EXPERIMENTAL INVESTIGATION OF TIME DELAYS DATA TRANSMISSION IN AUTOMATIC CONTROL SYSTEMS

UDC 621.314.58

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INTRODUCTION

The performance requirements of many applications, such as real-time control, signal processing, far exceed the capabilities of single-processor architectures. Parallel machines break a single problem down into parallel tasks that are performed concurrently, reducing significantly the application processing time.

Any parallel system that employs more than one processor per application program must be designed to allow its processors to communicate efficiently; otherwise, the advantages of parallel processing may be negated by inefficient communication. This fact emphasizes the importance of interconnection networks to overall parallel system performance. In many proposed or existing parallel processing architectures, an interconnection network is used to realize transportation of data between processors [1].

Microintegrated systems are used in modern electric power installations. Operating efficiency of automatic control systems in case of considerable moving away of a control object is related in certain degree to the time delay of signaling, caused by the nodes of this system [5]. The presence of delay has a negative influence on system availability in whole. It is not always possible to remove delays only with a help of technology. Therefore it becomes necessary theoretically to estimate and prognose delays, and also determine the influence of delays on the system stability. In this work [2] it was researched the influence of Ethernet network dynamics' on quality of controlling the simulated autonomous electric power installation, however there was not got any time delays statistical characteristics of information and control packets transmission.

A time delay of packets transmission may be considered as continuous random quantity, which describes with some law. If this law is found, it is possible theoretically to determine the delay.

Purpose. The purpose of this work is solving the problem of theoretical prognosis of time delays of information packets transmission through the Internet network on basis of statistical analysis of experimental data.

THE MAIN MATERIAL

Assigned task was solved in few stages.

1. There were made trial tests for the purpose of determination of minimum sample size, which was used for evaluation of the average time delays with prescribed accuracy. The essence of a test includes the following. From computer which situated in city Nikolayev sends request to computer, which situated in city Odessa. Special program "Ping" let us to determine the time delay, which was measured in milliseconds.

2. The results of the tests in the form of 50 values are in the table 1.

3. There was made a test with minimum sample size, which was determined in item 1.

4. There was made a statistical analysis of information packets transmission delays, presented in the form of varia-

tional series and identified the main characteristics of these series and a histogram of the relative frequencies.

Table 1.

The results of time delays' measuring

№	τ	№	τ	№	τ	№	τ	№	τ
1	23,349	11	23,262	21	23,081	31	27,323	41	23,156
2	23,143	12	23,293	22	23,413	32	23,92	42	23,334
3	23,333	13	23,645	23	23,442	33	22,684	43	23,205
4	23,325	14	23,338	24	25,072	34	23,439	44	23,654
5	24,312	15	25,436	25	23,28	35	23,303	45	23,368
6	23,571	16	23,951	26	23,365	36	23,59	46	23,72
7	23,17	17	22,451	27	23,397	37	23,514	47	23,242
8	22,31	18	23,776	28	22,82	38	23,403	48	23,537
9	23,572	19	24,104	29	23,041	39	22,409	49	27,452
10	25,575	20	23,869	30	23,411	40	27,942	50	23,234

5. In consideration of the form of histogram and by using least-squares method, there was selected the theoretical dependence, which defines probability density of time delay.

6. Theoretical determination of the time delays was performed by using a Monte Carlo. For evaluation of the delay's average value there was made a construction of confidence interval according to the experimental results. Theoretical value of average delay was obtained with a certain confidence interval.

For determination of minimum sample size there were made trial tests (5 series, 50 tests in each series). Testing accuracy *δ* is 0,1 ms. Confidence level γ=0,95. Calculation of minimum sample size is made by using this expression:

$$n_{\min} = \frac{t_\gamma^2 S^2}{\delta^2},$$

where t_γ – reference parameter [2], t_γ (γ=0,95, *n*=50) = 2,006, S^2 – sample variance. As a result n_{min}=500.

There were made 6 series with size 500 samples in each. These tests are generalized in the form of average variation series.

In the table there are used next conventional signs: n_i – sampling frequency, *n* – sample size, *h* – the interval.

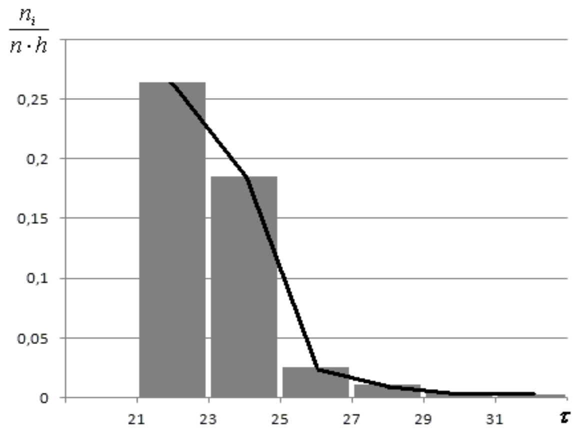
There were evaluated the main numerical characteristics: mode M_0=22; median *M*=27; average $\bar{\tau} = 27$; variance S^2=16,824; statistical deviation *S*=4,102; variation coefficient *V*=62,3%.

Table 2.

Results of the tests in the form of average variation series

i	$\tau_i - \tau_{i+1}$	n_i	$\frac{n_i}{n \cdot h}$
1	21 ÷ 23	264	0,264
2	23 ÷ 25	185	0,185
3	25 ÷ 27	25	0,025
4	27 ÷ 29	11	0,011
5	29 ÷ 31	4	0,004
6	31 ÷ 33	3	0,003

By results of the experiment there was constructed the histogram of relative frequencies (pic. 1), on which a polyline is empirical probability density.



Pic.1 Histogram of relative frequencies

By basing on the shape of observed distribution curve (pic. 1), can be evaluated theoretical probability density by using this expression:

$$f(\tau) = ae^{b\tau}. \qquad (1)$$

Coefficients *a* and *b* in the expression (1) can be evaluated with a help of least-squares method. Meanwhile must be found the logarithm of the expression (1). As a result it comes out a system of linear algebraic equations:

$$\begin{cases} nA + B\sum_{i=1}^{n} \tau_i = \sum_{i=1}^{n} \lg f(\tau_i) \\ A\sum_{i=1}^{n} \tau_i + B\sum_{i=1}^{n} \tau_i^{\,2} = \sum_{i=1}^{n} \tau_i \lg f(\tau_i) \end{cases}, \qquad (2)$$

where

$$A = lg\ a\ ,\ B = b\ lg\ e\ .$$

The system of equations takes the following form after substitution of numerical value:

$$\begin{cases} 6A + 162B = -9{,}793 \\ 162A + 4444B = -279{,}488 \end{cases} \quad (3)$$

The solutions of the system of equations (3) is: A=4,183, B=-0,215. Then $a = 10^{4{,}183} = 15240$, b=-0,495. Thereby the required probability density of a delay can be written as:

$$f(\tau) = 15240 \cdot e^{-0{,}495\tau} \quad (4)$$

Delays, which were obtained by using the expression (4) changing the variable τ_i by 22 to 32 step 2, have next values: 0,284; 0,106; 0,039; 0,015; 0,005; 0,002.

Comparing them with the experimental delays, we can note that they coincide.

Theoretical determination of delays by using the Monte Carlo method is considered in [4]. Possible values of continuous random quantity are determined after solution the following equation by using the Monte Carlo method:

$$\int_k^{\tau_i} f(\tau) d\tau = r_i \quad (5)$$

where k – the least of the recorded delays, r_i – random numbers.

Based on the dependence (1) and after its integration, the expression (5) is rearranged in the form:

$$\tau_i = \frac{1}{b} \ln\left(\frac{b}{a} r_i + e^{bk}\right) \quad (6)$$

Given a=15240, b=-0,495, k=21, expression (6) takes following the form:

$$\tau_i = -2{,}02 \ln(-3{,}25 \cdot 10^{-5} r_i + e^{-10{,}395}) \quad (7)$$

1. According to the direct experiment (5 series, 500 tests in each series) there was calculated the average delay in each series and the average delay of all 5 series. Group average delays are in the table 3.

Table 3.

Average delay in the each test series

№	1	2	3	4	5
$\bar{\tau}$	23,845	24,332	23,63	23,666	23,99

The results are following: average delay $\bar{\tau}_B = 23{,}89$, variance S^2=16,824, statistical deviation S_B=0,29.

2. There was constructed confidence interval (99%) for evaluation of the average delay.

3. There were calculated the theoretical delays in 5 series, 5 meanings in each series by using the expression (7). Results of the calculation are in table 4.

Table 4.

Theoretical meanings of delays

№	1		2		3		4		5	
	r_i	τ_i	r_i	τ_i	r_i	τ_i	r_i	τ_i	r_i	τ_i
1	0,1	21,227	0,34	21,905	0,61	23,108	0,85	25,706	0,26	21,653
2	0,09	21,203	0,07	21,156	0,19	21,455	0,15	21,351	0,89	26,865
3	0,73	24,016	0,27	21,683	0,69	23,666	0,74	24,113	0,8	24,827
4	0,25	21,623	0,68	23,587	0,04	21,088	0,79	24,689	0,93	29,874
5	0,33	21,872	0,5	22,53	0,46	22,354	0,54	22,721	0,54	22,721
Average		22,579		22,737		22,83		24,161		23,772
Variance		2,438		0,931		1,346		2,827		8,022
Statistical deviation		1,561		0,965		1,16		1,681		2,832

4. There were calculated group average delays and average delays among groups: $\bar{\tau}_{theor} = 23{,}216$.

Theoretically found the average delay $\bar{\tau}_{theor}$ was compared with a confidence interval of the experimental average delay.

Confidence interval for average delay's estimation is following [3]:

$$\bar{\tau}_B - \frac{t_\gamma \bar{S}_B}{\sqrt{n}} < \bar{\tau}_\Gamma < \bar{\tau}_B + \frac{t_\gamma \bar{S}_B}{\sqrt{n}},$$

where

$$\bar{S}_B = \frac{n}{n-1} S_B, \gamma=0{,}99, n=5, t_\gamma=4{,}6.$$

Thereby, confidence interval is determined by the following expression:

$$23{,}149 < \bar{\tau}_{con} < 24{,}631 \qquad (8)$$

Conclusions. A very important characteristics of the network is that it can transmit a set of data at the same time. Theoretical received average value is not outside of the confidence interval. It is indicated that the resulting scheme of delay's theoretical definition is consistent with experimental data. In order to compensate for the network transmission delay, a network delay compensator in the channel from the controller to the actuator shall be used.

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