ANALYTICAL MODELS OF THE AVERAGE DELIVERY TIME OF MESSAGES (PACKETS) IN HIGH-SPEED DATA NETWORKS WITH ABSOLUTE PRIORITY SERVICE

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Abstract. *This paper is viewed the average delivery time of messages (packets), which is one of the parameters characterizing the reliability characteristics of high-speed data transmission networks with priority service. Analytical models and a computational algorithm for the average delivery time of messages (packets) for data networks with absolute priority service for real and ideal reliability are presented.*

Keywords: *data network, priority, reliability, flow, message, packet, Laplace-Stieltjes transform.*

Introduction. Currently, the requirements for high-speed data transmission networks are increasing. There are various types and types of data transmission networks that carry out their functional purposes at different levels of data transport.

According to the service discipline, data transmission networks are divided into two large groups: with non-priority and priority service. Non-priority data networks are a type of network in which all data is processed without regard to its priority. In data networks with non-priority service, all messages or requests are processed in the order they are received, without assigning any priorities or preferences to them. In priority service data networks, high priority data is processed first before lower priority data is processed.

Research materials and method. Let m message streams λ_1, λ_2, …, λ_m arrive in a high-speed data transmission network. Message flows λ_i (i =1, m) will be called messages of priority i. Suppose message threads λ_i have higher priority than message threads λ_j if $i < j$. Higher priority message flows have an advantage over lower priority message flows, which is as follows [1, 2]:

- among messages awaiting the start of servicing, messages of higher priority are serviced earlier than messages of lower priority;
- single priority messages are processed in the order in which they arrive;
- with an absolute priority message servicing discipline, if while servicing a certain message flow a flow of a higher priority arrives, then servicing of this message is interrupted and servicing of the incoming message of a higher priority immediately begins.

In work [3], based on the use of the method of introducing an additional event and the Laplace-Stieltjes transformations [1], analytical models are presented that describe data transmission networks for various types of priority service.

For a data transmission network with message switching with ideal reliability and relative priority service, the following model of the average delivery time of messages of the k^{th} priority is proposed [3]:

$$T_{DTk} = A\left(1-\sum_{i=1}^{r}\frac{\lambda_i}{\mu_i}\right)+\sum_{j=k+1}^{r}\frac{\lambda_j}{\mu_j+L(0)}\left[A-\frac{B}{\mu_j+L(0)}\right], \qquad (1)$$

Where $A = \frac{1}{\rho_k^2}\left[\frac{1}{\mu_k} + \frac{1}{L(0)}\right]$; $B = \frac{1}{\rho}\left[1 + \delta_{k-1}\pi_{k-1}\right]$; $L(0) = \delta_{k-1} - \delta_{k-1}\pi_{k-1}(0)$;

$$\rho_k = \frac{\lambda_k}{\mu_k};\ \pi_{k-1}(0) = \frac{\mu_k + \delta_{k-1} - \sqrt{\left(\mu_k + \delta_{k-1}\right)^2 - 4\sum_{i=1}^{k-1}\lambda_i\mu_i}}{2\delta_{k-1}};$$

λ_i – intensity of arrival of messages of *the* i^{th} priority;

μ_i – intensity of servicing messages of the i^{th} priority;

δ_{k-1} – total intensity of arrival of priority messages above k;

ρ_k – loading messages of the k^{th} priority;

π_{k-1} (0) – Laplace-Stieltjes transformation of the distribution function of the period of occupancy of the data network by transmission of priority messages higher than k at v_k =0;

A , B , L (0) – scale factors.

One type of data transmission networks with priority service are networks with absolute priority service. An absolute priority data network is a type of network in which certain data (requests) have absolute priority over others.

This means that this data is served first, regardless of when it entered the system. This can be useful in situations where some data is critical and needs to be processed as quickly as possible. For example, in peer-to-peer networks, where queuing theory is used, modeling of a queuing system with absolute service priority is used [4-8].

For a packet-switched data network with absolute priority service, the ratio of the average delivery time of k^{th} priority messages was obtained [3]:

$$T_{DTk} = \sum_{i=1}^{n}\frac{2\mu_{ei} - \lambda_{ki}}{2\mu_{ei}\left(\mu_{ei} - \lambda_{ki}\right)}\left[1 + \frac{\mu_{ei}\left(1 - K_{Rei}\right)}{d_{ei}}\right], \qquad (2)$$

Where $\mu_{ek} = \mu_k K_{Re}$; $K_{Re} = K_R - \sum_{i=1}^{k-1}\frac{\lambda_i}{\mu_i}$;

$$v_{ek} = v_k\left[1 + \frac{\mu_{ek}K_{De}}{v_k K_{Re} + d_e}\right];\ d_e = \frac{1}{T_{Fe}} = \frac{\delta_{k-1}K_{Re}}{K_{De}};$$

λ_e, μ_e – operational intensity of receipt and service intensity of messages;

λ_k, λ_{ek} – intensity and operational intensity of arrival of messages of the k^{th} priority;

μ_k, μ_{ek} – intensity and operational intensity of servicing messages of the k^{th} priority;

K_R – data transmission network readiness factor;

K_{Re} – operational readiness factor of the data transmission network;

v_k - aging rate of the k^{th} priority message;

v_{ek} – equivalent aging intensity of the k^{th} priority message;

d_e – equivalent recovery rate of network failures;

T_{Fe} – average failure recovery time;

K_{De} - – operational downtime factor of the data transmission network.

Fig.1 shows the timing diagram of the data transmission channel with absolute priority service.

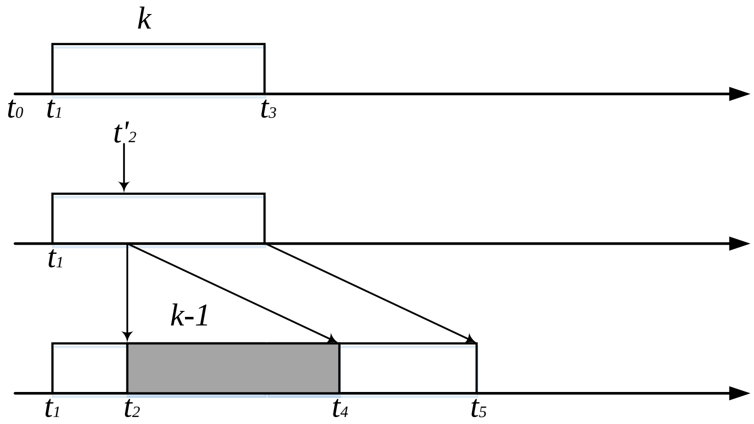

Fig.1. Timing diagram of the data transmission channel with absolute priority service: t_0 - moment of arrival of the k^{th} priority message; (t_0 - t_1) - waiting time for the start of servicing messages of the k^{th} priority; (t_1 - t_2) - service time of part of the messages of the k^{th} priority; (t_1 - t_3) - time of servicing messages of the k^{th} priority; t'_2 - moment of arrival of priority messages higher than k; (t_2 - t_4) - service time for priority messages higher than k; (t_4 - t_3) - service time for the remaining part of the messages of the k^{th} priority

From the timing diagram (Fig.1) it is clear that with an absolute priority message servicing discipline, the interruption of a k^{th} priority message with a priority higher than k-1 occurs during the transmission of information over the communication channel. Based on (2) and the transformations carried out, we obtain the following relations for the average delivery time of messages (packets) of the k^{th} priority data network for the general case:

- with ideal reliability:

$$T_{DTk}=\sum_{i=1}^{n}\frac{2\mu_k\left(1-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k}{2\mu_k\left(1-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)\left[\mu_k\left(1-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k\right]}\left(1+\frac{\mu_k\left(1-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)\left(\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)}{d}\right), \qquad (3)$$

- with real reliability:

$$T_{DTk}=\sum_{i=1}^{n}\frac{2\mu_k\left(K_R-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k}{2\mu_k\left(K_R-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)\left[\mu_k\left(K_R-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k\right]}\left(1+\frac{\mu_k\left(K_R-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)\left[1-\left(K_R-\sum_{i}^{k-1}\frac{\lambda_i}{\mu_i}\right)\right]}{d}\right). \qquad (4)$$

In accordance with [1-3, 9, 10] and taking into account the interruption of a message of k^{th} priority, one can obtain an analytical expression for the average delivery time of messages (packets) of k^{th} priority in high-speed data networks with absolute priority service:

- with real reliability:

$$T_{DTk}=\frac{2\mu_k K_R-\lambda_k}{2\mu_k K_{Г}\left[\mu_k\left(K_R-\sum_{i=1}^{k-1}\frac{\lambda_i}{\mu_i}\right)-\lambda_k\right]}\cdot\left[1+\frac{\mu_k K_R(1-K_R)}{d}\right]\cdot n, \qquad (5)$$

where n - number of data network nodes;

- with ideal reliability (at K_R =1):

$$T_{DTk} = \frac{2\mu_k - \lambda_k}{2\mu_k \left[\mu_k \left(1 - \sum_{i=1}^{k-1} \frac{\lambda_i}{\mu_i} \right) - \lambda_k \right]} \cdot n. \qquad (6)$$

Analysis and results. The proposed models (5) and (6) do not affect message (packet) processing, but only take into account transmission and interruption over the communication channel. To conduct research on the average delivery time of messages of the k^{th} priority in data networks with absolute priority service based on (5) and (6), a computational algorithm has been developed (Fig.2).

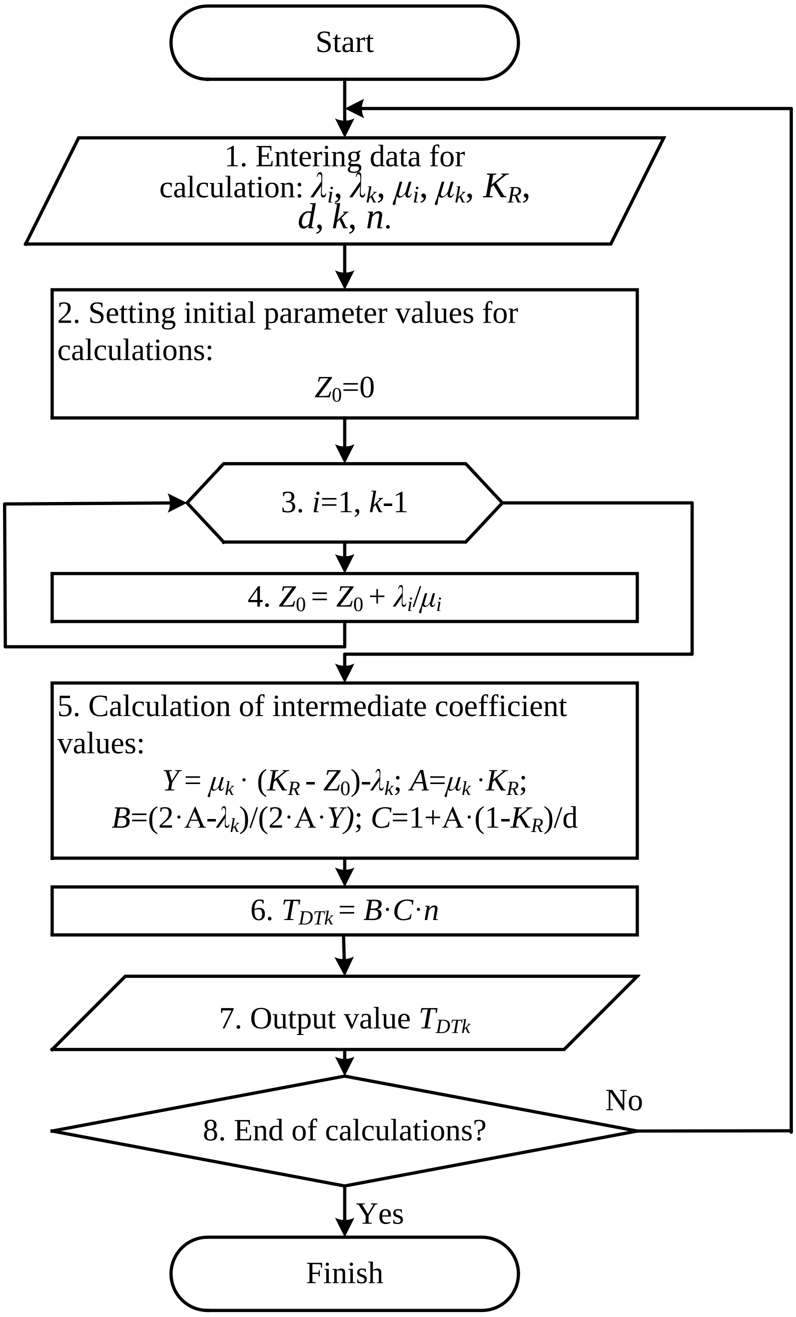

Fig.2. Computational algorithm for the average delivery time of k^{th} priority messages with absolute priority service

Based on the proposed analytical models (5), (6) and the developed computational algorithm, numerical studies were carried out on the influence of data transmission network parameters on the average delivery time of k^{th} priority messages with absolute priority service (Fig.3, Fig.4).

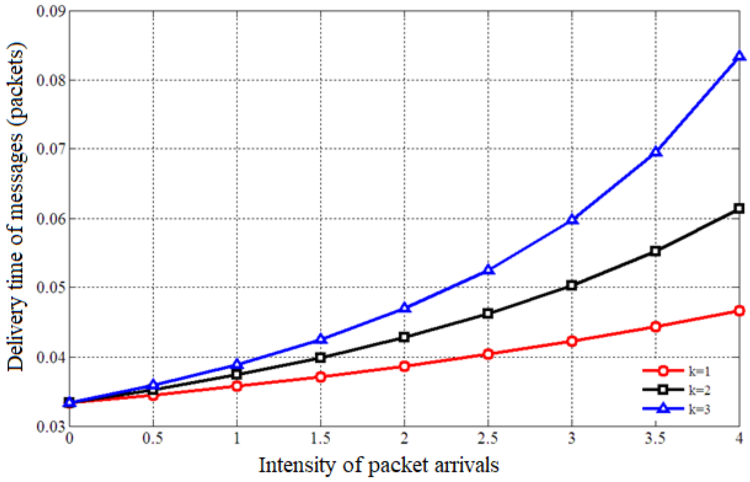

Fig.3. Average Delivery time of messages (packets) of k^{th} priority (k =1, 2, 3) depending on the intensity of packet arrivals with ideal reliability (K_R=1)

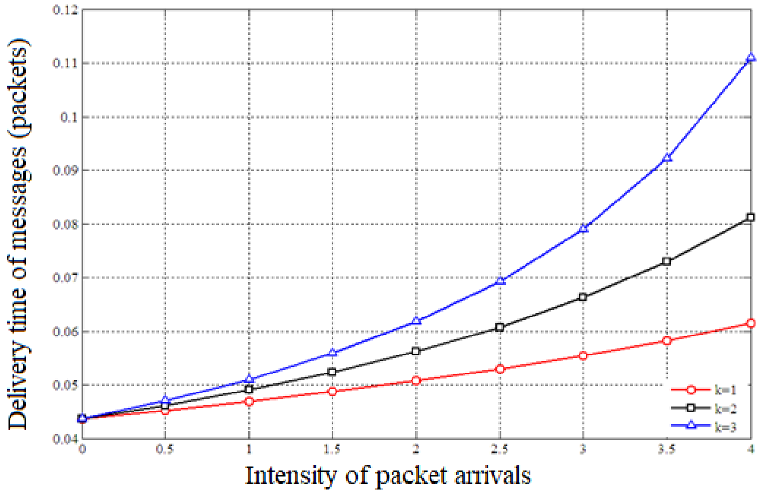

Fig.4. Average delivery time of messages (packets) of k^{th} priority (k =1; 2; 3) depending on the intensity of packet arrivals with real reliability (K_R=0,99)

Functions (5) and (6) are monotonically increasing. The analysis of these functions, as well as the numerical studies carried out, showed that in the case when, $\lambda_k \rightarrow \mu_k$ that is, the value of the intensity of arrival of messages of the k^{th} priority approaches the value of the intensity of service of messages of the k^{th} priority, functions (5) and (6) tend to infinity [1-3].

Conclusion. The developed analytical models and a computational algorithm for the average delivery time of k^{th} priority messages in high-speed data networks with absolute priority service allow us to study changes in the characteristics of data networks.

Models (5) and (6) are completely adequate and characterize the indicator of a data transmission network with an absolute priority service discipline, which is the average delivery time of messages (packets).

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