

Performance Measures of Data Network Node with Buffer Threshold Control

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Introduction

Analysis of $M/M/1/N+K$ queuing data network node, which is a Markov birth and death system with threshold control, may be obtained by applying the general solution given by Bolsh G. and Hock Ng Chee [1,2,3]. Our proposed data packets queuing system with losses and constant bit rate channel model can be used to investigate processes of the Poisson arrival flows of data packets in the data networks. Many research efforts have been and are still devoted to improve performance measures of MPLS networks [4].

In this paper we study network node using one unreliable transmission channel and with buffer capacity threshold control. We shall study an efficient way how to investigate such queuing system by means of Markov chains [2]. In this article we propose the queuing data network node forwarding high and low priority data packets by one link.

While most research to date has focused on supporting quality of service (QoS) within a single network node, analysis of such data networks nodes is currently an active area of research [5].

MPLS data network allows for QoS in terms of precedence or class of service to be fully or partial inferred from the label. MPLS network routers may then apply different discard thresholds and scheduling disciplines to different priority packets [4].

An accurate modeling of the offered data network traffic load and its transmission control is the first step in optimizing data network resources [5]. QoS in our model is expressed in such parameters: both priority data packet losses, mean value of waiting times in queue, channel utilization parameter.

Analytical model for data network node performance measures evaluation

We will investigate the telecommunication data network queuing node using one unreliable data transmission channel which is transmitting low and high priority Poisson data packet flows (Fig. 1). The data

packets arrival processes of each priority class are assumed to be independent. Within each priority class data packets are served on their order of arrival.

In this section we present analytical model of data packets transmission processes when transmission channel is reliable, without failures.

Consider two priority class Poisson data packet arrival flows with rates λ_1 , λ_2 each. Both priority MPLS data packets transmission intensities in channel consequently are equal μ_1 , μ_2 . The structure of network node is shown in Fig.1.

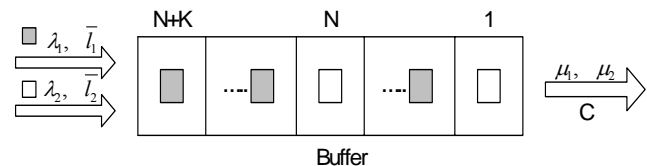


Fig. 1. The structure of data network queuing node with buffer threshold control

System parameters (Fig.1):

λ_1 - flow intensity of high priority data packets,

λ_2 - flow intensity of low priority data packets,

\bar{l}_1 - mean value of high priority data packet length,

\bar{l}_2 - mean value of low priority data packet length,

N - system buffer threshold level,

$N+K$ - number of packets in system,

C - data packet transmission channel bit rate,

μ_1 - high priority data packet transmission intensity through the channel,

μ_2 - low priority data packet transmission intensity through the channel.

The data packet lengths l_1 , l_2 are exponentially distributed with mean values \bar{l}_1 , \bar{l}_2 :

$$P(l_i \leq k) = 1 - e^{-\frac{k}{l_i}}, \quad i=1,2; \quad k=0,1,2,\dots \quad (1)$$

Data packets transmission intensity by channel is given by:

$$\mu_i = \frac{l_i}{C}, \quad i=1,2. \quad (2)$$

Transmission time of data packets through the channel:

$$\tau_i = \frac{1}{\mu_i} = \frac{C}{l_i}, \quad i=1,2. \quad (3)$$

System utilization parameter:

$$\rho = \frac{\lambda_1 + \lambda_2}{\mu}, \quad (4)$$

where $\mu = \mu_1 = \mu_2$.

Low priority data packets are accepted in the system when the total number of packets in the system (in buffer and channel) is less than threshold N . High priority data packets are always accepted till system capacity achieves final capacity $N+K$ value. Here, we shall demonstrate the general approach employed in evaluation performance measures of such Markov queuing system by modeling it as a birth-death process (Fig. 2).

System state transition diagram in Fig. 2 shows how the number of data packets in the system varies from 0 to $N+K$. In such case we shall investigate queuing system with data packet losses. Low and high priority data packet mean waiting time in the queue and data packet losses depends on buffer threshold N value and final system capacity $N+K$.

Using the global balance concept we can easily write down the following equations for the evaluation of system state probabilities P_i , $i=0,1,\dots,N+K$:

$$\begin{cases} (\lambda_1 + \lambda_2)P_0 - \mu P_1 = 0, \\ (\lambda_1 + \lambda_2 + \mu)P_1 - (\lambda_1 + \lambda_2)P_0 - \mu P_2 = 0, \\ (\lambda_1 + \lambda_2 + \mu)P_2 - (\lambda_1 + \lambda_2)P_1 - \mu P_3 = 0, \\ \vdots \\ (\lambda_1 + \lambda_2 + \mu)P_{N-1} - (\lambda_1 + \lambda_2)P_{N-2} - \mu P_N = 0, \\ (\lambda_1 + \mu)P_N - (\lambda_1 + \lambda_2)P_{N-1} - \mu P_{N+1} = 0, \\ (\lambda_1 + \mu)P_{N+1} - \lambda_1 P_N - \mu P_{N+2} = 0, \\ \vdots \\ (\lambda_1 + \mu)P_{N+K-1} - \lambda_1 P_{N+K-2} - \mu P_{N+K} = 0, \\ \mu P_{N+K} - \lambda_1 P_{N+K-1} = 0, \\ \sum_{i=0}^{N+K} P_i = 1. \end{cases} \quad (5)$$

To solve equations (5) we obtain the system state probabilities P_i , $i=1,2,\dots,N+K$.

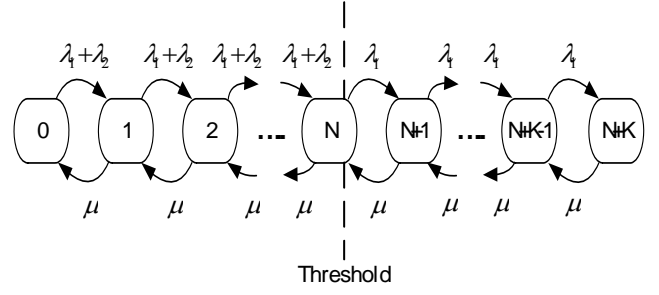


Fig. 2. Continuous time and discrete state Markov birth-death process of the network node with reliable transmission channel and buffer threshold control

Now we proceed to find the system performance measures such as:

Low priority data packet loss probability:

$$P_{2Loss} = \sum_{i=N}^{N+K} P_i. \quad (6)$$

High priority data packet loss probability:

$$P_{1Loss} = P_{N+K}. \quad (7)$$

Mean value of the number of high priority data packets in the queue:

$$\begin{aligned} \overline{N}_{q1} &= \frac{\lambda_1(1 - P_{N+K})}{\lambda_1(1 - P_{N+K}) + \lambda_2(1 - P_{2Loss})} \cdot \sum_{i=1}^N iP_i + \\ &+ \sum_{i=N+1}^{N+K} (i - N)P_i. \end{aligned} \quad (8)$$

Mean number of low priority data packets in the queue:

$$\overline{N}_{q2} = \frac{\lambda_2(1 - P_{2Loss})}{\lambda_1(1 - P_{N+K}) + \lambda_2(1 - P_{2Loss})} \cdot \sum_{i=1}^N iP_i. \quad (9)$$

Mean value of waiting time in the queue for high priority data packets according to Little's law:

$$\begin{aligned} \overline{W}_1 &= \overline{N}_{q1} / (\lambda_1 - P_{N+K}) = \\ &= \frac{\sum_{i=1}^N iP_i}{\lambda_1(1 - P_{N+K}) + \lambda_2(1 - P_{2Loss})} + \frac{\sum_{i=N+1}^{N+K} (i - N)P_i}{\lambda_1(1 - P_{N+K})}. \end{aligned} \quad (10)$$

Mean value of waiting time in the queue for low priority data packets according to Little's law:

$$\overline{W}_2 = \frac{\overline{N}_{q2}}{\lambda_2(1 - P_{2Loss})} = \frac{\sum_{i=1}^N iP_i}{\lambda_1(1 - P_{N+K}) + \lambda_2(1 - P_{2Loss})}. \quad (11)$$

Mean value of the number of data packets in the system:

$$\begin{aligned} \overline{N_S} &= \overline{N_{q1}} + \overline{N_{q2}} + \rho_{ch} = \\ &= \overline{N_{q1}} + \overline{N_{q2}} + \frac{\lambda_1(1-P_{N+K}) + \lambda_2(1-P_{2Loss})}{\mu \sum_{i=1}^N P_i + \mu_1 \sum_{i=N+1}^{N+K} P_i}, \end{aligned} \quad (12)$$

where ρ_{ch} – data packet transmission channel real utilization parameter equal $1-P_0$.

The rest of this article analyzes the same data network node (Fig.1) but with unreliable transmission channel.

Consider the channel failure rate γ and mean time to failure is exponentially distributed. Let the repair rate for transmission channel equal r with exponentially distributed repair time [7].

Let us consider a system (Fig.1) state vector with two parameters X, Y . Parameter $X=0, 1, \dots, N+K$ and represents number of data packets in the system. Parameter $Y=1$ when transmission channel is operating correctly and $Y=0$ when there is transmission channel failure. If data transmission channel failed both priorities data packets are not accepted by system. Then the system discrete states and continuous time Markov chains are shown in Fig.3.

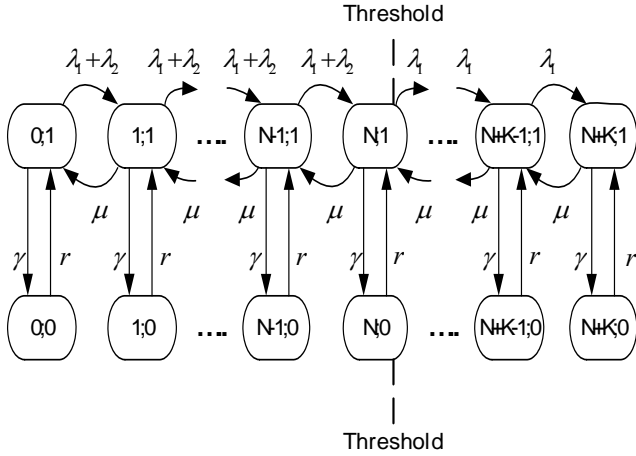


Fig. 3. Markov process of an unreliable network node with buffer threshold control

The single channel is subject to failure and repair, both times to failure and repair times being exponentially distributed with parameters γ and r respectively. Repair of a failed channel takes much longer than traffic-related events in our system. While traffic-related events in data networks take place in the order of micro seconds, repair durations are in the order of minutes, hours, or days and failure events in the order of months, years, or multiple thereof. Thus the transition rates λ_i, μ_i can be classified as being fast, and γ and r as slow. Our system is treated as continuous time Markov chains, and performance measures are calculated by solving the underlying system (13) of linear equations. In such way system steady-state probabilities P_{XY} are obtained.

$$\left\{ \begin{aligned} (\lambda_1 + \lambda_2 + \gamma)P_{0;1} - \mu P_{1;1} - rP_{0;0} &= 0, \\ (\lambda_1 + \lambda_2 + \mu + \gamma)P_{1;1} - (\lambda_1 + \lambda_2)P_{0;1} - \mu P_{2;1} - rP_{1;0} &= 0, \\ (\lambda_1 + \lambda_2 + \mu + \gamma)P_{2;1} - (\lambda_1 + \lambda_2)P_{1;1} - \mu P_{3;1} - rP_{2;0} &= 0, \\ &\vdots \\ (\lambda_1 + \mu + \gamma)P_{N;1} - (\lambda_1 + \lambda_2)P_{N-1;1} - \mu P_{N+1;1} - rP_{N;0} &= 0, \\ &\vdots \\ (\lambda_1 + \mu + \gamma)P_{N+K-1;1} - \lambda_1 P_{N+K-2;1} - \mu P_{N+K;1} - rP_{N+K-1;0} &= 0, \\ (\mu + \gamma)P_{N+K;1} - \lambda_1 P_{N+K-1;1} - rP_{N+K;0} &= 0, \\ rP_{0;0} - \gamma P_{0;1} &= 0, \\ rP_{1;0} - \gamma P_{1;1} &= 0, \\ &\vdots \\ rP_{N;0} - \gamma P_{N;1} &= 0, \\ &\vdots \\ rP_{N+K;0} - \gamma P_{N+K;1} &= 0, \\ \sum_{all X;Y} P_{X;Y} &= 1. \end{aligned} \right. \quad (13)$$

In this way some results of performance measures of the data network node are obtained:

Low priority packet loss probability:

$$P_{2Loss} = \sum_{X=N}^K P_{X;1} + \sum_{X=0}^{N+K} P_{X;0}. \quad (14)$$

High priority packet loss probability:

$$P_{1Loss} = P_{N+K;1} + \sum_{X=0}^{N+K} P_{X;0}. \quad (15)$$

Mean value of the number of high priority packets in the queue:

$$\overline{N_{q1}} = \sum_{X=2}^N \frac{(X-1)P_{X;1}\lambda_1}{\lambda_1 + \lambda_2} + \sum_{X=N+1}^{N+K} (X-N)P_{X;1}. \quad (16)$$

Mean value of the number of low priority packets in the queue:

$$\overline{N_{q2}} = \sum_{X=2}^N (X-1)P_{X;1} \cdot \frac{\lambda_2}{\lambda_1 + \lambda_2}. \quad (17)$$

Mean waiting time in queue for high priority data packets according to Little's law:

$$\overline{W_1} = \frac{\overline{N_{q1}}}{\lambda_1(1-P_{1Loss})}. \quad (18)$$

Mean waiting time in queue for low priority data packets according to Little's law:

$$\overline{W}_2 = \frac{\overline{N}_{q2}}{\lambda_2(1-P_{2Loss})}. \quad (19)$$

Mean value of time spent in the system for high priority data packets:

$$\overline{T}_{S1} = \overline{W}_1 + \frac{1}{\mu}. \quad (20)$$

Mean value of time spent in the system for low priority data packets:

$$\overline{T}_{S2} = \overline{W}_2 + \frac{1}{\mu}. \quad (21)$$

System performance results

The corresponding numerical results we have obtained applying our proposed methods of high and low priority data packets transmission by data packets transmission channel in queuing network node which architecture is shown in Fig. 1.

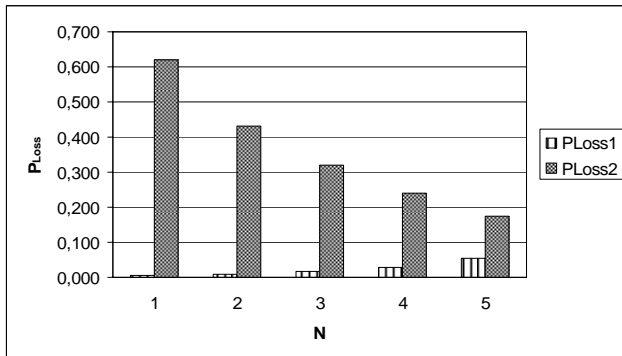


Fig. 4. Packet loss probabilities as a function of buffer threshold N for the reliable data transmission channel, when high and low priority data packets arrival rates $\lambda_1=\lambda_2=0.45$, channel data packets transmission rates $\mu=1$, and system capacity parameters $N+K=6$

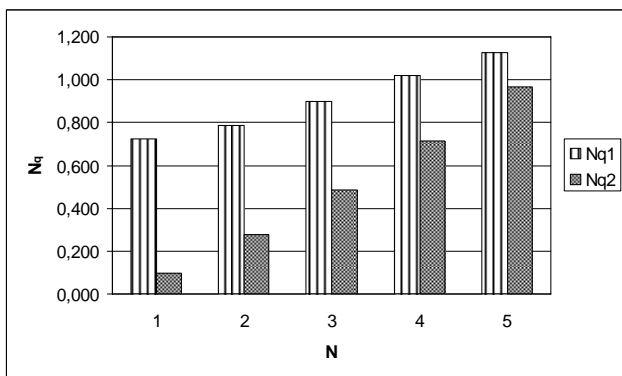


Fig. 5. Mean value of high and low priority data packet number in the system buffer, when high and low priority data packets

arrival rates $\lambda_1=\lambda_2=0.45$, channel data packets transmission rates $\mu=1$, and system capacity is $N+K=6$.

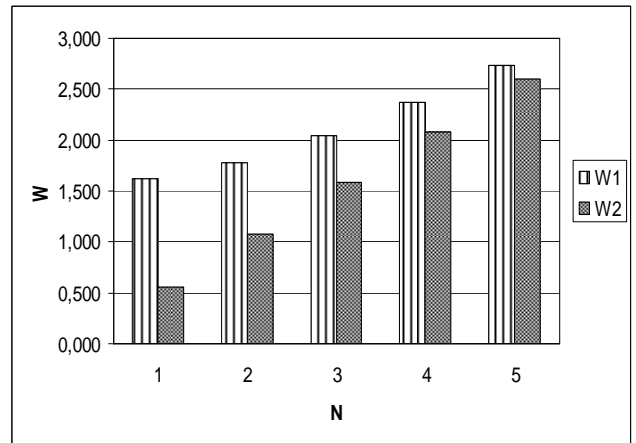


Fig. 6. Mean value of high and low priority data packet waiting time in the system buffer as a function of N , when high and low priority data packets arrival rates $\lambda_1=\lambda_2=0.45$, channel data packets transmission rates $\mu=1$, and system capacity $N+K=6$

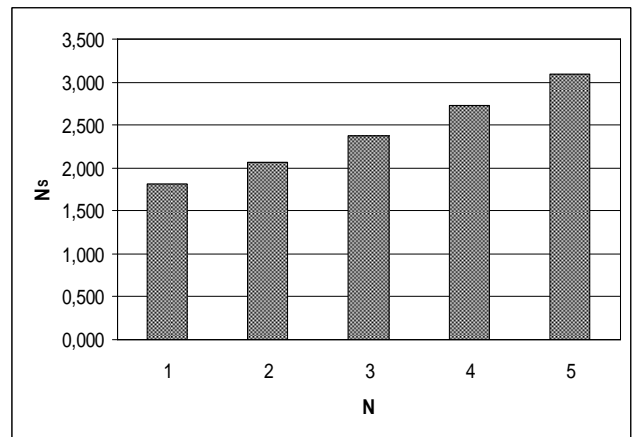


Fig. 7. Mean number of data packet in the system as a function of buffer threshold N for the reliable data transmission channel, when high and low priority data packets arrival rates $\lambda_1=\lambda_2=0.45$, channel data packets transmission rates $\mu=1$, and system capacity $N+K=6$

Now it is possible to evaluate how a different buffer threshold levels N in the system affects system performance measures such as data packet losses, mean value of data packets number in queue, mean value of waiting time in the buffer and mean value of packets in the system (Fig. 4–7).

System performance measures such as: probabilities of data packet losses; mean values of queue length; mean values of data packet delay in the buffer are respectively evaluated.

How channel unreliability parameters impact to system performance measures for data packet transmission is shown in Fig. 8–11.

In Fig. 8–9 we depicted high and low priority data packet losses and mean number of data packets in the queue as a function of channel failure rates.

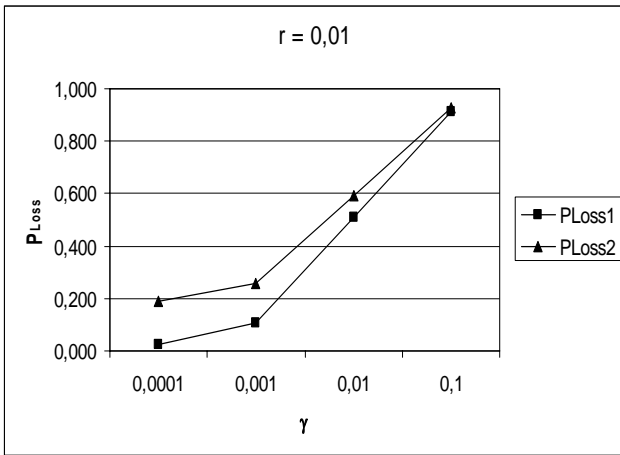


Fig. 8. High and low priority data packet losses as a function of data packets transmission channel failure rate γ , when $r=0,01$, $\lambda_1=\lambda_2=0,45$, $\mu=1$, $N=3$, $K=3$

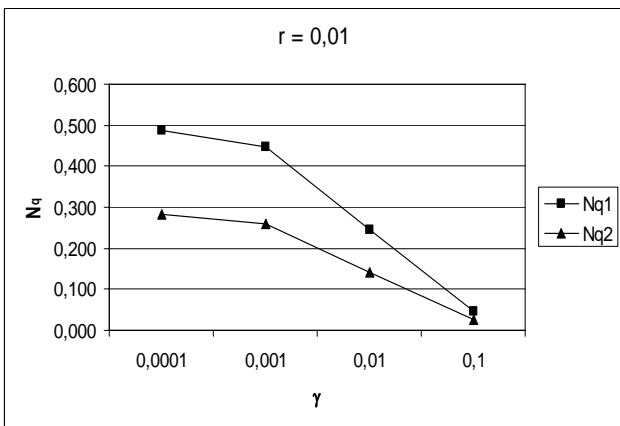


Fig. 9. Average number of high and low priority data packets in the buffer as a function of data packets transmission channel failure rate γ , when $r=0,01$, $\lambda_1=\lambda_2=0,45$, $\mu=1$, $N=3$, $K=3$

In next Fig.10 and Fig. 11 we depicted high and low priority data packet losses and mean number of data packets in the queue as a function of channel repair rates.

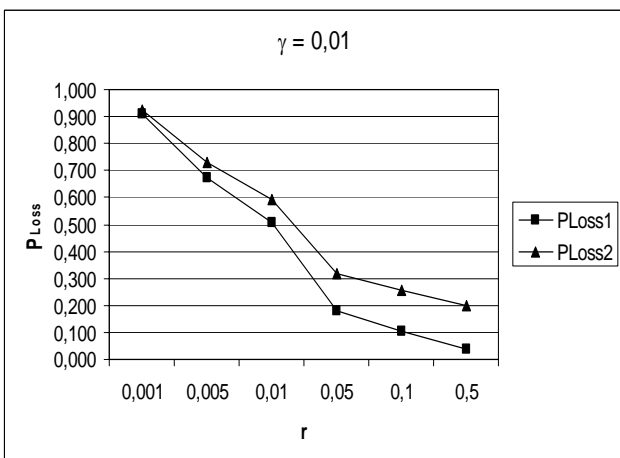


Fig. 10. High and low priority data packet losses as a function of data packets transmission channel repair rate r , when $\gamma=0,01$, $\lambda_1=\lambda_2=0,45$, $\mu=1$, $N=3$, $K=3$

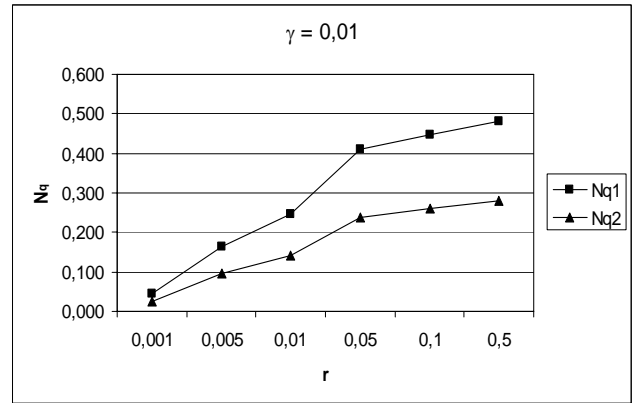


Fig. 11. Average number of high and low priority data packets in the buffer as a function of channel failure rate γ , when $r=0,01$, $\lambda_1=\lambda_2=0,45$, $\mu=1$, $N=3$, $K=3$

Conclusions

The system analytical models are accurate only in case of Poisson traffic and exponential data packet transmission time in channel. An exact analytical model becomes complicated when the system has an unreliable transmission channel and size of buffer is large. More general study of system performance measures may be achieved by means of simulation.

Different strategies used in data network queuing nodes for data packets transmission require new analytical and simulation models for estimating such network performance measures. The system buffer threshold control allows ensure proper data packets transmission parameters for priority queuing system.

Low rates of system channel failure γ and repair intensity r has negligible impact on increasing data packet losses and delay parameters.

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R. Rindzevičius, G. Adlys. Performance Measures of Data Network Node with Buffer Threshold Control // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 8(80). – P. 29–34.

We propose analysis of the data network node, which is using for transmission unreliable channel with constant bit transmission rate. For queuing system with finite buffer capacity and data packet losses the inter arrival time of high and low priority data packets flow and the transmission times of each priority data packet are exponentially distributed. The system buffer threshold control mechanism in data network node is applied. Research is in progress to develop analytical models for such network data packets transmission node which is using reliable channel without failures in one case and unreliable channel in other case. Using our proposed analytical models we can easily evaluate system performance measures such as data packet losses, mean value of waiting time in buffer, mean number of data packets in queue, mean number of data packets in the system. The results from analytical model of some performance measures are taken in figures. The processes in an unreliable channel data network queuing node are based on the Markov chains. The proposed analytical system models are suitable for analysis network node with finite data packets buffer. When the system buffer capacity is high analytical model for such queuing system node becomes very complicated. Simulation methods are applied for analysis the systems with infinite buffer. Ill. 11, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

Р. Риндзявичюс, Г. Адлис. Производительность узла сети с контролем порога заполнения буфера // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 29–34.

Предложенная модель анализа исследования производительности узла сети передачи данных, использующего метод контроля порога заполнения буфера. В систему ожидания с потерями, с конечной ёмкостью буфера поступают пуассоновские потоки пакетов двух приоритетов, время передачи каждого из класса пакетов распределено экспоненциально. В узле сети передачи данных применён контроль порогом заполнения буфера. Разработаны аналитические модели для анализа узла сети передачи данных, использующего надёжный и ненадёжный каналы передачи данных. На основе аналитической модели легко оценить параметры передачи пакетов, таких как потери пакетов, среднее время ожидания пакета в очереди, среднее число пакетов в очереди, среднее число пакетов в системе. На основе расчётов получены некоторые параметры качества передачи пакетов представлены в графиках. Анализ процессов, происходящих в узле сети передачи данных с ожиданием, базируется на цепях Маркова. Предложена аналитическая модель применима для анализа систем передачи данных с конечной ёмкостью буфера для пакетов. В результате исследования созданы аналитические модели для систем с ненадежными каналами передачи данных. Аналитическая модель становится довольно сложной, когда система имеет бесконечный буфер для пакетов и в том случае для анализа систем передачи данных целесообразно применить метод моделирования. Ил. 11, библи. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Rindzevičius, G. Adlys. Duomenų perdavimo tinklo mazgo, keičiančio buferio užpildymo slenkstį, našumo rodikliai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 29–34.

Pateikiamas duomenų perdavimo tinklo mazgo, naudojančio nepatikimą duomenų perdavimo kanalą, modelis. Į ribotos buferio talpos eiliavimo sistemą su duomenų paketų nuostoliais patenka aukšto ir žemo prioritetų paketų eksponentiniai srautai. Paketų perdavimo trukmės kanale pasiskirsčiusios pagal eksponentinį dėsnį. Duomenų perdavimo tinklo mazge panaudotas buferio užpildymo slenkščio valdymo algoritmas. Tyrimo tikslas – sukurti analitinį duomenų perdavimo tinklo veikimo modelį dviem atvejams: kai perdavimo kanalas patikimas ir kai jame yra gedimų. Remiantis pasiūlytais matematiniais modeliais, nesunku nustatyti tiriamosios sistemos našumo rodiklius, tokius kaip duomenų paketų praradimo tikimybė, vidutinė paketo laukimo eilėje trukmė, vidutinis paketų skaičius eilėje, vidutinis paketų skaičius sistemoje. Remiantis analitiniu modeliu gauti rezultatai pavaizduoti grafikuose. Procesų duomenų perdavimo tinklo mazge tyrimas remiasi Markovo grandinėmis. Pasiūlytas analizės modelis tinka sistemoms su ribotos talpos buferiais. Analizės modelis tampa komplikuoatas didinant buferio talpą ir šiuo atveju tikslinga taikyti imitacinį modeliavimą. Il. 11, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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