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Performance Analysis of Data Packet Transmission Network with the Unreliable Channels

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Introduction

In this article we propose exact analysis of the data packet transmission network with unreliable channels. Two types of the system with losses and with queuing are analyzed. Analytical analysis of the systems is based on Markov birth and death processes. Markov modeling has long been accepted as a fundamental and powerful technique for the systems reliability analysis [1]. Designers can use the Markov modeling technique to analyze safety, reliability, maintainability in the full range of complex telecommunications systems [2]. Our proposed analytical models are used for analysis processes in network nodes with one or two unreliable channels queuing system with losses and Poisson arrival flows of data packets in the data packet transmission networks. Many research efforts have been and are still devoted to improve performance measures of data packet transmission networks [3÷7].

At first we study network node with one and two unreliable transmission channels servicing data flow with losses.

We shall study an efficient way how to investigate such loss systems by means of Markov chains [1]. In this article also we propose the queuing systems of data network node analysis by means of simulations.

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].

An accurate modeling of the offered data network traffic load and it transmission via an unreliable system is the first step in optimizing data network resources [6]. *QoS* in our models are expressed in such parameters: data packet losses, channels utilization parameters, probabilities of channels and network node failures.

Peculiarities of data packet transmission over unreliable channels

Any transmission of information between endpoints or data terminal equipment (DTE) is made over a particular transmission media (Fig. 1). Type of the media, its information transmission characteristics, peculiarities and availability are the key determinants that affect the *QoS* of information transmission.

Data packet transmission routes in a network have different transmission characteristics. Selections of a particular route or rerouting are determined by the implemented routing protocols, network node failures or overflows. For example, it is shown in Fig. 1 that data packets, transmitted from DTE on the left side, have two possible route sections *a* and *b*. The section *a* is dominant and the *b* is used when network node *c* is unavailable (is in failure, overloaded or switched-off states).

Let's analyze how data packet transmission characteristics are determined by the mentioned factors using one week round trip time (*rtt*) measurement statistics (Fig. 2, a), which were made between VoIP endpoints in one of VoIP service providers in Lithuania – JSC "Eurofonas". Small grey dots in the figure represents collected *rtt* values and the packet losses (or packet receive timeouts) are represented by "x" marks on the abscise line.

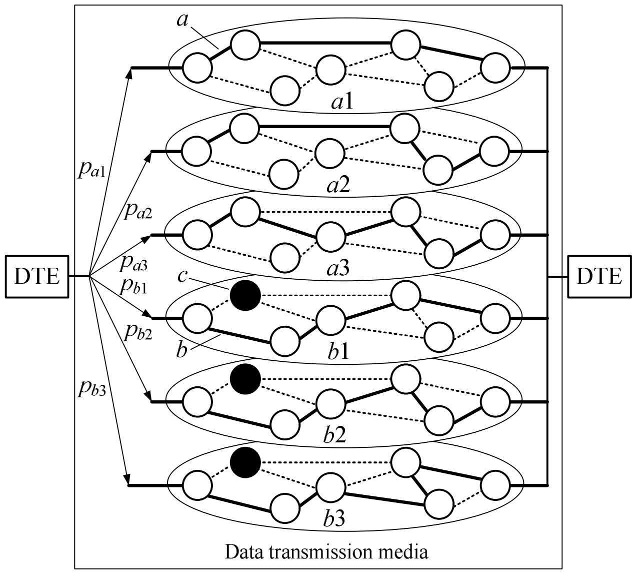

Fig. 1. Example of multi-route data transmission media between data terminal equipment (DTE) devices

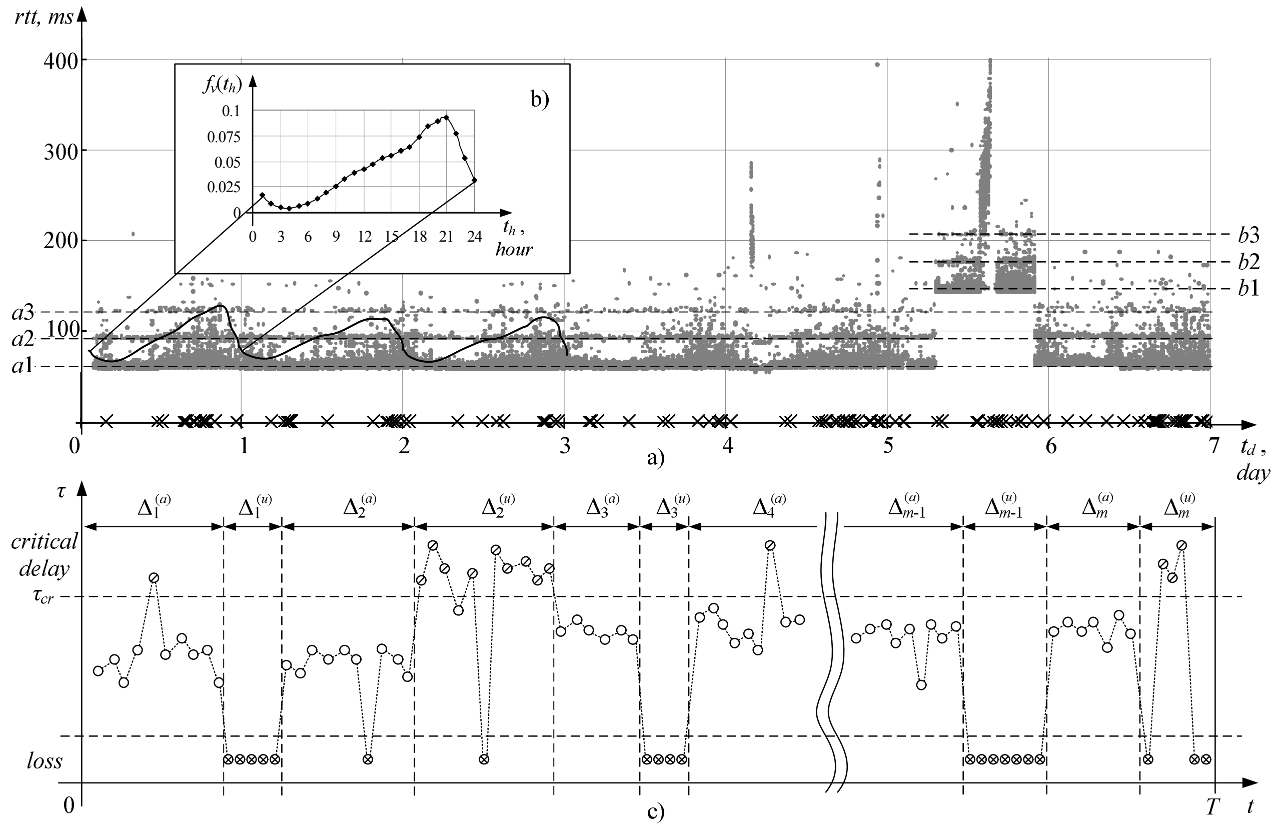

Fig. 2. Graphs of: a) one week *rtt* measurements between VoIP endpoints; b) distribution density function ($f_v(t_h)$) of VoIP calls during a daytime; c) alternating $\Delta_h^{(a)}$ and $\Delta_h^{(u)}$ periods (when the characteristics meet and do not meet *QoS* requirements) found in (0,T] duration of data packet transmission delay measurements

It is clear even from the visual analysis that the *rtt* values are correlated to the voice call activity over daytime ($f_v(t_h)$ – distribution density function of VoIP calls during a daytime (calculated from 12 month call data records) in Fig. 2, b). Also, it is possible to distinguish the effect of data packet transmissions over internet network's multi-route environment (Fig. 1) by the distribution density modes ($a1$, $a2$, $a3$, $b1$, $b2$, $b3$ in Fig. 2, *a*) of the *rtt* values.

Due to obvious stochastic nature of data packet transmissions the statistical methods should be applied to evaluate the transmission characteristics.

Therefore, in common case, if N is the number of possible data packet transmission routes and i is the index of a route ($i \in [1,2,3 \ldots N]$), then $p^{(i)}$ is the probability that a data packet will be transmitted over the i-th route (for illustration look at Fig. 1) and

$$\sum_i p^{(i)} = 1 . \qquad (1)$$

Data packet transmission delay ($\tau^{(i)}$) values and loss over the i-th route are random, therefore the transmission can be described by data packet transmission delay value distribution density ($f_\tau^{(i)}(\tau)$) and loss probability ($p_l^{(i)}$).

If for the acceptable quality level of a real-time data packet transmissions a critical delay value (τ_{cr}) is tolerable, then using statistical data the $\Pr(\tau^{(i)} \geq \tau_{cr})$ is given by

$$p_{\tau_{cr}}^{(i)} = 1 - \int_0^{\tau_{cr}} f_\tau^{(i)}(t)dt \approx \frac{1}{n^{(i)}} \cdot \sum_{j=1}^{n^{(i)}} H(\tau_{cr} - \tau_j^{(i)}); \qquad (2)$$

here

$$H(\tau_{cr} - \tau_j^{(i)}) = \begin{cases} 0, & \tau_{cr} - \tau_j^{(i)} < 0; \\ 1, & \tau_{cr} - \tau_j^{(i)} \geq 0; \end{cases} \qquad (3)$$

$n^{(i)}$ – number of collected $\tau^{(i)}$ samples.

Then in long-term perspective, the common $\Pr(\tau \geq \tau_{cr})$ is given by

$$P_{\tau_{cr}} = \sum_i p^{(i)} \cdot p_{\tau_{cr}}^{(i)} \qquad (4)$$

and the common packet loss probability –

$$P_l = \sum_i p^{(i)} \cdot p_l^{(i)} . \qquad (5)$$

The probability of a data packet transmission availability state, when data packet is not lost and its transmission delay values $\tau \leq \tau_{cr}$, is given by

$$P_a = (1 - P_l) \cdot (1 - P_{\tau_{cr}}) . \qquad (6)$$

More precise analysis of data packet transmission characteristic measurements allows to calculate time periods: $\Delta_h^{(a)}$ – when the characteristics meet *QoS* requirements (for example, τ_{cr} and tolerable packet loss ratio), $\Delta_h^{(u)}$ – when the characteristics do not meet *QoS* requirements. Here h – index of a time period ($h \in [1,2,..m]$) and m – number of alternating $\Delta_h^{(a)}$ and $\Delta_h^{(u)}$ periods found in (0,T] duration of data packet transmission characteristics measurements (Fig. 2, c).

Such short-term measurement analysis may reveal correlations between adjacent measurement samples of data packet transmission delay values, losses, route changes and failures.

Analytical model for data network node performance measures evaluation

We will investigate the telecommunication data network node using one unreliable data transmission channel. The data packets arrival processes are Poisson with λ intensity (Fig. 3). Data packets transmission duration over the channel is distributed exponentially with intensity μ.

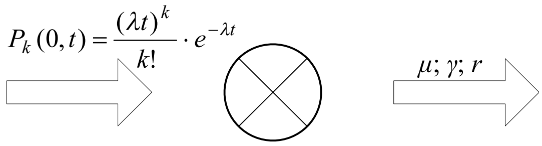

Fig. 3. The architecture of data network loss system with one unreliable data transmission channel

Reliability of the channel is its ability to perform required data packets transmission functions under state conditions for a specified period of time.

If to ensure the acceptable level of *QoS* data packet transmission parameter values have to meet particular requirements (for example, critical data packet transmission delay or loss ratio), then each channel's reliability function is given by

$$R(t) = e^{-t \cdot (\gamma_f + \gamma_d)}; \tag{7}$$

here γ_f – channel's failure rate, γ_d – rate of disturbances, which cause data packet transmission parameter values not to meet their requirements. The rates are given by $\gamma_f = 1/\overline{\tau_f}$ and $\gamma_d = 1/\overline{\tau_d}$; here $\overline{\tau_f}$ – the mean time between failures, $\overline{\tau_d}$ – the mean time between the critical disturbances to data packets transmission parameter values.

Time between channel's failures (τ_f) is equivalent to the expected number of channel's operating hours and often is distributed exponentially

$$F_{\tau f}(t) = \Pr(\tau_f < t) = 1 - e^{-t \cdot \gamma f}. \tag{8}$$

Time to repair (τ_r) can be modeled as an exponentially distributed variable also with the mean time to repair ($\overline{\tau_r}$)

$$F_{\tau_r}(t) = \Pr(\tau_r < t) = 1 - e^{-t \cdot r f} \tag{9}$$

here r_f – failure's repair rate, which is given by $r_f = 1/\overline{\tau_r}$.

$\overline{\tau_r}$ is the expected time to recover a channel from a failure. This may include the time it takes to diagnose the channel's failure, the time it takes to get a repair technician onsite, and the time it takes physically repair the channel.

In analogy to (6), th channel's availability A, considering *QoS*, is the degree to which a channel is operational and meets data packet transmission requirements. It is given by

$$A = \frac{\overline{\tau_f} - \overline{\tau_r}}{\overline{\tau_f}} \cdot \frac{\overline{\tau_d} - \overline{\tau_n}}{\overline{\tau_n}}; \tag{10}$$

here $\overline{\tau_n}$ – the mean duration, when packet transmission parameters do not meet their requirements between critical disturbances. In our case, τ_d, τ_n are modeled in analogy as τ_f and τ_r. Therefore, the common rate of channels failure and transmission parameters nonconformity (further, for simplicity, it will be mentioned as failure rate) is given by $\gamma = \gamma_f + \gamma_d$. The common rate of repair and conformity to transmission parameters (further, for simplicity, it will be mentioned as repair rate) is given by $r = r_f + r_n$; here $r_n = 1/\overline{\tau_n}$.

It is possible to calculate the γ, r values from $\Delta_h^{(a)}$ and $\Delta_h^{(u)}$ mean values by

$$\gamma = \frac{1}{\overline{\Delta^{(a)}} + \overline{\Delta^{(u)}}}; \tag{11}$$

$$r = \frac{1}{\overline{\Delta^{(u)}}}. \tag{12}$$

Therefore, in our investigated systems, each transmission channel is characterized by three parameters: μ, γ and r.

Let us consider a system with one data transmission channel, which is modeled using Markov chains (Fig. 4) with one parameter state vector X, which represents a state of channel's occupation: X=0 – channel is free, X=1 – channel transmits data packet, X=2 – channel is in failure state.

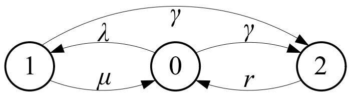

Fig. 4. Continuous time Markov chains for loss system with one unreliable channel

Then using the global balance concept we can easily write down the following equations for the evaluation of system state probabilities P_{XY}:

$$\begin{cases} (\lambda + \gamma)P_0 - \mu P_1 - rP_2 = 0; \\ (\mu + \gamma)P_1 - \lambda P_0 = 0; \\ rP_2 - \gamma(P_0 + P_{10}) = 0; \\ P_0 + P_1 + P_2 = 1. \end{cases} \tag{13}$$

By solving the underlying system (13) equations system steady-state probabilities P_X are obtained:

$$P_0 = \frac{r \cdot (\mu + \lambda)}{(\gamma + r) \cdot (\lambda + \mu + \gamma)}; \tag{14}$$

$$P_1 = \frac{r \cdot \lambda}{(\gamma + r)\cdot(\lambda + \mu + \gamma)}; \tag{15}$$

$$P_2 = \frac{\gamma}{\gamma + r}. \tag{16}$$

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

- data packet loss probability:

$$P_l = P_1 + P_2; \tag{17}$$

- served traffic intensity:

$$Y = \lambda(1 - P_l); \tag{18}$$

- data packet transmission channel faulty probability $P_{faulty} = P_2$.

Now we examine two unreliable channels network node with data packet losses (Fig. 5). Each channel is referred by parameters μ_1, μ_2, γ_1, γ_2 and r_1, r_2. Let us consider a system (Fig.5) state vector with four parameters X,Y where: X=0 – first channel is free; X=1 – first channel is transmitting data packet, X=2 – first channel is in failure state, Y=0 – second channel is free; Y=1 – second channel is transmitting data packet, Y=2 – second channel is in failure state.

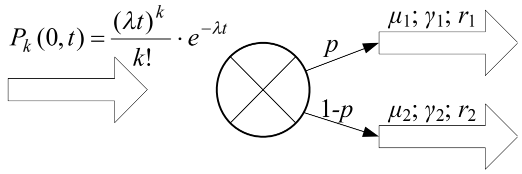

Fig. 5. The architecture of data network loss system with two unreliable data transmission channels

Let us consider that the first free channel is occupied with probability p, and the second channel will be occupied with probability 1-p. In such case our system can be mapped onto continuous time and discrete state Markov process chains as shown in Fig. 6.

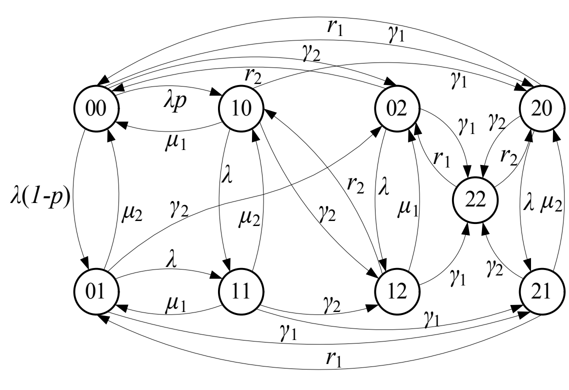

Fig. 6. Continuous time Markov chains for loss system with two unreliable channels

Using the global balance concept, we can easily write down the following equations:

$$\begin{cases} (\lambda + \gamma_1 + \gamma_2)P_{00} - \mu_1 P_{10} - \mu_2 P_{01} - r_1 P_{02} - r_2 P_{02} = 0; \\ (\lambda + \mu_1 + \gamma_1 + \gamma_2)P_{10} - \lambda p P_{00} - \mu_2 P_{11} - r_2 P_{12} = 0; \\ (\lambda + \gamma_1 + r_2)P_{02} - \mu_1 P_{12} - \gamma_2(P_{00} + P_{01}) - r_1 P_{22} = 0; \\ (\mu_1 + \mu_2 + \gamma_1 + \gamma_2)P_{11} - \lambda(P_{10} + P_{01}) = 0; \\ (\mu_1 + \gamma_1 + r_2)P_{12} - \lambda P_{02} - \gamma_2(P_{10} + P_{11}) = 0; \\ (\mu_2 + \gamma_2 + r_1)P_{21} - \lambda P_{20} - \gamma_1(P_{01} + P_{11}) = 0; \\ (r_1 + r_2)P_{22} - \gamma_1(P_{02} + P_{12}) - \gamma_2(P_{21} + P_{20}) = 0; \\ (\lambda + \gamma_2 + r_1)P_{20} - \mu_2 P_{21} - \gamma_1(P_{00} + P_{10}) - r_2 P_{22} = 0; \\ (\lambda + \mu_2 + \gamma_1 + \gamma_2)P_{01} - \lambda(1-p)P_{00} - \mu_1 P_{11} - r_1 P_{21} = 0; \\ \sum_{all\ xyzv} P_{xyzv} = 1. \end{cases} \tag{19}$$

By solving equations (19) we obtain the system's state probabilities P_{XY}. It can be used to find other system performance measures such as:

- data packet loss probability

$$P_l = P_{11} + P_{22}; \tag{20}$$

- first and second channels served traffic intensities

$$Y_1 = P_{10} + P_{11} + P_{12}; \tag{21}$$

$$Y_2 = P_{01} + P_{11} + P_{21}; \tag{22}$$

- probabilities of the first and second channels failure

$$P_{1fail} = P_{20} + P_{21} + P_{22}; \tag{23}$$

$$P_{2fail} = P_{02} + P_{12} + P_{22}; \tag{24}$$

- system faulty probability $P_{faulty} = P_{22}$.

Mainly the data packet transmission quality in such loss system is characterized by: data packet loss probability, channels served traffic intensity, and system or channel probability of fails.

The simulation model of queuing systems with unreliable channels

An exact analytical system model is useful and not complicated for the system with losses. More general study of queuing (K – queue length) systems shown in Fig. 7, 8 performance measures may be achieved by means of simulation.

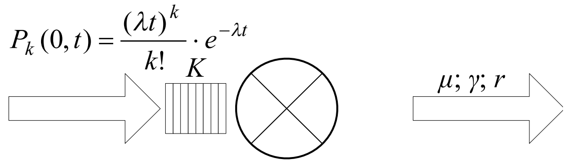

Fig. 7. One unreliable channel queuing system structure

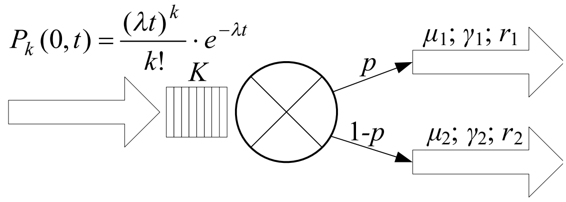

Fig. 8. Two unreliable channels queuing system structure

The simulation experiments were run on Pentium based PC with program developed using object oriented library for developing simulation models specified by aggregate approach and C# programming language in the Microsoft.Net environment. High accuracy and fast simulation is obtained. Each system performance measure is estimated by minimum, maximum, mean and standard deviation values.

System performance measures simulation

Let's use some real data as basis for performance measures simulation of VoIP packets transmission over data transmission network with unreliable channels.

Analysis of real *rtt* statistics, which was accumulated over 12 months between VoIP endpoints, shows that the smallest failure rate value was on 2007 February ($\gamma' = 0.00061\ s^{-1}$, $r' = 0.03949\ s^{-1}$) and the biggest – on April ($\gamma'' = 0.00095\ s^{-1}$, $r'' = 0.00495\ s^{-1}$).

If voice is encoded using G.729 codec with 60 ms voice frame size, then during one call VoIP packets are generated with intensity – $\lambda_1 = 16.66$ *pack*/*s*. Therefore, if v is the number of simultaneous calls, then the common VoIP packet generation intensity is $\lambda = v \cdot \lambda_1$. Length of the VoIP packet with Ethernet, IP, UDP and RTP headers is equal to 118 bytes. Therefore, the intensity of VoIP packet transmission over a 256 *kbit*/*s* channel – $\mu = 277.69$ *pack*/*s*.

Using proposed analytical and simulation methods some system's evaluation results are given in Fig. 9, 10, 11, 12 (here simulation results are denoted by "*").

It is shown in the Fig. 9, that difference between analytical and simulation result values in average is approximately equal to 2 %. It can be decreased by increasing simulation time or by taking an average value from simulation series.

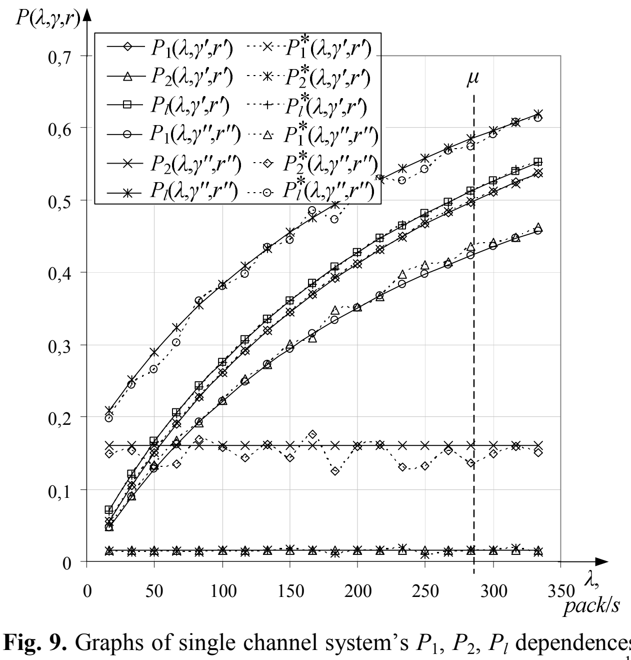

Fig. 9. Graphs of single channel system's P_1, P_2, P_l dependences on λ and γ, when $K = 0$, $\mu = 277.69$ *pack*/*s*, $\gamma' = 0.00061\ s^{-1}$, $\gamma'' = 0.00095\ s^{-1}$, $r' = 0.03949\ s^{-1}$, $r'' = 0.00495\ s^{-1}$

VoIP packet transmission delay is random, therefore to remove the delay variation (or jitter) a de-jitter buffer is used in the receiving VoIP endpoint. The length of the buffer is very small in order to add as small additional delay as possible. In Welltech's 3804A VoIP gateway a delay in the de-jitter buffer for the used codec can be set to 0, 60 and 120 ms. Because 60 ms voice frames are used, then for simulation model we take queue lengths $K' = 0$, $K'' = 1$ and $K''' = 2$.

It is shown in Fig.10, Fig. 11 and Fig. 12 how queue length affects system's performance parameters ($P_1^*(\lambda, \gamma)$, $P_l^*(\lambda, \gamma)$ and $Y_{1c}^*(\lambda, K)$, $Y_{2c}^*(\lambda, K)$) when λ is increased (here $\lambda^{(d)}$ – data packet intensity with constant times between VoIP packets).

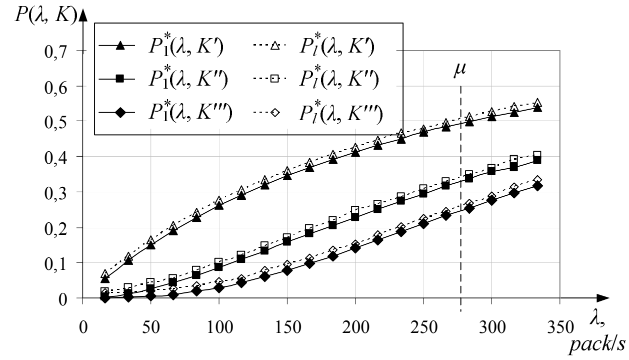

Fig. 10. Graphs of single channel system's P_1, P_l dependences on λ and K, when $\mu = 277.69$ *pack*/*s*, $\gamma = 0.00061\ s^{-1}$, $r = 0.03949\ s^{-1}$, $K' = 0$, $K'' = 1$, $K''' = 2$

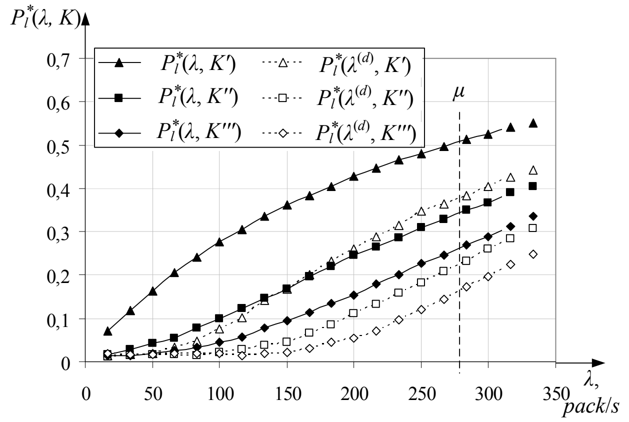

Fig. 11. Graphs of single channel system's P_l dependences on λ and K, when μ=277.69 *pack*/*s*, $\gamma = 0.00061\ s^{-1}$, $r = 0.03949\ s^{-1}$, $K' = 0$, $K'' = 1$, $K''' = 2$

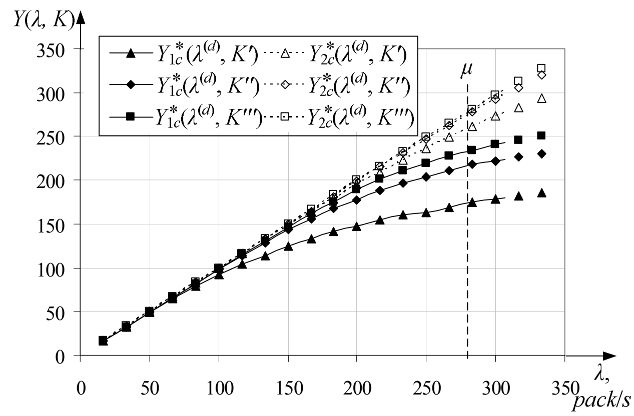

Fig. 12. Graphs of served traffic intensity (Y_{1c} – for single channel system, Y_{2c} – for two channel system with identical channel parameters) dependences on λ and K, when $\mu = 277.69$ *pack*/*s*, $\gamma = 0.00061\ s^{-1}$, $r = 0.03949\ s^{-1}$, $K' = 0$, $K'' = 1$, $K''' = 2$

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.

Simulation results show that data packet loss probability (P_2), which is caused by network node's failures, depends on selected γ an r values, but does not essential depend on the data intensity λ.

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

Data packet loss probability can be substantially decreased by increasing system's queue length, when the losses happen due to queue's overflow. It is possible to calculate optimal queue length (K) for a given performance values.

By increasing the number of independent working channels for a network node it is possible to increase it availability and traffic serving possibilities. For maximum efficiency the optimal number of network channels should be selected for required (demanded) system performance values.

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We propose analysis of the data network node, which uses one or two unreliable transmission channels. Inter arrival time of incoming data packets and their transmission times over the system with finite buffer capacity and data packet losses are exponentially distributed. The processes in an unreliable channel data network queuing node are based on the Markov chains. Using the proposed simulation and analytical models it is possible to evaluate the system's performance parameters such as: data packet transmission channel's failure probability, data packet loss probability, served traffic intensity in the IP based data packet transmission network. Ill. 12, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

Р. Риндзявичюс, П. Тервидис, Л. Нарбутайте, В. Пилкаускас. Анализ производительности сети передачи пакетов данных с ненадежными каналами передачи // Электроника и электротехника. – Каунас: Технология, 2008. – № 4(84). – С. 53–58.

Предложенная модель анализа исследования узла сети передачи данных, использующего один или два ненадёжные канала передачи данных. Время между пакетами данных в потоке и время передачи пакета данных по каналу распределено экспоненциально. Система ожидания с конечной ёмкосью буфера и потерями. Процессы в узле ожидания с потерями и с конечной ёмкостью буфера обусловлены марковским процессом. На основе предложенной аналитической и имитационной модели легко оценить параметры передачи пакетов в системе, таких как вероятность неисправности системы, вероятность потери пакетов, интенсивность обслуженной нагрузки в сети передачи IP пакетов. Ил. 12, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Rindzevičius, P. Tervydis, L. Narbutaitė, V. Pilkauskas. Duomenų paketų perdavimo tinklo su nepatikimais kanalais našumo analizė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 4(84). – P. 53–58.

Pateikiami analitiniai duomenų perdavimo tinklo mazgo, naudojančio vieną ar du nepatikimus duomenų perdavimo kanalus, veikimo modeliai. Į nagrinėjamą ribotos buferio talpos eiliavimo sistemą su duomenų paketų nuostoliais patenka eksponentiniai paketų srautai, kurie perduodami vienu ar dviem nepatikimai veikiančiais kanalais, o jų perdavimo trukmės kanale pasiskirsčiusios pagal eksponentinį dėsnį. Procesų duomenų perdavimo tinklo mazge tyrimas remiasi Markovo grandinėmis. Remiantis pasiūlytais imitaciniu ir matematiniais modeliais, nesunku nustatyti tiriamosios sistemos našumo rodiklius, kaip antai: duomenų perdavimo kanalo gedimo tikimybė, duomenų paketų praradimo tikimybę ir aptarnautos apkrovos intensyvumus. Il. 12, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.11133