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International Journal of Engineering, Science and Technology
Vol. 1, No. 1, 2009, pp. 33-42

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY
www.ijest-ng.com

Evaluation of the information servicing in a distributed learning environment by using monitoring and stochastic modeling

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Abstract

The distributed learning is an instructional model that allows instructor, students, and content to be located in different nodes in the global network. The authors' main idea is to organize a distributed learning environment (DLE) based on information and communication resources of global network in combination with the technologies for virtual reality and 3D simulation. In this reason a conceptual model of the DLE architecture and learning processes is defined, and preliminary investigation is carried out. The purpose of this paper is to present an evaluation of information servicing in DLE by using stochastic model designed on the base of the results from program monitoring. A formalization of the DLE processes is made and a stochastic model based on the apparatus of Markov's chains and queuing theory is designed. The results obtained from program monitoring are used for determination of the values of the basic model parameters to secure high model adequacy. The program monitoring is realized by using two program applications and a preliminary statistical analysis is made. Finally, an evaluation of the information servicing in DLE is realized and the obtained assessment are presented in suitable manner.

Keywords: Distributed learning, information servicing evaluation, Markov's modeling, monitoring, statistical analysis

1. Introduction

The distributed learning (DL) is an instructional model that allows instructor, students, and content to be located in different, noncentralized locations so that instruction and learning occur independent of time and place (Oblinger, 1996; Bowman, 1999; Dede, 2004). This requires building a distributed learning environment (DLE) based on information and communication resources of global network and web-space, including wireless networks (Predd *et al*., 2006). The development of the technologies for virtual reality and 3D simulation (Funkhouser, 2005; Bierbaum, *et al*., 2008) create a possibility to organize a virtual environment for e-learning based on computer generated 3D models.

The main idea of the authors of this article is to combine the technological principles of the web-environment with the possibilities for e-learning based on the virtual reality and 3D learning objects. The main goal is to organize DLE and a conceptual model (Romansky and Parvanova, 2008) and for this purpose principles of virtual environment (Romansky and Parvanova, 2009a) are defined. A preliminary investigation of the distributed learning processes is needed to secure effective organization of the DLE architecture. In this reason we carry out different experiments by using modeling based on deterministic (Romansky and Parvanova, 2009b) and stochastic tools.

The purpose of this paper is to present an evaluation of information servicing in DLE by using stochastic model designed on the base of the results from program monitoring. The apparatus of Markov's chains (Deshpande and Karypis, 2004) is selected to design the model with the combination of the main principles of queuing theory. The results obtained from program monitoring are used for determination of the values of the basic model parameters in order to secure high model adequacy.

The goal of the paper is to present basic steps of the evaluation organization and summary of the obtained analytical assessments. In this reason a formalization of the environment is given and a Markov's model is designed. The program monitoring is realized by using two program applications and a preliminary statistical analysis is made. Finally, an evaluation of the information servicing in DLE is realized and obtained assessment are presented in suitable manner.

2. Formalization and Abstract Description

The conceptual model for organization of DLE is proposed in (Romansky and Parvanova, 2008) and consists of some basic components – students, teachers, clients, information and education resources, communication tools, etc. The DLE is an interactive environment for knowledge presentation and servicing based on requests sent by users. The access to the learning resources could be realized from different remote nodes by communication resources of Internet. The main components defined in this conceptual model are users, information learning resources and communication medium. All these components could be described as discrete independent objects with their own internal structure and functionality. This formulation permits to build an abstract model of DLE as an ordered discrete structure DLE = {U, R, T, D} (Figure 1) based on the following formalization:

a) abstract object:
- ✓ Set of independent users $U = \{U_i \,/\, i=1 \div N\}$, $U \neq \varnothing$;
- ✓ Set of distributed learning resources in different nodes of the DLE $R = \{R_j \,/\, j=1 \div M\}$, $R \neq \varnothing$;
- ✓ Set of network communication tools (transmitters) $T = \{T_q \,/\, q=1 \div K\}$, $T \neq \varnothing$;
- ✓ Distributor (D) that routs all information objects in the communication medium by using information in the packets.

a) interactions between defined abstract objects:
- ✓ requesting a learning resource initialized by user $req{:}U_i \rightarrow R_j$ (for $\forall U_i \in U$ & $\forall R_j \in R$);
- ✓ responding by sending the requested learning object (information block) $Inf{:}R_j \rightarrow U_i$ (for $\forall U_i \in U$ & $\forall R_j \in R$).

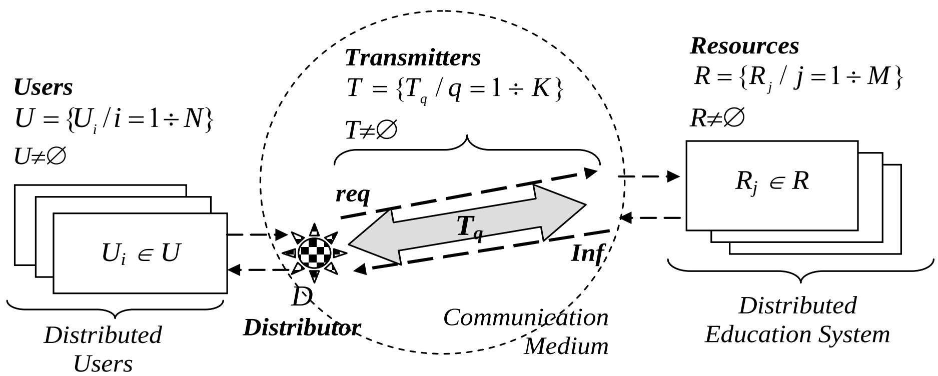


Figure 1. Abstract model of education process in the DLE

The information servicing in the DLE has a stochastic nature. This permits to use a stochastic apparatus for modeling of the DLE components and interaction. In this reason, the apparatus of Markov's chains is suitable for the description of system behavior as a sequence of discrete states $<S(0), S(1), ..., S(k),...>$ for each sequence of times $t_1<t_2<...<t_k<t_{k+1}<...$. For model designing is necessary to define a finite set of discrete states $\{s_1, s_2, ..., s_n\}$ presenting the main events or situations in the educational process and determining the matrix of transitive probabilities $\mathbf{P}=\{p_{ii}{:}[S(t_k)=s_i] \rightarrow [S(t_{k+1})=s_j]\}$ and vector of initial probabilities $P_0=\{p_1(0), p_2(0), ..., p_n(0)\}$. The stochastic analytical model of the servicing in the DLE could be defined by using the following formulas:

- ✓ formula for composite probability:

$$p_j(k) \;=\; \sum_{i=1}^{n} p_i(k-1).p_{ij} \qquad ; j = 1,2,...,n;$$

- ✓ condition for normalization:

$$\sum_{j=1}^{n} p_{ij}(k) = 1 \;\; ; i = 1,2,..., \; n \cdot$$

3. Stochastic modeling by using Markov's chain

3.1. Model defining

Two basic situations could be realized in the distributed learning environment (Figure 2): (a) remote access of multiple users to selected information-learning resource situated in node of the global network; (b) remote access of only one user to multiple information-learning resources situated in different nodes of the global network.

a) multi-user remote access to selected distributed resource b) one-user remote access to multiple distributed resources

Figure 2. Abstract presentation of the remote access to the learning resources

To describe the stochastic nature of the information servicing two basic intensities are defined – the intensity of the input flow of requests (λ) and intensity of the flow of servicing in the node of the requested resource (μ). It is possible each learning resource R_j in the DLE to be requested by different number of users and this number could be from 0 (minimum) to N (maximum). Each new user will generate request with the intensity λ. After the full servicing of each user request by the resource (by the server in the node) the Markov's process will be returned to the previous state by the intensity μ. In this reason the stochastic nature of the information servicing in the DLE could be described by Markov's model shown in the Figure 3.

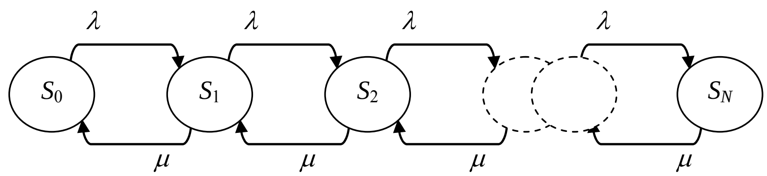


Figure 3. Markov's chain model of the multi-user access in DLE

The stochastic investigation is connected to the determination of assessments for the parameters for the steady-state regime – assessments of the final probabilities for all defined states in the Markov's model. It is known that to ensure the steady-state regime it is necessary to by realized the condition $\rho = \lambda/\mu < 1$, i.e. $\lambda < \mu$. The general Markov's model is presented below:

$$\left| \begin{array}{l} \lambda . p_0 = \mu . p_1 \\ (\lambda + \mu). p_i = \lambda . p_{i-1} + \mu . p_{i+1}; \; for \; 1 \le i \le N - 1 \\ \mu . p_N = \lambda . p_{N-1} \\ \sum_{i=0}^{N} p_i = 1 \end{array} \right. \tag{1}$$

After some transformations of the (1) we define the next form of the Markov's model:

$$\left| \begin{array}{l} p_1 = \dfrac{\lambda}{\mu} . p_0 \Rightarrow p_1 = \rho . p_0 \\ (\lambda + \mu). p_i = \lambda . p_{i-1} + \mu . p_{i+1} \Rightarrow \left(\dfrac{\lambda + \mu}{\mu} \right) . p_i = \dfrac{\lambda}{\mu} . p_{i-1} + \dfrac{\mu}{\mu} . p_{i+1} \Rightarrow \\ \qquad \Rightarrow (\rho + 1). p_i = \rho . p_{i-1} + p_{i+1} \Rightarrow p_i = \rho^i . p_0 ; \quad for \; 1 \le i \le N - 1. \\ \lambda . p_{N-1} = \mu . p_N \Rightarrow p_N = \rho . p_{N-1} = \rho^N . p_0 \\ \sum_{i=0}^{N} p_i = 1 \Rightarrow p_0 + \rho^1 . p_0 + \rho 2 . p_0 + ... + \rho^N . p_0 = 1 \Rightarrow \\ \qquad \Rightarrow p_0 (1 + \rho + \rho^2 + ... + \rho^N) = 1 \end{array} \right. \tag{2}$$

The theory of probabilities gives some assessments for the main stochastic parameters if $N \to \infty$ that could be interpreted in our case:

- ✓ Expectation of the number of the active users $E[N] = N_{av} = \rho/(1-\rho) = \lambda/(\mu-\lambda)$;
- ✓ Variance of the number of the active users $V[N] = N_{av} + N_{av}^2$;

✓ Expectation of the number of the users waiting servicing $E[W] = W_{av} = \rho^2/(1-\rho)$;
✓ Expectation of the waiting time for servicing $E[T_W] = N/\mu = \rho/[\mu .(1-\rho)]$.

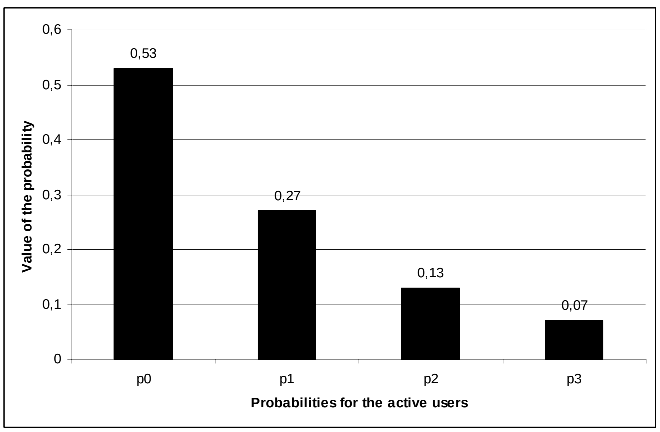
The stochastic analysis of the information servicing in the learning environment is carried out in three basic directions:
✓ Analysis of the influence of the number of active users;
✓ Analysis of the user's access to the resources;
✓ Analysis of the influence of the learning contents size.

3.2. Preliminary model solution

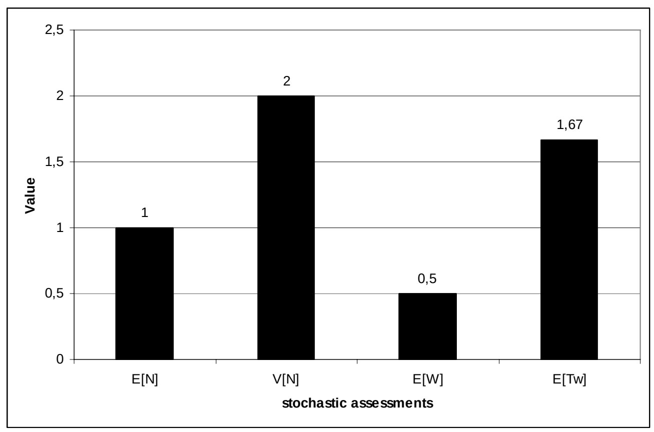
The preliminary solution of the Markov's model is made for its verification and to define the model sensitivity. In this reason concrete values for the basic model parameters are accepted: $N = 3$; $\lambda = 0.3$ (the average time between user's requests is 3s); $\mu = 0.6$ (the average time for a request servicing is 1.5s) ⇨ ρ = 1/2 < 1. The Markov's model is the following:

$$\left|\begin{array}{l} 0{,}3.p_0 = 0{,}6.p_1 \\ (0{,}3+0{,}6).p_1 = 0{,}3.p_0 + 0{,}6.p_2 \\ (0{,}3+0{,}6).p_2 = 0{,}3.p_1 + 0{,}6.p_3 \\ \sum_{i=0}^{3} p_i = 1 \end{array}\right. \quad \Rightarrow \quad \left|\begin{array}{l} p_1 = 0{,}5.p_0 \\ p_2 = 0{,}5^2.p_0 \\ p_3 = 0{,}5^3.p_0 \\ \sum_{i=0}^{3} p_i = 1 \end{array}\right. \qquad (3)$$

The analytical solution of the model gives the assessments for the final probabilities presented in the Figure 4. Each value for the p_i (i=0,1,2,3) presents the probability of the number of active users in the steady-state regime. The measures of the stochastic parameters' values are: 'number' for $E[N]$ and $V[N]$; 'second' for $E[W]$ and $E[Tw]$.



a) assessments of the final probabilities



b) assessments of the stochastic parameters

Figure 4. Results obtained by the model solution

3.3. Organization of the stochastic evaluation

To organize the adequate analysis of the information servicing in the distributed learning environment based on the defined stochastic model is necessary to determine the adequate values for the main model parameters – intensities of the input requests flow and of the servicing in the resource's nodes. One of the suitable manners for determining of these parameters is by using program monitoring in the real distributed medium. In this reason, an organization of the monitoring experiments and preliminary statistical analysis of the measured data are presented in the next section.

4. Monitoring and preliminary statistical analysis

4.1. Monitoring organization

A program monitoring of the network traffic parameters is organized to collect real data for information processes and distributed servicing (Romansky, 2006). The measurement is realized in two directions – to collect details for the frames passed via network medium and to determine statistical data about communication and servicing parameters. An adequate experimental plan should be defined to obtain correct assessments for the probability distribution of the investigated parameters (in particular, for the intensities of the input request flow and of the servicing processes).

The monitoring of network traffic parameters and characteristics of the distributed information servicing could be made by using different program tools for measurement, registration and analysis, for example: *Webserver Stress Tool* (HTTP client-server tool); *Iris* (measurement and control of network traffic); *Distinct Network Monitor* (packets catching and analysis of the network protocols); *Microsoft Performance Monitor* (standard instrument of the Windows NT system); *Microsoft Network Monitor* (typical network analyzer in the basic version of Windows NT); *LANAlyzer* (instrument of Novell for long time observation of the network traffic), etc.

4.2. Program application for statistical analysis

Two independent program applications are designed for interpretation of monitored data and to determine basic statistical assessments.

✓ *NetMonitor* is an application for data interpretation of real network traffic registered by using the standard monitoring program Distinct Network Monitor. The application is developed by using Visual C++ 6.0 and MFC library of classes. It gives information about packet length, time, source and destination of the packets, protocol type, etc. and presents graphical visualization of the main statistical assessments (Figure 5).

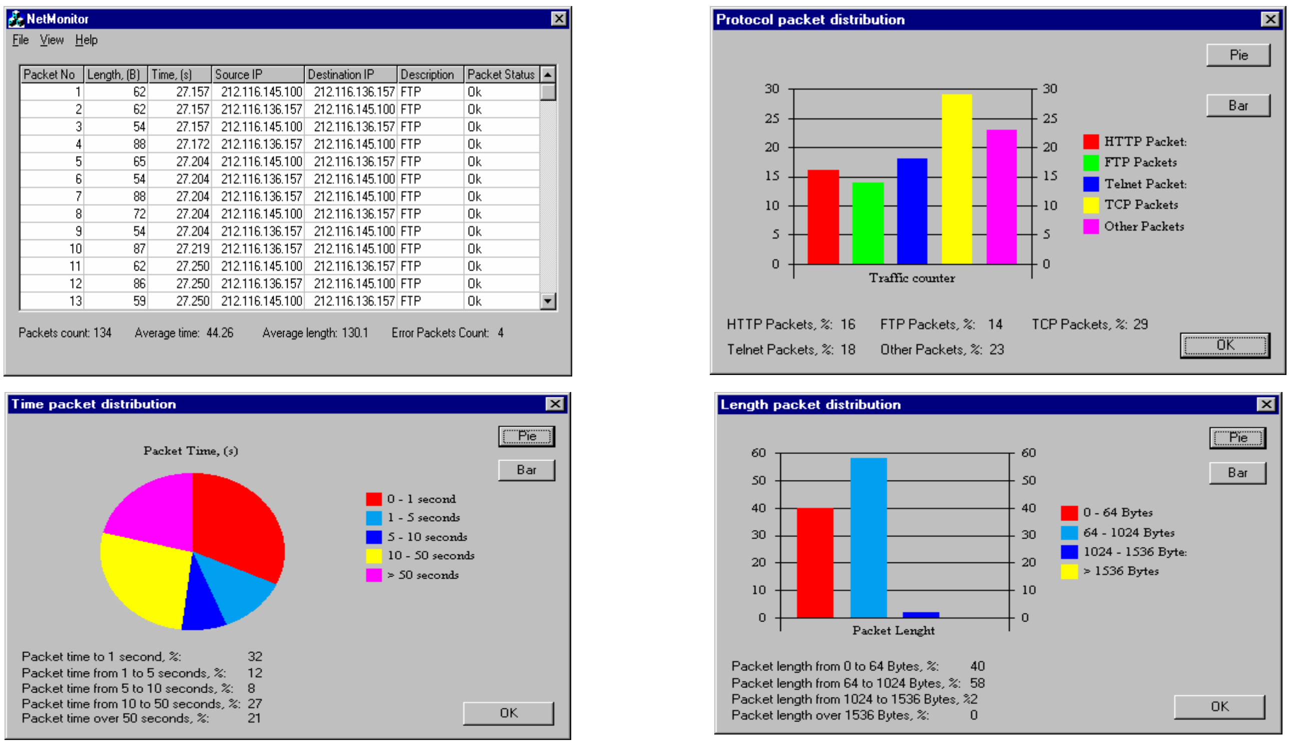


Figure 5. Interpretation of monitored data by NetMonitor

✓ *Network Analyzer* is an application realized by using of C# in the Microsoft Visual Studio.NET environment. It analyses empirical data from monitoring and calculates basic statistical assessments (average value, correlation, variation, regression). The application permits to determine the functional dependency between two parameters (variables) as a regression line based on the registered empirical data $\left\{x_i^{(q)}\right\}$ for $q=1, \ldots, N$ (Figure 6).

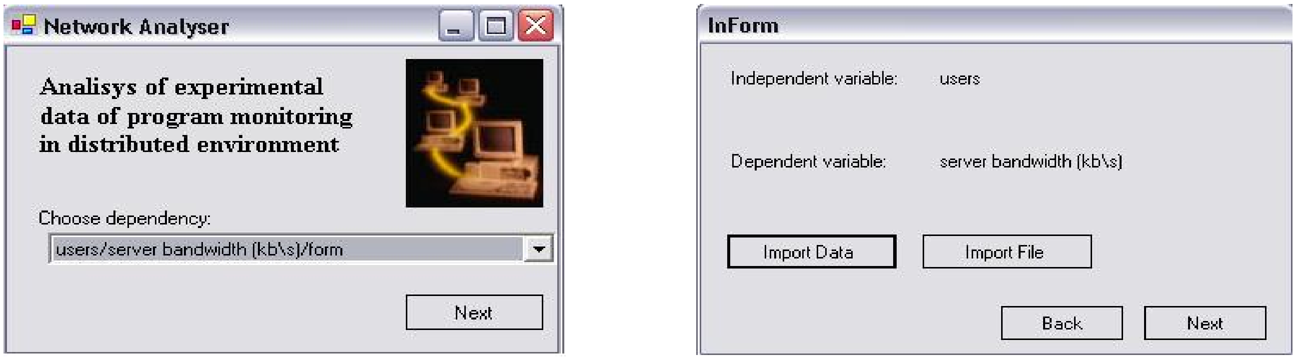


Figure 6. Initial forms of the Network Analyzer

4.3. Preliminary statistical analysis

Some of the basic statistical parameters are presented below:

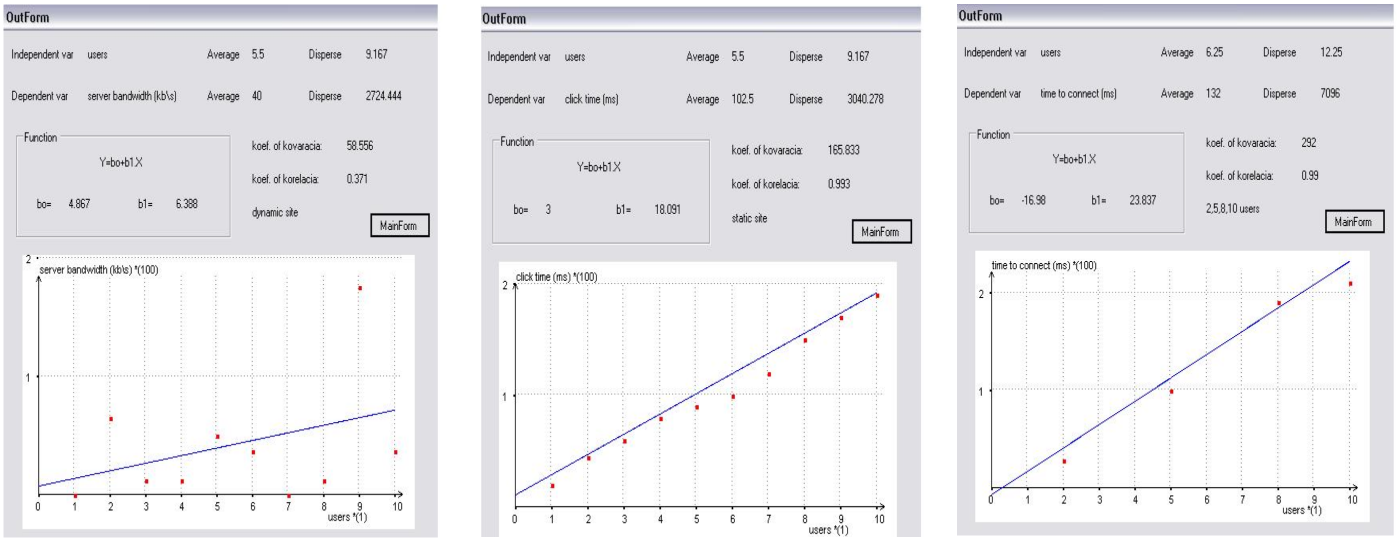
* number of active users (*users*);
* bandwidth for server (*server bandwidth*) and user access (*user bandwidth*);
* average value of the time for information object selection (*average click time*);
* waiting time for the selection activation (*click time*);
* time for URL interpretation by using DNS server of the client machine (*time for DNS*);
* time to connect with the server of the selected object (*time to connect*);
* average time for request servicing (*average request time*);
* time for the first byte receiving of the response from the server (*time to first byte – TFB*);
* average packet length;

The statistical analysis that is carried out using Network Analyzer is based on the formulas presented in table 1.

Table 1. Basic statistical assessments

Parameter	*Analytical formula*
Expectation for x_i (average value)	$EX = \frac{1}{N}\sum_{q=1}^{N} x_i^{(q)} = x_{i\_av} = \overline{x}_i$
Variance for x_i	$DX = \frac{1}{N}\sum_{q=1}^{N}\left[x_i^{(q)} - \overline{x}_i\right]^2 = \sigma_i^2$
Mean square deviation	$\sigma = +\sqrt{DX}$
Coefficient of variance	$C_V = \frac{\sigma}{x_{av}}$
Covariation between x_i and x_j	$\sigma_{ij} = \frac{1}{N}\sum_{q=1}^{N}\left[x_i^{(q)} - \overline{x}_i\right]\left[x_j^{(q)} - \overline{x}_j\right]$
Coefficient of correlation	$r_{ij} = \frac{\sigma_{ij}}{\sigma_i.\sigma_j}$
Model of simple line regression (b_0 – displacement; b_1 – coefficient of regression)	$x_j = b_0 + b_1.x_i;\; b_1 = \frac{\sigma_{ij}}{\sigma_i^2};\, b_0 = \overline{x}_j - b_1.\overline{x}_i$

The experiments simulate access to www-object and they are carried out for values of the number of active users from 1 to 10. This permits to analyze the users' number influence on the other statistical parameters. Some of the statistical assessments for the functional dependency between parameters, calculated by using Network Analyzer, are presented in Figure 7.



server bandwidth = f(users) *click time = f(users)* *time to connect = f(users)*

Figure 7. Assessment obtained by regression analysis

Statistical analysis of the measured data that was carried out using Network Analyzer permits us to determine basic stochastic parameters for investigation of the designed Markov's model. The intensity of the input flow of requests (λ) could be determined on the base of the calculated average values for the monitored parameters *average click time* (4,83 s), *click time* (4,88 s), *time to DNS* (0,118 s) and *time to connect* (0,118 s). These values permit to determine $\lambda = 0{,}1\ s^{-1}$. In the same way, the intensity of the flow of servicing in the node of the requested resource (μ) could be connected to the parameter *average request time* (4,83 s) which determines value $\mu \approx 0{,}2\ s^{-1}$. These values for the intensities define $\rho = \lambda/\mu = 0{,}5\ s^{-1}$. All assessments are summarized in table 2.

Table 2. Assessments obtained during the preliminary statistical analysis [s]

users	*average click time*	*click time*	*time to DNS*	*time to connect*	*average request time*
2	1	0,57	0,024	0,028	1.0
3	3.5	3,6	0,076	0,047	3.5
5	4.0	4	0,090	0,100	4.0
6	3.5	3,8	0,120	0,132	3.5
8	6.0	6,3	0,190	0,190	6.0
10	11.0	11	0,210	0,210	11.0
Average:	4,83 s	4,88 s	0,118 s	0,118 s	T_S = 4.83 s
	Total time T_R = 9,95 s ⇨ $\lambda = 0{,}1\ s^{-1}$				$\mu = 0{,}207\ s^{-1}$

5. Evaluation of the stochastic parameters of the information servicing in DLE

5.1. Analysis of the influence of the number of active users (ρ = const; N = var)

The investigation is carried out for constant value $\rho = 0{,}5$ and different number of the active users from 1 to 10. The goal is to evaluate the influence of the parameter N on the stochastic assessments of the final probabilities for steady-state regime. The calculations are realized on the base of the main formula $p_i = \rho^i . p_0$ (for i = 1, 2,…, N) – see (2). Examples for some of the calculations are presented below and all obtained assessments are summarized in table 3.

$N = 1$: $p_1 = \rho . p_0$ ⇨ $p_0(1 + \rho) = 1$ ⇨ $p_0 = 1/(1+\rho) = 0{,}67$ ⇨ $p_1 = 0{,}33$.

$N = 2$: $p_1 = \rho . p_0$ and $p_2 = \rho^2 . p_0$ ⇨ $p_0(1 + \rho + \rho^2) = 1$ ⇨ $p_0 = 1/(1{,}75) = 0{,}57$ ⇨ $p_1 = 0{,}29$ and $p_2 = 0{,}14$.

$N = 3$: $p_0(1 + \rho + \rho^2 + \rho^3) = 1$ ⇨ $p_0 = 1/(1{,}875) = 0{,}53$ ⇨ $p_1 = 0{,}27$, $p_2 = 0{,}13$ and $p_2 = 0{,}07$.

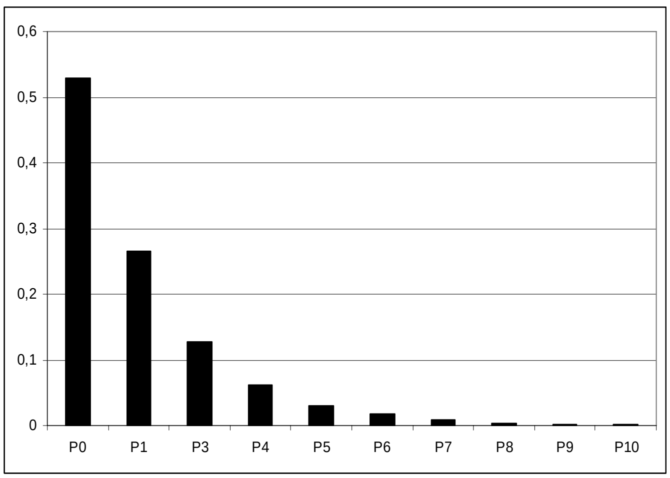
. . .

$N = 10$: $p_0(1 + \rho + \rho^2 + \rho^3 + \ldots + \rho^{10}) = 1$ ⇨ $p_0 = 1/(1{,}999225) = 0{,}50$ ⇨ $p_1 = 0{,}25$, $p_2 = 0{,}125$, etc.

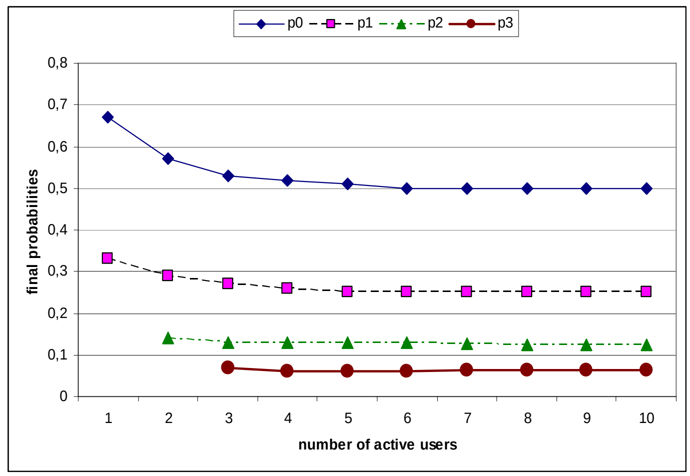
Table 3. Evaluation of the final probabilities for steady-state regime

N	p_0	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}
1	0,67	0,33									
2	0,57	0,29	0,14								
3	0,53	0,27	0,13	0,07							
4	0,52	0,26	0,13	0,06	0,03						
5	0,51	0,25	0,13	0,06	0,03	0,02					
6	0,50	0,25	0,13	0,06	0,03	0,02	0,01				
7	0,50	0,25	0,126	0,063	0,031	0,016	0,008	0,004			
8	0,50	0,25	0,125	0,0626	0,031	0,0157	0,0078	0,0039	0,00196		
9	0,50	0,25	0,125	0,0626	0,031	0,0157	0,0078	0,0039	0,00195	0,00098	
10	0,50	0,25	0,125	0,0625	0,031	0,0156	0,0078	0,0039	0,00195	0,00098	0,00049
average	0,53	0,265	0,128	0,0626	0,03	0,0172	0,0083	0,0039	0,00195	0,00098	0,00049

The average values of the determined final probabilities for steady-state regime and graphical interpretation of the functions $p_i(N)$ for i = 1,2,3,4 are shown in Figure 8. The results show that for N<4 the number of active users has a little influence on the final probabilities and for N≥5 the probability for multi-user access to the informational resources is practically equal to zero.



Average values of the final probabilities



functions $p_i(N)$ for i = 1,2,3,4

Figure 8. Interpretation of the obtained assessments

5.2. Analysis of the user's access to the resources (λ = var; N =const; μ = const)

The experiments are carried out for different values of the intensity λ (average time between two requests from 5,55 s to 100 s) and the intensity of servicing μ is fixed as average value 0,2 s^{-1}. All assessments obtained by the analytical analysis are summarized in table 4 and some of them are graphically interpreted in Figure 9.

Table 4. Assessments from the analytical evaluation for λ = *var*

λ	μ	ρ	p_0	p_1	p_2	p_3	$E[N]$	$V[N]$	$E[W]$	$E[Tw]$
0,18	0,2	0,9	0,29	0,26	0,24	0,21	9	90	8,1	45
0,16		0,8	0,34	0,27	0,22	0,17	4	20	3,2	20
0,14		0,7	0,39	0,28	0,19	0,14	2,33	5,76	1,67	11,67
0,12		0,6	0,46	0,27	0,17	0,10	1,5	3,75	0,9	2,5
0,1		0,5	0,53	0,27	0,13	0,07	1	2	0,5	5
0,08		0,4	0,61	0,25	0,10	0,04	0,67	1,12	0,27	3,33
0,06		0,3	0,71	0,21	0,06	0,02	0,43	0,61	0,13	2,14
0,04		0,2	0,8	0,16	0,03	0,01	0,25	0,31	0,05	1,25
0,01		0,1	0,9	0,09	0,009	0,0009	0,11	0,12	0,01	0,56

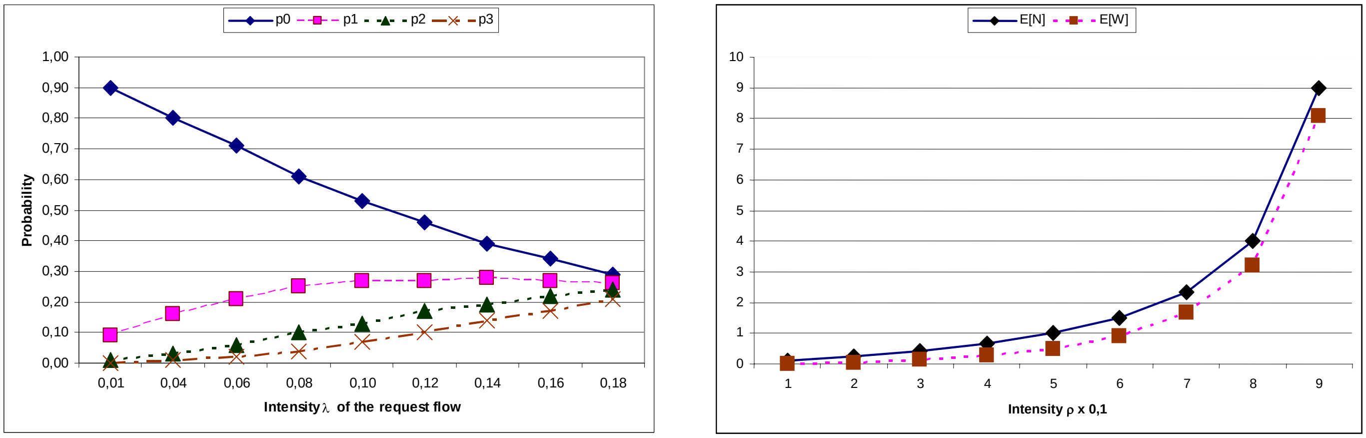


Figure 9. Graphical interpretation of the final probabilities and expectations for users

5.3. Analysis of the influence of the learning contents size (μ = var; N =const; λ = const)

The experiments are carried out for different values of the intensity of servicing μ (the average time of request's servicing depends on the size of the learning content in the separate nodes of DLE and range from 2 s to 8 s) and the intensity of input flow of requests λ is fixed as average value 0,1 s^{-1}. The main assessments obtained by the analytical analysis are summarized in table 5 and some of them are graphically interpreted in Figure 10.

Table 5. Assessments from the analytical evaluation for μ = *var*

λ	μ	ρ	p_0	p_1	p_2	p_3	$E[N]$	$V[N]$	$E[W]$	$E[Tw]$
0,1	0,125	0,8	0,34	0,27	0,22	0,17	4	20	3,2	32
	0,15	0,67	0,41	0,28	0,19	0,12	2	6	1,36	13,54
	0,175	0,57	0,48	0,27	0,16	0,09	1,32	4,08	0,76	7,57
	0,2	0,5	0,53	0,27	0,13	0,07	1	2	0,5	5
	0,25	0,4	0,61	0,25	0,10	0,04	0,67	1,12	0,27	2,67
	0,30	0,33	0,68	0,22	0,07	0,03	0,49	0,73	0,16	1,64
	0,35	0,286	0,72	0,20	0,06	0,02	0,4	0,56	0,12	1,14
	0,40	0,25	0,75	0,19	0,05	0,01	0,33	0,44	0,08	0,67
	0,5	0,2	0,8	0,16	0,03	0,01	0,25	0,31	0,05	0,5

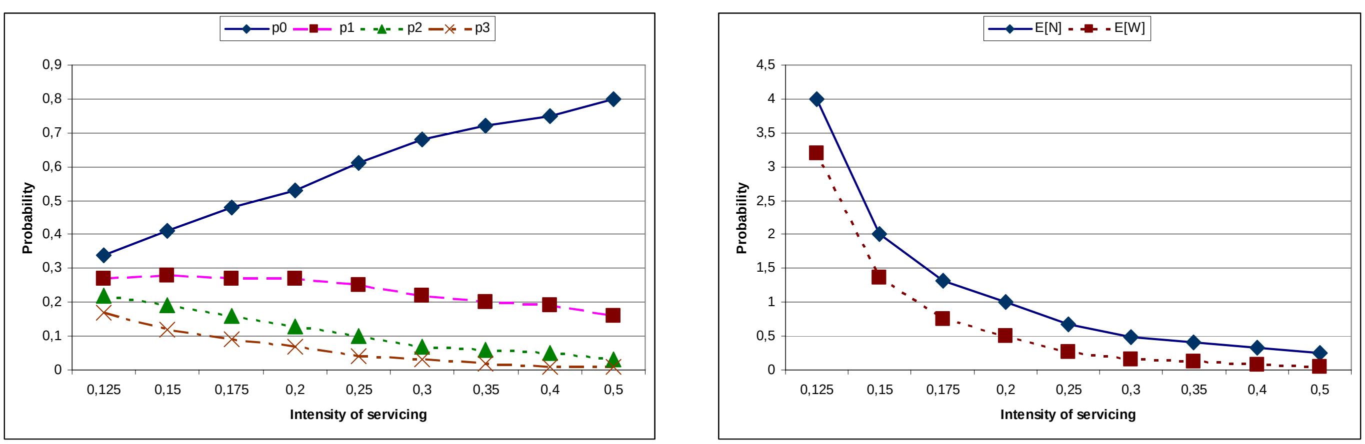


Figure 10. Graphical interpretation of the final probabilities and expectations $E[N]$ and $E[W]$

6. Conclusions

The following conclusions could be made from the study conducted:

1. The processes in the DLE have a stochastic nature that determines the usefulness of a stochastic apparatus like the Markov's chain. In this case the theory of Markov's stochastic processes is combined with the principles of queuing theory for servicing of an input flow of requests. This combination permits to use the model from Figure 3 defined by (1) and (2).

2. The evaluation in this paper is different from the investigations presented in (Romansky and Parvanova, 2009b), and permits to compare the main results of servicing and to define the specific parameters for DLE organization in a real medium. To define the frame of the current investigation a preliminary model solution is made and program monitoring is realized.
3. The statistical analysis of the monitored data in part 4.3 permits to determine the functional dependency of the main parameters by the number of active users and to define the tendencies for regression and variation needed for the next stochastic evaluation.
4. The stochastic evaluation shows that the number of active users has a little influence on the variation of the other parameters of the education servicing in DLE. This fact permits to use a fixed value for N during the evaluation of the influence of input requests and servicing intensities.
5. The assessments in parts 5.2 and 5.3 permit to determine the range of variation for some important stochastic parameters like the situation of servicing in steady-state regime, expectation of active users $E[N]$, expectation of waiting users $E[W]$, etc. These analytical assessments define the optimal frame of servicing in DLE determined by ranges $\lambda = 0{,}1s^{-1} \pm 0{,}02s^{-1}$ and $\mu = 0{,}2s^{-1} \pm 0{,}05s^{-1}$.

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Received: August 2009
Accepted: September 2009
Final acceptance in revised form: September 2009