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SOFTWARE PACKAGE FOR DETERMINING CHARACTERISTICS OF TASK MANAGERS OF RECONFIGURABLE COMPUTER SYSTEMS USING PRIORITY QUEUEING NETWORKS

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Abstract

The paper presents mathematical models of task managers with a time-sharing strategy and a space-sharing strategy for reconfigurable (including multiprocessor and distributed) systems. The mathematical models under study are based on open queueing networks, with unmatched FIFO disciplines, absolute, relative and mixed priorities. The description of the developed software package for calculating the characteristics of these classes of task managers as part of reconfigurable computer systems according to given parameters is presented. The complex is characterized by a convenient visual user interface, which simplifies the procedure for setting the parameters of the modelling object and obtaining a larger number of experimental data per unit time. The proposed set of programs allows the characteristics of the entire queueing network, as well as individual systems to calculate. A significant difference between the developed software package and existing analogues is the ability to calculate stochastic queueing networks containing systems with a limited queue length in front of the service device and priority queueing systems, as well as calculating the network using several simultaneously varying initial parameters. The software package allows the parameters of the systems M / M / n / m and M / G / 1 to calculate.

Keywords

Task manager – Reconfigurable computation system – Software – Software package

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Introduction

Computer modelling has found its practical application in all spheres of human economic activity. A review of mathematical modelling systems shows that analytical modelling (AM) is perhaps the most popular modelling tool. Its main value lies in the application of the system analysis concept operations analysis. Analytical modelling allows performing the study of an analysed or designed system according to the operational research scheme which contains several interrelated steps:

1) A problem description;
2) A conceptual model development;
3) Development and software implementation of the simulation model;
4) Validation,
5) Verification of the reliability and adequacy of the mathematical model and assessment of the accuracy of the simulation results;
6) Planning and conducting experiments;
7) Decision making[1].

All of the above allows the use of analytical modelling as a universal approach for decision making under conditions of uncertainty, taking into account difficult formalized factors in mathematical models, as well as applying the basic principles of a systematic approach to solving practical problems. The widespread implementation of this method in practice is facilitated by its versatility which consists in quickly reconfiguring models when changing the initial data of mathematical modelling, which reduces the time of the system design stage. On the other hand, the complexity of analytical dependencies impedes the use of the method, which necessitates the creation of software for their calculation. The efforts of software developers are aimed at simplifying software implementations of models: for these purposes, methods of approximate calculations have been created. The main purpose of all these tools is to reduce the complexity of creating and calculating analytical modelling, as well as experimenting with mathematical models. Purpose of the work is the creation of a software package for visual modelling the queueing networks and collecting statistics on the elements of the mathematical model and the entire stochastic network as a whole. The object of development is mathematical models of the kernels of operating systems (OS) that implement various functions of process and flow control in reconfigurable (multiprocessor and distributed) systems, in particular, functions for task dispatching and scheduling.

Problem description

There are a large number of dispatching and scheduling disciplines which consist of the rules of queueing ready tasks and the rules for selecting tasks to perform. In particular, these include FIFO, LIFO disciplines, priority disciplines with absolute, relative and mixed priorities, as well as some mixture of these disciplines, providing an expanded area of use of the operating system, for example, for both general-purpose and real-time systems[2]. When dispatching and scheduling processes (flows), one should also take into

[1] T. I. Aliev, Fundamentals of modelling discrete systems (St. Petersburg: St. Petersburg State University. ITMO, 2009).
[2] A. I. Martyshkin and O. N. Yasarevskaya, “Queries Service Time Research and Estimation during Information Exchange in Multiprocessor Systems with "Uni Bus" Interface and Shared Memory”, National Academy of Managerial Staff of Culture and Arts Herald Issue 3 (2018): 790-797.

account the limited resources of a computation system, for example, a limited number of buffers for storing task descriptors that makeup queue elements[3].

When designing new operating systems for reconfigurable computation systems, and in particular, schedulers and task managers, it is necessary to determine the effectiveness of possible implementations. One of the main criteria for such developments is performance. To evaluate the performance indicators of task dispatchers, the authors developed analytical mathematical models of *n*-processor systems with process planning algorithms for the time-sharing (Fig. 1, a) and space separation strategies (Fig. 1, b)[4]. Models are presented as an open queueing network.

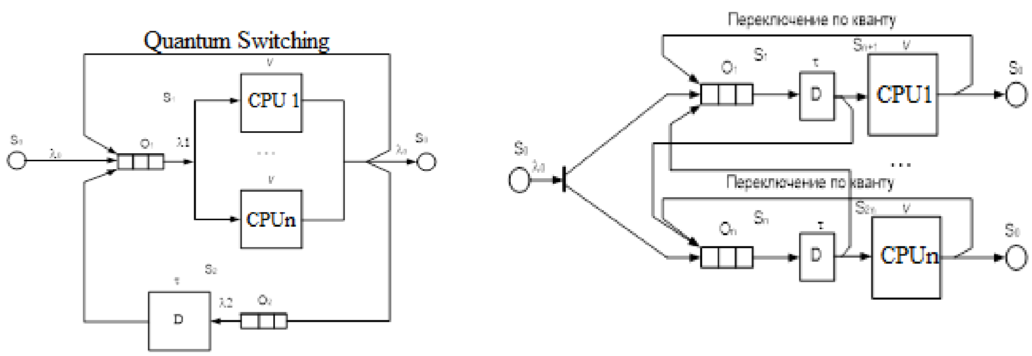
In a time-sharing mathematical model, a request (task) coming from outside (source S_0), or after switching a context can be assigned to any processor (CPU), therefore it is represented as a multi-channel queueing network (S_1) (see Fig. 1a). Free CPUs are requested by the task manager which functions are to select a task from the queue, select one of the CPUs to serve the task, and transfer control to the CPU to serve it. The choice of the task and the choice of the serving processor can be carried out either according to the priority principle, or in the FIFO order, and the queue has a limit on the number of places. Since task management is performed by one task manager, therefore, it is a common resource for all requesting processors. Therefore, the mathematical model for the processor to manager access mechanism is a single-channel queueing network (S_2). The advantage of such a task manager is that a single queue provides automatic load balancing of the CPU, in contrast to the analogue task manager[5]. It should be borne in mind that the task scheduler forms the queue; therefore, it is the scheduler that acts as the source of network requests (S_0).

The task accepted for service is in the queue until it arrives for execution in one of the CPUs. If the quantization mode is used, the unfinished task is placed at the end of the current quantum at the end of the global queue, otherwise, the result is given to the user, and one place is freed in the queue. When the current task is completed, the task manager scans the queue, and if it contains service requests and the task is assigned for service which is in the head of the list or has the highest priority. If the queue is empty, free CPUs go into standby mode. If the queue is full, then the newly received request is denied (in the real system, the scheduler does not select a task from external memory). The task manager is a program that runs on one of the CPUs, and any free CPU that requests another process (task) for service can call this program. Therefore, the sources of requests for the task manager are free processors requesting the next task for service. If the task manager is busy, then the requesting CPU is suspended; a peculiar queue O_1 is formed from such processors[6].

[3] V. M. Vishnevsky, Theoretical Foundations of Computer Network Design (Moscú: Technosphere, 2003).
[4] E. Tanenbaum and H. Bos, Modern Operating Systems. 4th ed. (SPb.: Peter, 2015).
[5] A. I. Martyshkin, Visual software package for simulation of computer systems. Modern technologies in science and education. STNO-2018: Proceedings of the international scientific and technical forum: in 11 volumes. Under the general editorship of O.V. Milovzorova. 2018 y A. I. Martyshkin, "Mathematical modelling of Tasks Managers with the strategy in space with a homogeneous and heterogeneous input flow and finite queue", ARPN Journal of Engineering and Applied Sciences Vol: 11 Issue 19 (2016): 11325-11332.
[6] A. I. Martyshkin and O. N. Yasarevskaya, "Mathematical modelling of Task Managers for Multiprocessor systems on the basis of open-loop queuing networks", ARPN Journal of Engineering and Applied Sciences Vol: 10 Issue 16 (2015): 6744-6749.

The mathematical model with the separation of space consists of *n* single-channel queueing networks ($S_1, \ldots, S_n$) (see Fig. 1b). Each such queueing network simulates service in a processor node, which includes a CPU and a task manager. The source S_0 models the flows of requests λ_0 (user processes generated by the scheduler), and absorbs the served orders (issuing the result to the user). The newly received task is queued to one of the processor nodes, the length of which is limited. If there is free space in one of the queues, then the task takes it. The task accepted for service is in the local queue until it arrives at the processor for execution. If the quantization mode is used, then the unfinished task at the end of the current quantum is placed at the end of the same queue where it was previously, otherwise, the result is given to the user, and one place is freed in the local queue. When the task completes, the task manager scans the local queue. If it contains service requests, then the task at the head of the list (FIFO) or having the highest priority is assigned for execution. If the queue is empty, the CPU goes into standby mode.

In this case, the task scheduler not only forms queues in the processor nodes but also performs load balancing according to some algorithm. Therefore, requests can be extracted from the *i*- th queue and transferred with some probability to the queue of the least loaded *j*- th processor node.



a) b)

Figure 1

Diagram of the n-processor system analytical model with process scheduling algorithms for the time-sharing (a) and space separation (b) strategies

If we assume that requests form the simplest flows of requests, and service times follow exponential law, then the models of processor nodes and the task manager are represented by Markov queueing networks of the type M / M / 1 /, M / M / n / m, where m is the number of places in the queue finished tasks. If priority queues of tasks or the priority choice of a serving processor are used, then semi-Markov queueing networks of types M / G / 1, M / G / 1 / m, M / G / n / m, in which the duration of service of requests is distributed following an arbitrary law, should be used as models[7].

[7] T. I. Aliev, Fundamentals of modelling discrete systems…; R. A. Biktashev; A. I. Martyshkin and N. G. Vostokov, “A complex of programs for determining the characteristics of task managers in multiprocessor systems using priority stochastic queueing networks”, Fundamental Research num 10-1 (2013): 13-20 y E. S. Ventzel, Introduction to the study of operations (Moscú: "YOE Media", 2012).

Let us consider in more detail the development of a mathematical model of a reconfigurable system using a time-sharing task manager. In it, queueing network 1 represents a model serviced in processor nodes; queueing network 2 is a task manager serviced model. Let the queue in queueing network 1 be organized according to the FIFO principle and have a limit on the number of places. Then the waiting time in the queue is determined by the famous Little formula: $w_1 = l_1 / \lambda_1$ where λ_1 are the requests flow intensity at the input of queueing network 1, and l_1 is the average number of tasks in the queue, the value of which can be determined by the formula[8].

$$l_1 = \sum_{i=1}^{m} i p_{n+i} = \frac{\omega_1^{n+1}(1-(\omega_1/n)^m(1+m(1-\omega_1/n))}{nn!(1-\omega_1/n)^2} p_0 \quad , \qquad (1)$$

where n is the number of serving devices (processors), m is the number of places in the queue, $\omega_1 = \lambda_1 / \mu_1$ is the reduced flow rate which is the average number of tasks entering into the queueing network *S 1* during the service time of one task, μ_1 is the intensity of servicing user tasks and is the reciprocal of the average service time for one task, p_0 is the probability of the absence of requests in the queueing network determined by the formula obtained in[9]:

$$p_0 = \left(1 + \frac{\omega_1}{1!} + \frac{\omega_1^2}{2!} + ... + \frac{\omega_1^n}{n!} + \frac{\omega_1^{n+1}(1-(\omega_1/n)^m)}{nn!(1-\omega_1/n)}\right)^{-1} \quad , \qquad (2)$$

We assume that the task manager selects the serving processor according to the priority principle. Then, the mathematical model of the task manager will be represented by a single-channel queueing network (S 2) with a priority queue. We assume that task manager service consists in switching the context of the *i*- th processor according to the average time τ_i .

CPUs are the source of requests to the task manager, which intensity is λ_2. Let the task manager use relative priorities when choosing a serving processor, and each processor has a priority number k, and the higher the number, the lower the priority. The queueing time by the task manager for the flow generated by the k priority processor w_2^k will be determined by the formula.[10]

[8] H. Takha, Introduction to Operations Research. 7th ed. (Moscú: Williams, 2005) y A. I. Martyshkin and O. N. Yasarevskaya, "Mathematical modelling of Task…

[9] L. Kleinrock, Computation systems with queues (Moscú: Publisher Mir, 1979) y M. A. Matalytsky; O. M. Tikhonenko and E. V. Koluzaeva, Queueing systems and networks: analysis and requests: Monograph (Grodno: GrSU, 2011).

[10] T. I. Aliev, Fundamentals of modelling discrete systems… y V. F. Matveev and V. G. Ushakov, Queueing systems (Moscú: Publishing House of Moscow State University, 1984).

$$w_2^k = \frac{\sum_{i=1}^{n} \omega_i \tau_i \left(1+\nu_i^2\right)}{2\left(1-R_{k-1}\right)\left(1-R_k\right)} \qquad \left(k=1,...,n\right), \qquad (3)$$

Where $R_{k-1} = \rho_1 + ... + \rho_{k-1}$ and $R_k = \rho_1 + ... + \rho_k$ are downloads created by request flows from free processors CPU_1,…, CPU $_{k-1}$ and CPU_1,…, CPU $_k$ respectively, $\nu_i = \sigma_i / \tau_i$ - coefficient of variation of service time, which determines the ratio of standard deviation σ_i of service duration to its expectation τ_i .

Intensities λ_1 and λ_2 will depend on the incoming intensity of the source *S $_0$* tasks and the probabilities of transitions from S $_1$ to S $_2$ (P $_{12}$) and from S $_1$ to S $_0$ (P $_{10}$). Since denial of service occurs in queueing network S $_2$, the flow rates λ_1 and λ_2 will decrease:

$$\begin{cases} \lambda_1 = \lambda_0 / P_{10} \, (1-P_{отк}); \\ \lambda_2 = \lambda_0 P_{12} / P_{10} \, (1-P_{отк}). \end{cases} \qquad (4)$$

A denial of service occurs when all *m* seats are occupied:

$$P_{отк} = \frac{\omega_1^{n+m}}{n^m \cdot n!} \cdot p_0 \qquad (5)$$

Requests are moved over the network and may repeatedly visit the same queueing network, so the transition coefficient is introduced[11] showing how many times the task will pass through the *i*- th queueing network, $\alpha_i = \frac{\lambda_i}{\lambda_0}$ where λ_i is the intensity at the entry of *i*-th queueing network, λ_0 is the intensity of the source of the incoming request flow.

As each task can get service in the *i*-th queueing network on average α_i times, then, respectively, the waiting time for the service and its residence time in the system will increase in α_i times. Average task wait time in network queues is:

$$W = \alpha_1 w_1 + \alpha_2 w_2 . \qquad (6)$$

[11] T. I. Aliev, Fundamentals of modelling discrete systems… y E. S. Ventzel, Introduction to the study of operations…

Implementation of the software package

To calculate the probabilistic and temporal characteristics of the presented mathematical models, the task was set to develop a specialized software package for visual analytical modelling of task managers of reconfigurable computer systems based on queueing networks. To implement the mathematical modelling algorithm, the Borland Delphi 7 programming environment was used[12].

In the software package mentioned above, it is possible to set the probabilities of transferring requests on the network, the queueing network parameters can vary and be edited, and a report on the results of the study is created., single-channel and multi-channel queueing networks with unlimited queue and queue restriction, without priorities, with relative priorities, with absolute priorities and with mixed priorities are used as models of stochastic queueing network, the coefficient of variation for the M / G / 1 models is taken into account[13].

The network configuration is specified by the transition probability matrix or visually in the form of a transition graph[14].

Tasks that are solved using the software package:

B. input, viewing and editing of source data;
C. calculation of stochastic queueing network characteristics;
D. variation of some queueing network parameters and calculation of the queueing network characteristics taking into account the variable parameters (each parameter separately);
E. the output of the calculation results to the screen, to the text file of the report or in the form of a graph.

Separate software modules have been developed to implement the specified tasks.

For calculations, the following parameters are entered in the program:

- Queueing network name.
- Service time.
- Queue length limit.
- System relative priority.
- The number of priority classes.
- The input flow share.
- The number of channels in each queueing network.
- The performance of each queueing network channel.
- Transition Probability Matrix.
- The intensity of the input flow.

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12 A. Ya. Arkhangelsky, Programming in Delphi 7. Binom Publishing House. 2003.

13 A. I. Martyshkin, "Study of Distributed Task Manager Mathematical Models for Multiprocessor Systems Based On Open Networks of Mass Servicing", Ad Alta-Journal Of Interdisciplinary Research. Vol: 8 Issue 1 Special Issue 3 (2018): 309-314.

14 T. I. Aliev, Fundamentals of modelling discrete systems… y L. Kleinrock, Computation systems with queues…

Variable parameters have the following meanings:

- Service time in queueing network.
- The intensity of the input flow.
- The number of channels in the queueing network.
- The number of places in the queueing network.
- The initial value of the variable parameter.
- The number of sweep cycles.

The calculated characteristic is:

a) characteristics of the individual queueing network:

- Network transfer ratio.
- The intensity of the input flow.
- Load factor.
- The average number of busy channels.
- The average number of requests in the queueing network.
- The average queue length.
- The average waiting time for a request in the queue.
- The average time the request has been in the queue.

b) the characteristics of the entire network as a whole:

- the average number of requests in the network;
- average time spent by one request in the network;
- average waiting time for one request in the network;
- the total length of the queues.

Figure 2 shows the sequence of actions performed by the software package.

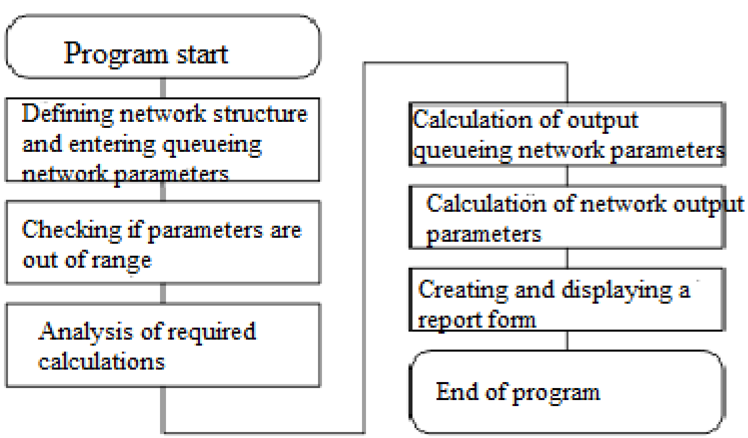

Figure 2
The sequence of actions performed by software package

After loading the program for execution, a window for entering the network structure opens. Subsequently, changes to the configuration of the network model occur, the network parameters are entered and the individual queueing network operator and the variable network parameters are entered (if necessary). When starting the calculation, the entered parameters are checked for validity; if all the parameters are valid, the calculation of statistics for the given parameters is started.

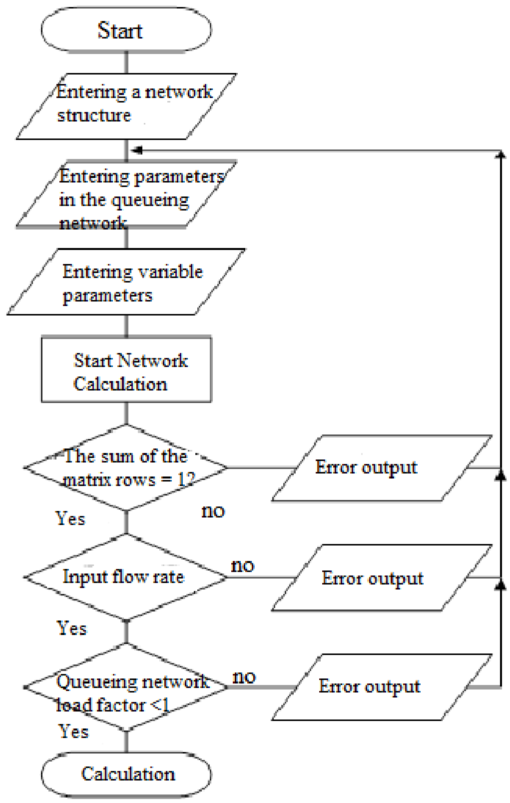

Figure 3
Diagram of the algorithm for entering the initial network parameters and checking them

The main one is the block in which the network model and individual queueing network are calculated. The calculations are based on the theoretical and mathematical apparatus of the theory of computer systems. In the general case, the statistical characteristics of a network are the sum of the characteristics of the queueing network included in it, and those, in turn, are the sum the characteristics calculated for each channel and the priority within the data of the queueing network.

We present below the main windows of the software package (see Fig.4):

– the visual editor window (Fig. 4, a) where the user can use the graphical elements provided to create and edit the stochastic network diagram;

– the transition probability matrix editor window (Fig. 4, b) allows the probabilities of transitions from one queueing network to another to edit, as well as to edit the intensity of the input requests flow;

– the queueing network parameters window (Fig. 4, c) allows the main characteristics of each queueing network to edit (take into account priority, number of places in the queue, number of channels, service time);

– the network calculation parameters window (Fig. 4d) allows a calculation with variable parameters to select and to declare these parameters.

– the results window (Fig. 4, e) is a table of the report on statistical calculations carried out for this network.

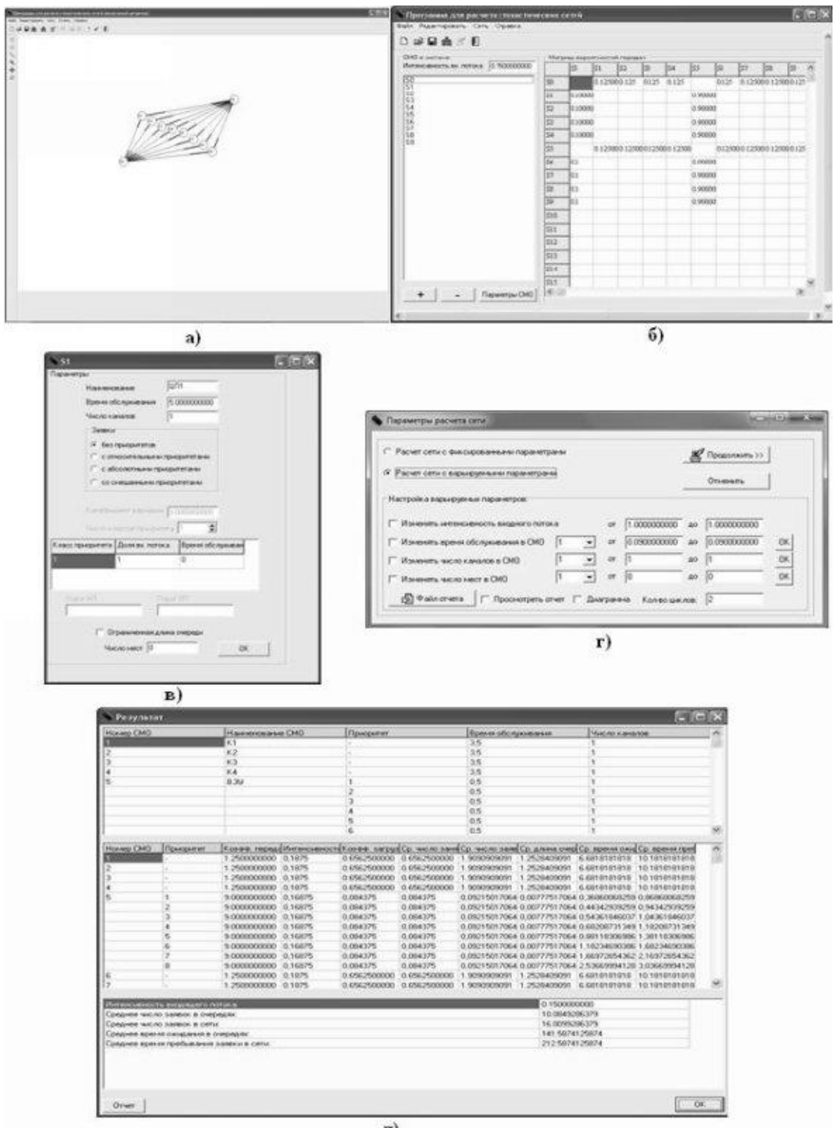

Figure 4
The software package main windows

When designing the software package, the modular principle of writing programs was used, which greatly facilitated the development of the software package and its debugging[15]. During the designing, all the goals set for the developers were achieved. The software package guarantees quick access to information and convenient user interface.

[15] A. Ya. Arkhangelsky, Programming in Delphi 7…

The software package is registered with the Federal Service for Intellectual Property. The presented software package is used for mathematical modelling of the above task manager with a time-sharing strategy[16], which has the following initial data:

- Input task flow intensity λ_0 = 0.03; 0.06; 0.09 tasks / μs (respectively low, medium and high CPU load);
- Time for context switch by task manager τ = 9 μs, which corresponds to the average values of the OS context switching time of the "soft" real-time (for example, in Linux RT) [Mikhalev V. 2012];
- The probability of the output of the served task P_{10} = 0.05. The probability of sending a task for additional maintenance P_{12} = 0.95;
- Processing time of one CPU task is ν = 10 ms. The size of the general queue upstream of the processors is N = 128 tasks;
- The number of CPUs ranged from 4 to 100.

The results of mathematical modelling showed that the task manager with the specified parameters has a latency (waiting time for service) not exceeding 13 μs. Such latency corresponds to many existing real-time systems, for example, LinuxRT[17]. The adequacy of the analytical model for task managers with time-sharing is confirmed by the data obtained in the course of modelling. The error of analytical models does not exceed 20%, which is quite acceptable for evaluating task manager implementation options at the system design stage.

Conclusions

A significant difference of the developed software package is the ability to calculate stochastic queueing networks containing a queueing network with a limited queue length, priority queueing network, as well as the ability to calculate by several simultaneously varying initial parameters. The software package provides the convenience of input and display of source data, as well as a visual representation of the mathematical modelling results in the form of tables or graphs.

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[17] V. Mikhalev, “QNX Neutrino Performance Test Results”, Modern automation technologies: Scientific and technical journal num 2 (2012): 82-88.

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