Researching optical channel productivity with queuing model H_2/M/1in local networks

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Abstract

The Riverbed Modeler system presents the following statistics in graphs: Ethernet delay, throughput of the channel, channel loading, etc. The obtained results are compared with the theoretical ones. Theoretical calculation of the network delay requires the initial moments of the intervals between the traffic packets; they will be identified with the help of the developed network tap program. In this work a queuing system H_2/M/1 is selected for modeling the optical link channel. The received data are compared with the results of the Riverbed Modeler simulation.

Keywords: optical cable; Ethernet delay; throughput; utilization; the numerical characteristic of time interval

1. Introduction

In order to simulate the traffic in modern telecommunication networks, a class of exponential distributions is widely used; it includes the Weibull distribution, lognormal, etc. Under certain parameter values the coefficients of variation of random variables is more than 1 ($C_r > 1$). A coefficient of variation greater than 1 indicates that the tail of this distribution is located to the right of the tail in a classic exponential distribution. In this case distribution tail of the random variable ξ is the function: $Q(x) = P(\xi \geq x) = Q([x, \infty))$. In addition, right-sided long tail of the distribution may indicate larger values of a random variable. For example, for hyperexponential random distribution with the coefficient of variation more than 1, the probability of large random value is significantly higher in comparison with exponential random distribution.

According to the queuing theory, the average upstream response time is an constituent part of delay in packet-data network. It is also known that the average waiting time in the queue $\bar{W}$ in a queuing system (QS) with input distributions having coefficients of interval variation between the upstream request time $c_\lambda < 1$ and response time $c_\mu < 1$ is less than in M/M/1 system, and less than in M/G/1 system when $c_\mu > 1$ and less than in G/G/1 system under the conditions ($c_\lambda > 1, c_\mu > 1$ with the equal loading:

$\bar{W} \big| \left(c_\lambda < 1, c_\mu < 1\right) < \bar{W} \big| \left(c_\lambda = 1, c_\mu = 1\right) < \bar{W} \big| \left(c_\lambda = 1, c_\mu > 1\right) < \bar{W} | (c_\lambda > 1, c_\mu > 1)$.

These inequations also reflect the absolute facts of queuing theory.

In the article QS H_2/M/1 is selected for modeling the optical link channel, where H_2 stands for the hyperexponential distribution law of 2nd order. This system belongs to the G/M/1 class of systems; its detailed analysis is a relevant task. The work [2] presents the main findings of this system research. Additionally, it confirms the fact that such distributions occur in practice, for example, the interval distribution between packets of the incoming traffic on the university server.

2. Capturing traffic

To conduct this study we have chosen a network segment (fig. 1) of the Volga State University of Telecommunication and Informatics (PSUTI). The examined optical link channel (1000Base-LX) serves for passing traffic between POUTS department and PSUTI network as well as for external traffic. A specially developed network traffic analyzer is connected to a mirror switch port (Cisco SGE2000 24 Port). The traffic analyzer defines the initial data for the network segment. The received data are stored in simulation modeling system Riverbed Modeler.

It takes 20 minutes to record the number of packets (8567 pps) and the data volume (12,850,500 bps).

3. Simulation in Riverbed Modeler

IT Guru Technology is a set of actions for modeling a network and conducting simulation experiments in it. The result of simulation modeling is the collection of statistical data in the process of model work in real time. It fixes the most important characteristics of the network: response time and delay time, utilization rates of network resources, the probability of packet loss, etc. Riverbed Modeler allows accelerating the simulation of communications networks, devices, protocols and applications. Then it is possible to analyze the simulation results in order to compare the impact of diverse configurations on the probability-time characteristics of a network. Riverbed Modeler comprises a wide range of protocols and technologies as well as Integrated Development Environment IDE), which allows simulating all types of networks and technologies, including VoIP, TCP, OSPFv3, MPLS, IPv6, and others [1].

Riverbed Modeler constructs a model of the network based on initial traffic data (fig. 2).

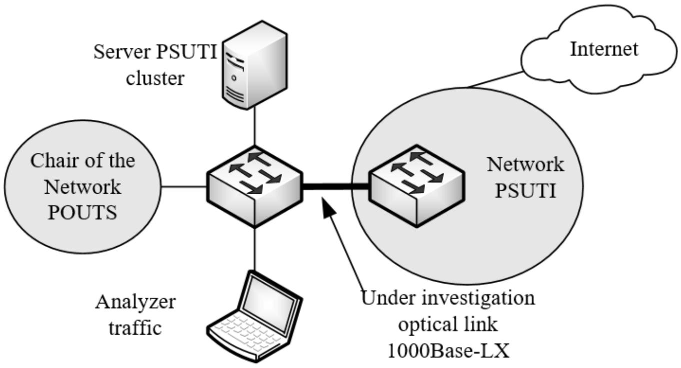

Fig. 1. PSUTI network segment.

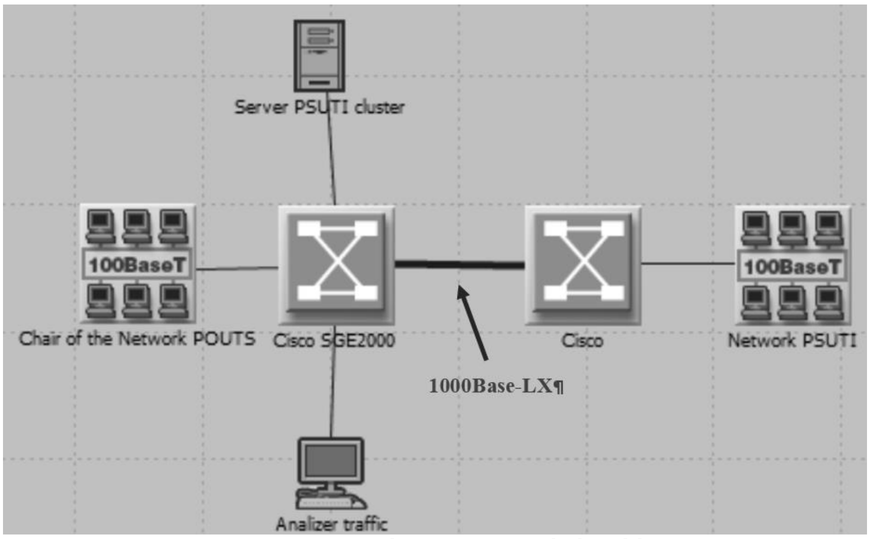

Fig. 2. PSUTI network segment in Riverbed Modeler.

Riverbed Modeler determines the network delay (fig. 3), as well as the following important design and performance characteristic of a communication channel [1]:

1. Queuing delay (sec) is waiting time indicator that measures a number of packets in the queue from the transmitting device (fig. 4);
2. Throughput (bits (packets)/sec) indicates the average number of bits (packets), successfully received/transmitted by a receiver/sender channel per time unit (fig. 5).
3. Utilization (loading) is the ratio of current network traffic to the maximum (100 %) traffic that the port can handle. (fig. 5).

4. Simulation results in Riverbed Modeler

Simulation results presented in a graphic form in this paragraph are further compared with theoretical results.

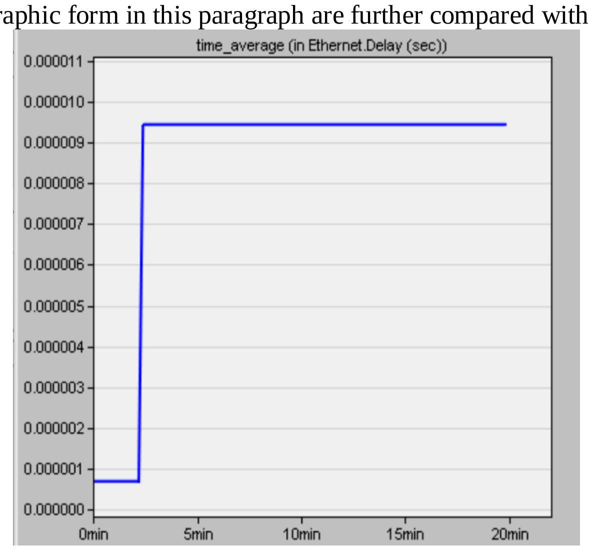

Fig. 3. Network delay.

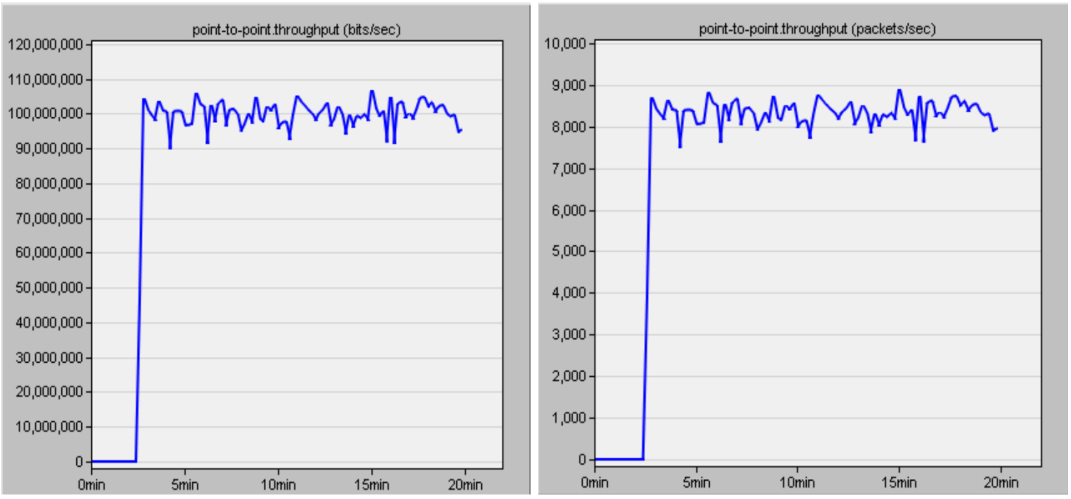

Fig. 4. Throughput (bits (packets)/sec).

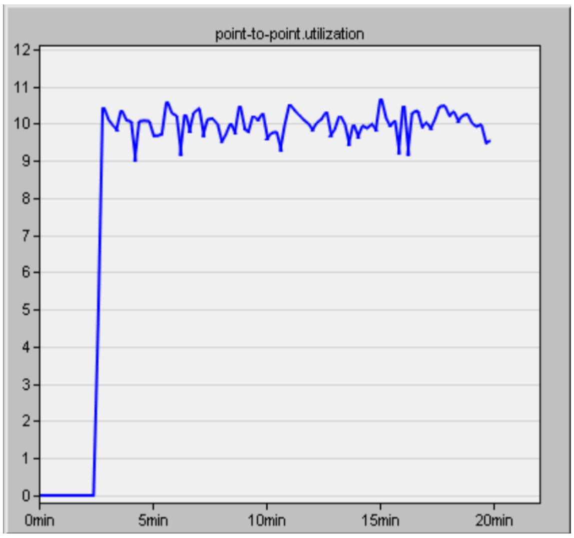

Fig. 5. Network Utilization.

5. Empirical research of delays

The research defines quantitative characteristics (moments) of time intervals for the examined traffic [2]. The theoretical analysis of delay will require the first, second and third initial moments of interval distribution between traffic packets. The average time delay (1) for packets in the network is calculated by the method entirely described in the works [2,3].

The average interval value between adjacent packets equals:

$$\bar{\tau} = \frac{1}{N}\sum_{k=0}^{N}(t_{k+1} - t_k),$$

where t_k is the time of the input packets; N is the amount of analyzed intervals.

The calculated formula for sample is $D_{\text{в}} = \overline{t^2} - \bar{\tau}^2$, where $\overline{t^2}$ is the second initial moment:

$$\overline{t^2} = \frac{1}{N}\sum_{k=0}^{N}(t_{k+1} - t_k)^2$$

The coefficient of the interval variation between the packets is $= \sigma_{\text{в}}/\bar{\tau}$, where $\sigma_{\text{в}} = \sqrt{D_{\text{в}}}$.

The formula to calculate asymmetry is $A_s = (\overline{t^3} - 3\overline{t^2} * \bar{\tau} + 2\bar{\tau}^3)/\sigma_{\text{в}}^3$, where $\overline{t^3}$ is the third initial moment given by:

$$\overline{t^3} = \frac{1}{N}\sum_{k=0}^{N}(t_{k+1} - t_k)^3$$

From the data obtained while capturing traffic we receive quantitative characteristics of the time intervals between the packets: $\bar{\tau} = 1.17 * 10^{-4}$, $\overline{t^2} = 2.45 * 10^{-6}$, $\overline{t^3} = 4.17 * 10^{-7}$, $D_{\text{в}} = 2.44 * 10^{-6}$, $c = 13.37$, $A_s = 109.50$

The obtained data demonstrate that the analyzed traffic considerably differs from Poisson distribution (coefficient of variation $c > 1$). The value of asymmetry $A_s > 2$ indicates that the distribution of time intervals between the traffic packets refers to heavy-tailed distributions and matches the queuing system (QS) $H_2/M/1$.

Theoretical calculation of delays in this case will require the first, second, third initial moments, and the intensity of an input stream, and the channel service intensity. Further we will refer to the source [5] that presents the findings for $H_2/M/1$ system.

The average time of delay is defined by the formula:

$$\overline{W} = \frac{1}{s_1} - \frac{1}{\mu}, \tag{1}$$

where μ is the channel service intensity; parameter

$$s_1 = \sqrt{\frac{c_2^2}{4} + c_1} - \frac{c_2}{2},$$

where $c_1 = \mu[\lambda_1(1-p) + \lambda_2 p] - \lambda_1\lambda_2$, $c_2 = \lambda_1 + \lambda_2 - \mu$. In this case, p, λ_1 and λ_2 are hyperexponential distribution parameters with a density function $a(t) = p\lambda_1 e^{-\lambda_1 t} + (1-p)\lambda_2 e^{-\lambda_2 t}$, where μ is an exponential distribution parameter with a density function $b(t) = \mu e^{-\mu t}$ for $H_2/M/1$ system.

To calculate the unknown parameters of input distribution, p, λ_1 and λ_2, we apply the initial moments of time intervals between the packets received in the experimental part of the article. We substitute them in the system of equations (2) according to the method of moments:

$$\begin{cases} \overline{\tau_\lambda} = \dfrac{p}{\lambda_1} - \dfrac{(1-p)}{\lambda_2} \\ \overline{\tau_\lambda^2} = \dfrac{2p}{\lambda_1^2} + \dfrac{2(1-p)}{\lambda_2^2} \\ \overline{\tau_\lambda^3} = \dfrac{6p}{\lambda_1^3} + \dfrac{6(1-p)}{\lambda_2^3} \end{cases} \tag{2}$$

The solutions of the system (2) in MathCad are: $p \approx 0.999$, $\lambda_1 \approx 1.044 * 10^4$ and $\lambda_2 \approx 17.494$.

The intermediate parameters are $c_1 \approx 1.59 * 10^6$, $c_2 \approx 1.046 * 10^4$, $s_1 \approx 150.662$. The average waiting time in a queue is $\overline{W} \approx 0.66 * 10^{-4}$ sec.

6. Conclusion

In the experiments we have received quantitative characteristic of intervals between the traffic packets. For theoretical calculation we applied $H_2/M/1$ system. The modeling system Riverbed Modeler provided us with the principal characteristics. The calculations for QS $H_2/M/1$ have resulted in the following: the waiting time in a queue is $0.66 * 10^{-4}$ sec, while Riverbed Modeler shows the result of $0.9 * 10^{-5}$ sec, which is an order of magnitude less. This result was obtained with 10% channel loading. Taken into consideration the fact that Academic Edition of Riverbed Modeler is only capable for Poisson input process, we, ultimately, receive the delay indicator that is close to M/M/1 system. Consequently, we conclude that the classic M/M/1 system gives excessively optimistic assessment of a delay.

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