# MODELLING COMPUTER NETWORK PROCESES BY USING QUEUING THEORY

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**Annotation**
*This article analyses e-learning network. It evaluates influence of network traffic parameters to its service quality. The empirical model of e-learning network is described. Based on the classical queuing theory methods mathematical model of the e-learning network M/M/m/N//LIFO was developed. The characteristics of data flow are described analytically: the average time of the packet existence in the system, the average number of packets, the probability of the packet being served, the average number of packets in the queue, the average time of the packet was waiting in queue. Formulas for the efficiency of the network service evaluation are described analytically according to the services provided in the network. Statistical simulation methods were applied for data flow delay estimation based on the results of the e-learning network traffic analysis.*

**Key words:** *M/M/m/N//LIFO, computer network service theory, service efficiency, delay, queuing theory.*

## Introduction

The network components and processes for efficient analysis of computer network packet flow must be mapped by using mathematical models and methods of queuing theory. Empirical studies confirm that the flow of computer network packets is self-similar (Samorodnitsky, 2006, Kaklauskas, Sakalauskas, 2008, Taqqu, Teverovsky 1998). This feature allows to predict traffic change and the results can be used to improve the quality of network service (QoS) by controlling packet delay, restricting fluctuations, packet loss in transport, data, and physical OSI (Open Systems Interconnection) layers (Salama, and etc. 2017, Yousefpour, and etc. 2017, Spurgeon, Zimmerman, 2014, Jankuniene, Priksaitis, 2010, Rutka, 2009, Kaklauskas, 2003). Quality assurance of the computer network service is one of the aspects of the theory developed by A. K. Erlong (Lee, Kumar, 2008). Erlang sought to establish method for determining the number of communication channels by analyzing the telephone network. This method would allow minimize call losses and service all subscribers of the network. Danish scientist V. B. Iversen has developed this aspect and called it tele traffic theory (Iversen, 1985, Iversen, 2005). Subsequently the basics of the queuing theory was developed by A. Chinchin, D. Kendall, J. Sztrik and many other scientists (Хинчин, 1963, Kendall, 1953, Sztrik, 2012). In Lithuania the queuing theory is being developed by Rindzevičius, Sakalauskas and other scientists. The queuing theory integrates a number of concepts specific to communication technologies: arrival rate ($\lambda$), service rate ($\mu$), service time, load factor ($\rho$), cannel load factor (q), number of serviced channels (M), average service time of one packet ($\overline{X}$), average number of packets in the system ($\overline{N}$) and etc. (Lee, Kumar, 2008).

Computer network nodes are often subject to unpredictable congestion, and therefore efficient network management requires monitoring and forecasting network load and overload to maximize network service quality. It is established that the classical Markov models, used for evaluation of phone networks, is not suitable for modeling modern computer networks (Taqqu, Teverovsky, 1998). The empirical Surveys of Ethernet network flow by A. Erramilli, O. Narayan and W. Willinger in 1989 confirmed that Ethernet Flow Characteristics have fractal properties and is self-similar with long-range dependence. Later self-similarity was investigated by Kaj, Taggu, Samarodnitsky and many other scientists (Samorodnitsky 2006, Kaklauskas, Sakalauskas, 2008, Taqqu, Teverovsky, 1998). The properties of modern communication networks flows are evaluated using statistical analysis methods and mathematical modeling. The network flow is analyzed as a fractal process, characterized by a second-order statistical self-similarity and by fractal measure (Kaklauskas, Sakalauskas, 2008). To simulate and describe network processes it is recommended to use non-linear analysis (chaos theory) methods with estimation of heavy – tails, which characterize large network fluctuations (Василенко, 2004, Feder, 2013). The purpose of the research was to develop a mathematical model for analyzing packet traffic flows for e-learning servers and clients (students, lecturers and other pedagogical staff) for service quality evaluation, based on the paradigms of the theory of queuing. It is important to note that there is a great deal of network traffic self-similarity research (Thomson, and etc. 2018, Jeong, and etc. 2017, Kim, and etc. 2007) although similar e-learning network traffic research by using queuing theory are absent. Initial research of the e-learning' computer network nodes flow confirmed their self-similarity (Kaklauskas, Sakalauskas, 2008, Kaklauskas, 2016). Measurement results were processed by calculating the correlation measure of aggregated rows, analyzing the attractors, evaluating the fractal dimension, calculating the Hurst index, using robust methods for stable random values measurement. The analysis of time series has shown that the measured flows are characterized by self-similarity and high traffic burstiness which affects data packet delays and its losses (Kaklauskas, Sakalauskas, 2013).

### 1. Empirical model of distance learning network

The analyzed e-learning network equipment is compatible with 802.3 (Ethernet / FastEthernet / GigabitEthernet) standard. Network segments serve customers at 100Mb, while the router with switches and server array connect 1000Mb (1Gb) speedways (Spurgeon, Zimmerman, 2014). The logical scheme of the e-learning network is provided in Fig. 1. The router is main network node, ensuring interoperability of the Ethernet and external network users with the e-learning' servers cluster. Queries are distributed through high-performance commutators (Jankuniene, Priksaitis, 2010, Kaklauskas, 2003).

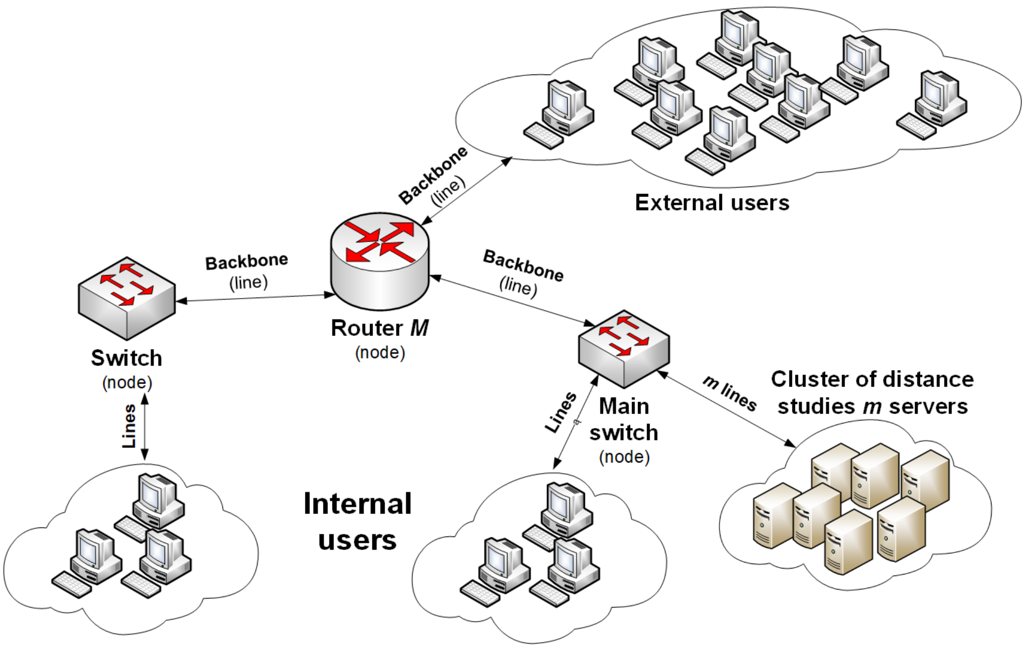


Fig. 1. The logical scheme of the distance learning subsystem

A router is used to form large networks, describe the routes of information streams, thus connecting various types of networks. The static and dynamic routing protocols can be used for data routing. The e-learning' network uses OSPF (Open Shortest Patch First) protocol, which generates links between other network nodes using the Deikstra algorithm for linked graphs G = (N, E), where N is a set of network nodes and E is lines connecting these nodes. This algorithm creates shortest routes - paths p from sender to recipient. The route list is generated by the algorithm (Tanenbaum, Wetherall, 2010, Kaklauskas, 2003):

- node M, which creates routing tables, sends all its network nodes a query to get information about weight coefficients of routing of connected lines, estimating the line speed;
- determines neighbors and their routes weighting coefficients are recorded on the first row of the route table, while the other weighting factors in that row are marked as infinity;
- now we calculate the weight coefficients from the nearest neighbor of M to its neighbors and write them in the second row of the routing table, rejecting the duplicate routes in the first row and the weight coefficients to other nodes marking as infinity;
- the calculations are continued until the coefficient of weight of each most distant from the M network node neighbor is evaluated.

The network routing is described by the formula, according to the classic network routing task: $\min \sum_{i,j} D_{ij}(F_{ij})$, when the selected traffic flow is subject to a restriction $\{x_p \mid w \in W, p \in P_w\}$, and the routes satisfy the conditions:

$\sum_{p \in P_w} x_p = r_w$ for all $w \in W$ and $x_p \geq 0$ for all routes $p \in P_w$.

The following denotation are used here: *W* – all possible pairs *w* “sender-recipient” set; $P_w$ – sender and recipient hosts connecting pairs *w* set; $x_p$ – road *p* flow; $r_w$ – network traffic requirements for connection pairs *w*; $F_{ij}$ – total flow passing $e_{ij}$ line, i.e. $F_{ij} = \sum x_p$ and summing up is performed by adding all routes *p* transmitted over the $e_{ij}$ line; $D_{ij}(F_{ij})$ – weight function associated with $e_{ij}$ line technical characteristics such as packet loss factor, interference, speed (Kendall, 1953, Sakalauskas, 2000).

Switches in the computer network distribute information flows based on the sender and recipient addresses that are used to create network segments. The switches of 802.3 standards, showed in fig 1. have 48 100 Mb ports with automatic speed determining and two 1000Mb ports. Packets delay are no more than 13.3μs, queuing use LIFO (Last-in-First-out) method, the switch can store up to 8000 address tables, switching speeds of 13.6 Gbps.

## 2. M/M/m/N//LIFO network queuing model

According to the theory of queuing packet a stream that comes in and are serviced in the network of e-learning are simple flows (M) so their packets are distributed according to the Poisson law. The flow is characterized by stationary (in the time interval, the number of T-packets depends only on the length of the interval and does not depend on the position of interval T on the time t-axis), the ordinality (the packets forming the flow, come in the system only one, not in pairs, in threes, etc.) and without interactions (such packet flow is described by the number of packets in the intervals for any non-overlapping time intervals that does not depend on the number of packets that fall into other intervals). *m* is a number of servers. N is a number of packets in queue that are served by using the LIFO method. The number of packets coming to the system is unlimited. This model will help to assess the impact of the network parameters to the quality of network work QoS (Giambene, 2014, Sakalauskas, 2000).

The duration between appearance of packets in the analyzed network traffic is described by the exponential distribution $F(t) = 1 - e^{-\lambda t}$ with the density function $f(t) = \lambda e^{-\lambda t}$. The probable value (average) of the time between events $\tau$ is calculated – $\bar{\tau} = \frac{1}{\lambda}$ and the flow dispersion – $D^2\tau = \frac{1}{\lambda^2}$. This packet stream of computer networks in general is distributed according to the Poisson law:

$$P(N_{t,\tau} = k) = \frac{(Q_{t,\tau})^k}{k!} \cdot e^{-Q_{t,\tau}},$$

where $N_{t,\tau}$ is the number of packets received in the packets serving system or main switch during the time interval $(t, t+\tau)$, $Q_{t,\tau}$ is average traffic intensity during the time interval $(t, t+\tau)$ and calculated by $Q_{t,\tau} = \int_t^{t+\tau} \lambda(u)du$, where $\lambda(t)$ is traffic intensity in the time interval *t* and $\lambda(t) = \lim_{\tau \to 0} \frac{Q_{t,\tau}}{\tau}$. The network flow described by the Poisson law is characterized by the features of boundary superposition and the random rarefaction (Giambene, 2014).

If we do not consider the fact that the network data flow is fractal, then the M/M/m/N//LIFO system characteristics can be calculated using the classical formulas. The average time the package is present in the system is found by the formula:

$$\bar{T}_s = \frac{\overline{N_s}}{\lambda} = \frac{1}{\mu} + P_s \cdot \frac{1}{m\mu - \lambda},$$

where $\mu$ – traffic flow rate, $\lambda$ – input flow rate, $P_s$ – the probability that all service devices will be occupied when the packet comes in to the system. To calculate the average packet, stay time in the system it is necessary to evaluate the distribution of packet lengths in service system. Generally, in computer networks, the lengths of packets are distributed according to the exponential law so the average of their length is calculated (Giambene, 2014, Sakalauskas, 2000). Average number $\overline{N}$ of packets in the system, when system load $\rho = \frac{\lambda}{\mu} = \lambda \overline{T_{pak}}$, is calculated according to the formula:

$$\overline{N} = \sum_{k=0}^{\infty} k p_k = m\rho + \rho \frac{(m\rho)^m}{m!} \frac{P_s}{(1-\rho)^2}.$$

The probability that all service facilities will be occupied during while packet's transition to the system is found by the formula:

$$P_s = \frac{\frac{\rho^m}{m!}}{\left[\frac{\rho^m}{m!} + (1-\rho)\sum_{k=0}^{m-1}\frac{\rho^k}{k!}\right]}.$$

The average number of packets in the queue is:

$$\overline{N_Q} = P_s \frac{\rho}{1-\rho}.$$

Average packet waiting time in the queue is calculated as:

$$\overline{W} = P_s \cdot \frac{1}{m\mu - \lambda}.$$

### 3. Evaluation of the efficiency of e-learning computer network service

The evaluation of effectiveness of e-learning computer networking is related to the services provided in it. It should be noted that in the network there is used e-learning environments. To maintain these environments there are used services:

- web server (Apache), serving the e-learning' environments via http (Hyper Text Transfer Protocol) protocol over logical port 80;
- a database server (MySql) for storing information and serving customers through a 3306-logical port.

In addition to these core services, the network provides additional services that ensure the reliable proceeding of the core services:

- DNS - works by 53 logical port and ensures the exchange of domain names into the numerical format of IP addresses;
- Packets serving Mysql protocol that provide client and MySql server connection setup and data transmission over the network: Handshake Initialization Packet, Client Authentication Packet, OK Packet, Error Packet, Command Packet, Result Set Packet;
- Eight methods of http protocol that ensures high quality customer service: head, get, post, put, delete, trace, options, connect;
- ICMP protocol service packets for network devices control: Echo Reply, Destination Unreachable, Source Quench, Redirect Message, Echo Request, Router Advertisement, Router Solicitation, Time Exceeded, Parameter Problem: Bad IP header, Timestamp, Timestamp Reply, Information Request, Information Reply, Address Mask Request, Address Mask Reply, Traceroute;
- Service package Hello in OSPF routing protocol;
- Other non-recognized packages circulating in the e-learning computer network for servicing other services.

Investigations have shown that the number of network service packets in the total traffic does not exceed one percent (Jankuniene, Priksaitis, 2010, Lemoine, 2004). The network model that is being analyzed complies with the Ethernet standard for the local area network, so the standard formula can be used to calculate its efficiency:

$$E = \sum_{i=1}^{S} \varphi_i P_i(t),$$

where $\varphi_i$ – the importance of the service *i*, where $\sum_{i=1}^{N} \varphi_i = 1$, $P_i(t)$– the probability of providing the service *i* at any time *t*, S – the quantity providing services in the network. The data packets from users to servers goes through the routers and switches (Fig. 1) which means that the standard formula needs to be rewritten according to estimation of the Router-Switch's service path and considering that all e-learning users are divided into lecturers (ensuring students group learning) and students:

$$E = \sum_{k=1}^{m} \phi_k \sum_{j=1}^{S} \varphi_{jk} \prod_{i=1}^{M_{kj}} P_{ijk}(t_{ijk}) ,$$

where $m$ – the quantity of servers used in the network, $S$ – the quantity of services provided, $M_{kj}$ – quantity of services provided by switching nodes (including routers) (2 nodes), $\phi_k$ – server importance coefficient, $\varphi_{jk}$ – the importance coefficient for the j-th service of the k-th server, $P_{ijk}$ – the probability that from k-th server providing j-th service on service way will be working i-th switching node in all connection time $t_{ijk}$. The exponential expression $P_{ijk}(t_{ijk}) = e^{-\lambda'_{ijk} t_{ijk}}$ is used to calculate the probability $P_{ijk}$, where $\lambda'_{ijk}$ – the frequency of the failure of the k-th server providing the j-th service through the i-th switch. If the reliability of a network depends on the importance of separate switches, then the efficiency of each switching device is calculated based on the formula:

$$K'_{sv} = \frac{\sum_{k=1}^{T} \phi_k \sum_{i=1}^{S} \varphi_{ik} \cdot n_{ik} \cdot t_{vi}}{\Delta t} ,$$

where $n_{ik}$ – the amount of use of the k-th server's i-th service over time $\Delta t$, $t_{vi}$ – the average time worked by the switching device for serving i-th service (Balaišis, Eidukas, 1999).

## 4. Evaluation of data flow delay

The e-learning' computer network is characterized by the following qualitative indicators:

- Throughput, that is used to explain the amount of data which can be transferred during a specific time interval and is related to network segment speed, node transfer rate, and network transmission rate of used applications;
- packet loss – the amount or extent of data packets lost in each time interval;
- packet delay – the time, required to reach online study server from the student computer, that is related to the packet's propagation delay time $t_{prop}$ (Propagation Delay) and $t_{prop} = \frac{L}{V}$, where $L$ is the length of the physical line, the $V$ – propagation line speed, Nodal processing delay $t_{node}$, Queueing time $t_{que}$ and Transmission Delay $t_{trans}$ and $t_{trans} = \frac{D}{B}$, where $B$ is the bandwidth, and $D$ is packets size measured in bits;
- Delay fluctuations (jitter) are changes in packet delay parameters during the studies, resulting from queues formed in network nodes, faults in the network, routing failures and social factors.

Delay for end users is calculated by adding up all four delay components (see Fig. 2), evaluating network nodes and is generally counted as a round trip time (RTT):

$$RTT = 2\left( t_{trans} + \sum_{i=1}^{N} (t_{node} + t_{que} + t_{prop} + t_{trans}) \right) + t_{serv} ,$$

where $N$ – quantity of network nodes, $t_{serv}$ – the time it takes for the package to be served on the server (Balaišis, Eidukas, 1999).

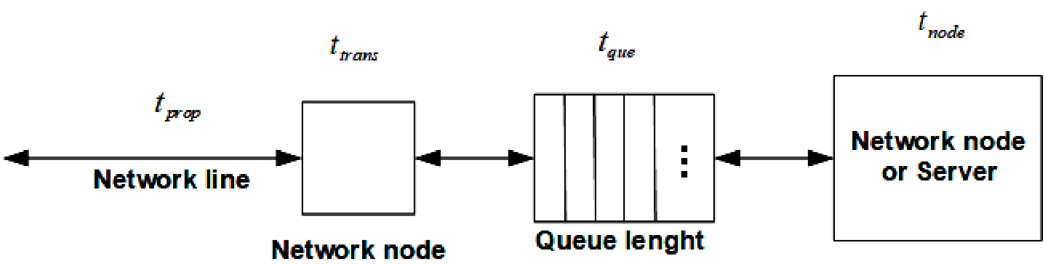


Fig. 2. Network Flow Delay Scheme

**Conclusions**

1. Based on the classical methods of service theory the mathematical model of the e-learning network M/M/m/N//LIFO was developed;
2. Empirical model of e-learning network was prepared;
3. The data flow characteristics was described analytically, and service model M/M/m/N//LIFT was designed;
4. The efficiency of the network service was described by using analytical formulas which dependes from services provided on the network;
5. The statistical simulation methods, based on the results of the distance learning network traffic analysis, were applied for estimating data flow delay.

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