\right)}{v_k \left(1 - \sum_i^{k-1} \frac{\lambda_i}{\mu_i}\right) + d} \right]. \qquad (12)$$

Let us determine the probability of timely delivery of messages (packets) of the *k*-th priority of the data transmission network with real reliability:

$$Q_k(v)=\left[\frac{e^{-v_{ek}/\mu_{ek}}\left(1-\lambda_k/\mu_{ek}\right)}{1-\frac{\lambda_k}{v_{ek}}\left(1-e^{-v_{ek}/\mu_{ek}}\right)}\right]^n, \qquad (13)$$

where

$$v_{ek}=v_k\left[1+\frac{\mu_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)\cdot\left(1-\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)\right)}{v_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)+d}\right], \qquad (14)$$

$\mu_{ek}=\mu_k\cdot K_R$,

K_R -readiness factor

IV. Results and discussion

1. The average delivery time for the delivery of messages (packets) of the *k*-thpriority of the data transmission network with ideal reliability:

$$T_k=\sum_{i=1}^{n}\frac{2\mu_k\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k}{2\mu_k\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)\left[\mu_k\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k\right]}\left(1+\frac{\mu_k\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}{d}\right). \qquad (15)$$

2. The average delivery time of delivery of messages (packets) of the *k*-th priority of the data transmission network with real reliability.

$$T_k=\sum_{i=1}^{n}\frac{2\mu_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k}{2\mu_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)\left[\mu_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k\right]}\left(1+\frac{\mu_k\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}{d}\right). \qquad (16)$$

To find the distribution function of the probability of timely delivery of messages (packets) of the *k*-th priority with ideal reliability, it is necessary to find the inverse transformation (11). However, due to the complexity of obtaining the distribution function of the probability of timely delivery of messages (packets) of the *k*-th priority with ideal reliability, we use an approximate method:

$$W_k(t)=1-\sum_{i=1}^{k}\frac{\lambda_i}{\mu_i\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}\exp\left(-\frac{\sum_{i=1}^{k}\frac{\lambda_i}{\mu_i\left(1-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}}{T_k}t\right). \qquad (17)$$

Based on [1], the distribution function of the probability of timely delivery of messages (packets) of the *k* - th priority with real reliability is determined by:

$$W_k(t)=1-\sum_{i=1}^{k}\frac{\lambda_i}{\mu_i\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}\exp\left(-\frac{\sum_{i=1}^{k}\frac{\lambda_i}{\mu_i\left(K_R-\sum_i^{k-1}\frac{\lambda_i}{\mu_i}\right)}}{T_k}t\right). \qquad (18)$$

V. Conclusion

Thus, the obtained mathematical model of the control system of the data transmission network with an absolute priority discipline of servicing messages (packets) allows you to determine the pre- failure state of the network by controlling the excess of the probability of timely delivery of messages (packets) of an acceptable value.

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