MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

ODESSA NATIONAL A.S. POPOV ACADEMY OF TELECOMMUNICATIONS

Switched Systems Department

TELETRAFFIC THEORY

METHODICAL INSTRUCTIONS

for laboratory works for bachelor students on course "Teletraffic Theory in Telecommunications"

Odessa 2013

Issue plan 2013

UDK 621.39

Reviewer – **prof. Lesovoy I.P.**

Editor **Chepeluk N.U.**

Compilers: prof. **Loshkovskii A.G.,** assoc. prof**. Shmeleva T.R.**

A.G. Loshkovskii. **Teletraffic Theory.** Methodical instructions for laboratory works on course «Teletraffic Theory in Telecommunications» / A.G. Loshkovskii, T.R. Shmeleva. – Odessa: ONAT after A.S. Popov, 2013. – 36 p.

The methodical instructions correspond to the program of discipline «Teletraffic Theory in Telecommunications», Module 4.1. In accordance with the program expounded: main positions and analysis methods of Teletraffic theory in telecommunications which procedures of planning of the telecommunication systems and networks are based on. The mathematical models of the distribution information systems are considered with losses, with order and priorities. Research methods of these systems are brought in the conditions of idealizing model of Poisson flow and real streams of requirements in multi-service communication networks.

Study guides are intended for students to daily, distant and distance forms of education for the bachelors degree obtaining by students in Telecommunication aria. Tasks are presented for independent preparation; cycle from seven laboratory works, allowing students to fasten theoretical material, control questions for quality of the got knowledge control.

APPROVED *by*
Council
ONAT after A.S. Popov
Transaction № 3/14 of
09.04.2013 year

RECOMMENDED *by*
Council of Switched
System Department
Transaction № 1 of
29.08.2013 year

CONTENTS

INTRODUCTION

The growing complexity of telecommunication systems and networks requires the solution of the problem of the development of adequate methods of calculation of these systems in order to obtain reliable estimations of their characteristic, realization of tasks of their optimization regarding the chosen criterion of service quality and the development of appropriate control algorithms.

The main content of Teletraffic theory is to research of carrying capacity and the bandwidth of telecommunication systems. Besides methods of this theory have developed new science-based methods of characteristic estimation of service quality . The Teletraffic theory provides the estimation of all parameters of the telecommunication systems, and takes into consideration the stochastic (random) nature of the requirements streams that incoming to the system to be serviced.

In these methodical instructions a series of laboratory works are presented on the study and application of Teletraffic theory on educational discipline “Teletraffic Theory in Telecommunications” for the bachelors’ degree obtaining by students in education aria of Telecommunication. The basic theoretical information is presented in student book [1] and textbook [2].

Part I. List of knowledge and skills

As a result of study of discipline "Teletraffic Theory in Telecommunications" a student must

know: classification and models of the Queuing systems (QS); mathematical models of call flow; the concept of the load and its types; the concept of dispersion and congestion of the load; QoS parameters for different queuing systems; concepts of carrying capacity and performance; methods of analysis and synthesis of telecommunications systems and networks;

be able: to analyze the classic models of Queuing systems with the Poisson distribution of requests with losses, with infinite (unlimited) queue, with the finite queue, with priorities, with losses, as well as in the conditions of the real flow of requests; to analyze the models of service multiservice traffic; to simulate various QS: Markov process, nested Markov chains, real service processes; to investigate probability-time characteristics of the traffic; to use the perspective methods of analysis and synthesis of the information distribution systems.

Part II. Thematic plan

Module 4.1 *Teletraffic Theory in Telecommunications*
Hours: *lect. – 14 h., pract – 14 h., lab – 14 h., self – 48 h.*

№	Lecture		№	Biblio-

	The theme and content of the two-hour lectures, additional material self-study	h. lect.	h. self	№ pract	lab.	graphy
1	*2*	*3*	*4*	*5*	*6*	*7*
1	**1 General provisions of Teletraffic theory**. Models of information distributing systems. Elements of probability theory. 2 **Mathematical model of flow requirements**. Load and its types. Definition and intensity of the load. Dispersion and congestion.	*2*	*7*	Pr-1	Lab-1	1, 2, 3
2	**3 QoS parameters**. Loss systems. Systems with the order. Combined systems (with orders and losses). Priority systems. Carrying capacity (throughput) and performance	*2*	*7*	Pr-2	Lab-2	1, 2, 3
3	**4 Analysis of queueing systems with the Poisson flow requirements**. 4.1 Loss system M/M/m. System with the infinite order M/M/m/∞. System with the finite queue M/M/m/r	*2*	*7*	Pr-3	Lab-3	1, 2, 4
4	4.2 System with the infinite queue M/D/m/∞. System with the infinite queue M/G/1/∞. 4.3 System with priorities M/G/1/∞. Relative (nonpreemptive) priority. Absolute priority with pre-emptive resume discipline	*2*	*7*	Pr-4	Lab-4	1, 2, 4
5	4.4 Service model of multiservice traffic. Hayward approximation. Distribution function of the system states with losses HM/D/m, QoS parameters.	*2*	*7*	Pr-5	Lab-5	1, 2, 5,6
6	**5 Analysis of queueing system in the real flow requirements.** 5.1 The probability of losses in the systems HM/D/m, HM/G/m. System unlimited queue HM/D/m/∞.	*2*	*7*	Pr-6	Lab-6	1, 2, 5, 6
7	5.2 System unlimited queue fBM/D/1/∞. System infinite queue G/M/1/∞. System G/D/1/∞ with infinite queue.	*2*	*6*	Pr-7	Lab-7	1, 2, 7, 8
In all:		***14***	***48***			

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2. Крылов В.В. Теория телетрафика и её приложения / В.В. Крылов, С.С. Самохвалова. – СПб.: БХВ-Петербург. – 2005. – 288 с.: ил.

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Part III. Self-studying task

SIMULATION MODELING ALGORITHM OF QUEUING SYSTEMS

1 Goal of work

To learn a simulation modeling algorithm of Queuing Systems (QS) and study a real process algorithm of the service requests. Find the aim of the algorithm.

2 Key positions

The *Modeling* – method for solving problems, by using which the system under studying is replaced by a simpler object, describing the real system and which is called the model.

The modeling is used in cases, when conducting experiments on a real system is impossible or impractical: for example, due to the fragility and of the prototype building high cost, or because of the duration of the experiment in real time.

There exists physical and mathematical modeling. An example of a physical model is a smaller version of the aircraft that is blown in the air stream. Using mathematical modeling systems behavior is described by the formulas. Special type of mathematical models is a simulation.

The *Simulation model* – is a computer program, which describes the structure and reproduces the behavior of the real system in time. The simulation model can obtain detailed statistics on various aspects of systems functionality, depending on the input data.

The simulation method can be demonstrated on the example of a bank branch serving physical persons. Suppose that it is necessary to determine the minimum number of staff that provides the required quality of the service.

The criterion for the quality of the service we define by the rule: the average size of the customers queue should not exceed N people. Obviously, to solve the problem it is necessary to have sufficient knowledge of the system: which customers visit the bank, how many clients come during the day, and how much time it takes to service a single customer.

Although this task may seem specialized, similar problems arise in many regions, where human and technical resources are involved. Work time of qualified workers and the time of the use of complex equipment are high proportion expanses of the company. Determination of the optimal graphic of resource using, allows the system to perform its objectives effectively, and also reduces costs, and thus increases profitability.

At the first stage of the problems solution a model that corresponds to the structure and business processes of the bank's branch is created. In developing of the model only those segments takes in a part, that have a significant effect on the studied aspects of the system. For example, the presence of corporate services department or credit department does not affect services to individuals, as they are physically and functionally separated from the latter. For example, the presence of corporate services department or credit department does not affect on services of individuals, since they are physically and functionally separated from the last. Schematically, such a model can be represented as a sequence of the following actions:

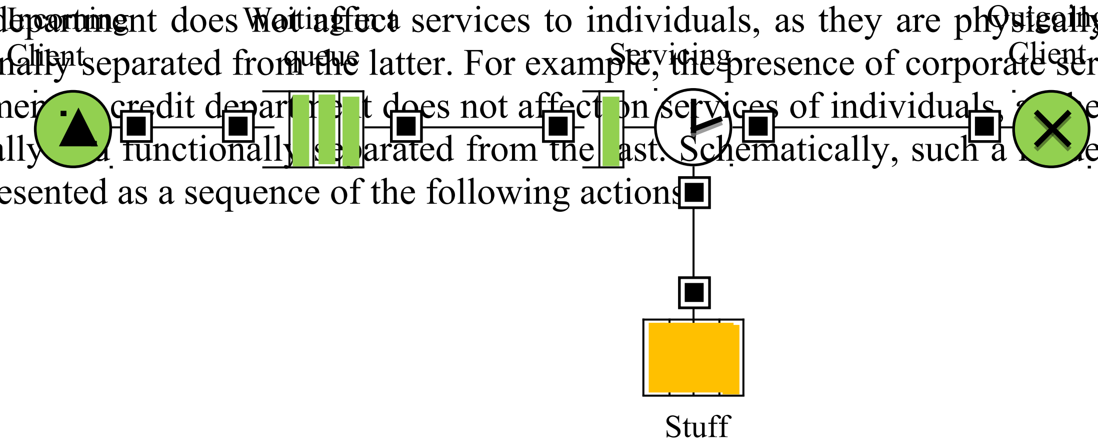

Fig 1 – Model of bank branches service of individuals

At the second stage to the input of the model the initial data are served: the intensity of the client's arrival, average time of client handling, quantity of available staff. Based on these data, the model imitates or reproduces the work of the bank for a specified period of time, such as working hours.

Time	Event
19:54	Client № 167 came and joined the queue
19:56	Client № 168 came and joined the queue
19:57	Client № 164 done servicing and left
19:58	Client № 167 start servicing

Fig 2 – The model of the events

The next step is to analyze the statistics which are compiled and presented by the model. If the average queue size of the customers exceeds the selected limit in N persons, the number of available staff should be increased and performed a new experiment.

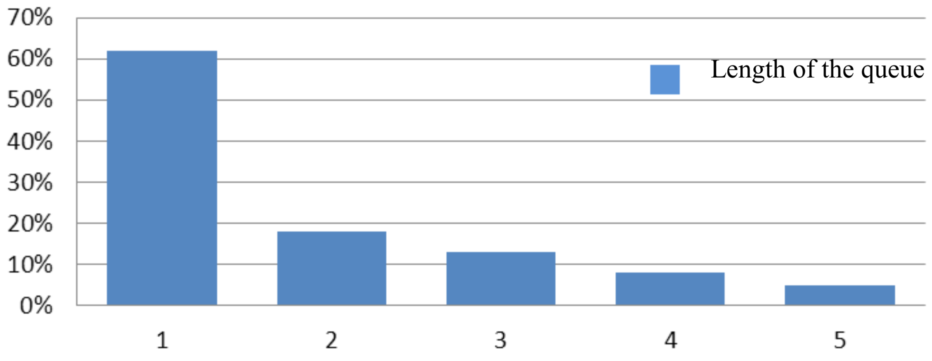

Fig 3 – Dependence of the queues length from the quantity of the stuff

As a result of the set of experiments with the model, we can determine the optimal number of staff. Using of the simulation models has many advantages in comparison with the performance of experiments on the real system and using other methods.

The benefits of the simulation modeling include:

1. *Cost*. Suppose the company laid off part of employees that led to the decreasing of the quality of service and loss part of customers. The simulation model

could help to make informed decisions, the cost of the use of which consist only of the price software and cost of consulting services.

2. *Time*. In reality, to evaluate the effectiveness of, for example, a new network of product distribution or restructuring of composition, it willbe possible only in months or even years. The simulation model allows to define the optimality of such changes for a few minutes required for the experiment.

3. *Repeatability*. Modern life requires entities rapid response the changes of market conditions. For example, the prediction of the demand volume of products should be made in time, and its changes are critical. Using the simulation model an unlimited number of experiments with different parameters to determine the best option can be carried out.

4. *Accuracy*. The traditional computational mathematical methods require the use of a high degree of abstraction and do not include important details. The simulation modeling allows us to describe the structure of the system and its processes in the natural form without the use of formulas and rigorous mathematical dependences.

5. *Visibility*. The simulation model has the capability of the system visualization process in time, specifies its schematic structure and outputs the results in graphical form. This allows you to visualize the obtained solution and bring the ideas embodied in it up to the customer and colleagues.

6. *Universality*. The simulation modeling allows to solve problems of any areas: manufacturing, logistics, finance, healthcare, telecommunications and many others. In each case, model simulates, reproduces real life and allows a wide range of experiments with no impact on the real objects.

3 Check questions

3.1 When is it advisable to apply the simulation modeling?
3.2 Name the types of modeling. What is the difference between them?
3.3 What is the simulation model?
3.4 What are the advantages of simulation modeling?

4 Homework

4.1 Answer the check questions in writing.
4.2 Study 9.1- 9.4. according to the references [2]

5 Description of work and implementation principles

The following algorithm is used for the simulation modeling:

– Markov processes;
– Semi-Markov process:
– Real process of the call serves.

Let's represent the algorithm of the real process of the serving requirements:

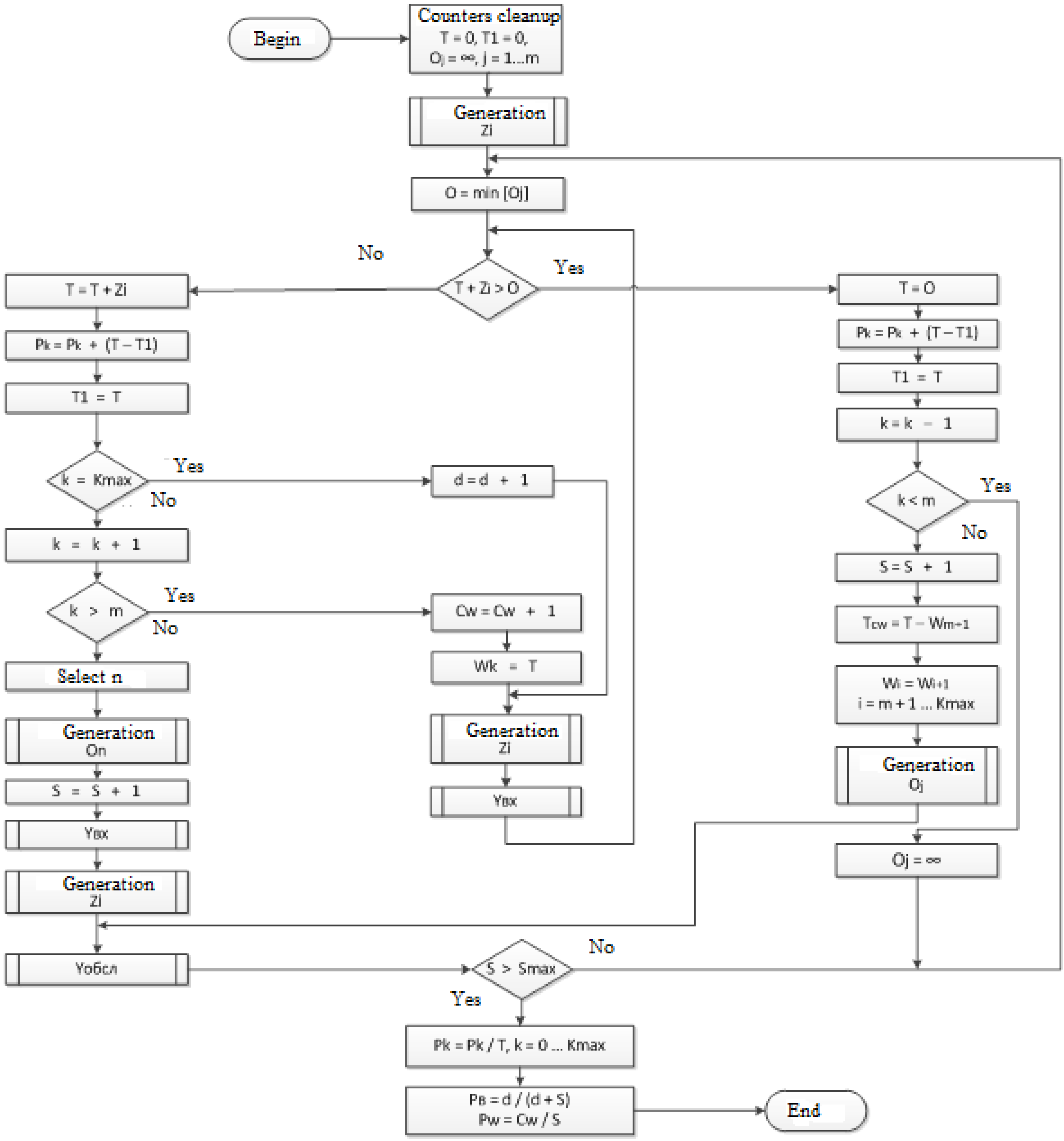

Fig 4 – Algorithm of the simulation model

The aim of the algorithm is to obtain the numerical characteristics of the CMO quality of service.

For the main variables of the simulation model, the following notation is accepted:

- S – the current quantity of served requirements;
- S_{max} – maximum quantity of served requirements;
- d – quantity of lose requirements;
- k – the current quantity of requirements, which are in the system (on service and in the queue);
- r – quantity of places for waiting (places in the queue);
- m – quantity of the servers in the system (serves places);

– n – number of the busy server ($n \leq m$);
– K_{max} – maximum quantity of requirements, that are in the system; ($K_{max} = m + r$);
– C_w – quantity of requirements, which are in the waiting queue and subsequent service.

This algorithm allows us to study a wide range of QS type *G/G/m/r*. It means, that it can be incoming flow of any type, any distribution of serves durationлюбое, any discipline of serve: with loses when $r = 0$, with unlimited (infinite) queue for $r = \infty$, and combined discipline with discipline $0 < r < \infty$.

Full description of the algorithm can be found in section 9.5 [2].

6 Content of report

In a report on implementation of this laboratory the student must bring: topic, purpose, answers to control questions, scheme and short description of the algorithm, conclusions.

7 References

1. Simulation modeling for science and business. http://www.xjtek.ru/
2. Queuing systems in telecommunications. / A.G. Loshkovskii. – Odessa, 2010. – 112 p. (in Russian and Ukrainian).

Part IV. Laboratory works

Laboratory work № 1

INTRODUCTION TO THE SIMULATION PROGRAM “MODELING CMO”

1 Goal of laboratory work

To study an interface of simulation program for queue system. To clarify capabilities of program for “Modeling CMO”. To study interaction between program’s components. To carry out first experiments with modeling of queue system, to define possible states of the system.

2 Key positions

After starting program for “Modeling CMO”, the interface looks like:

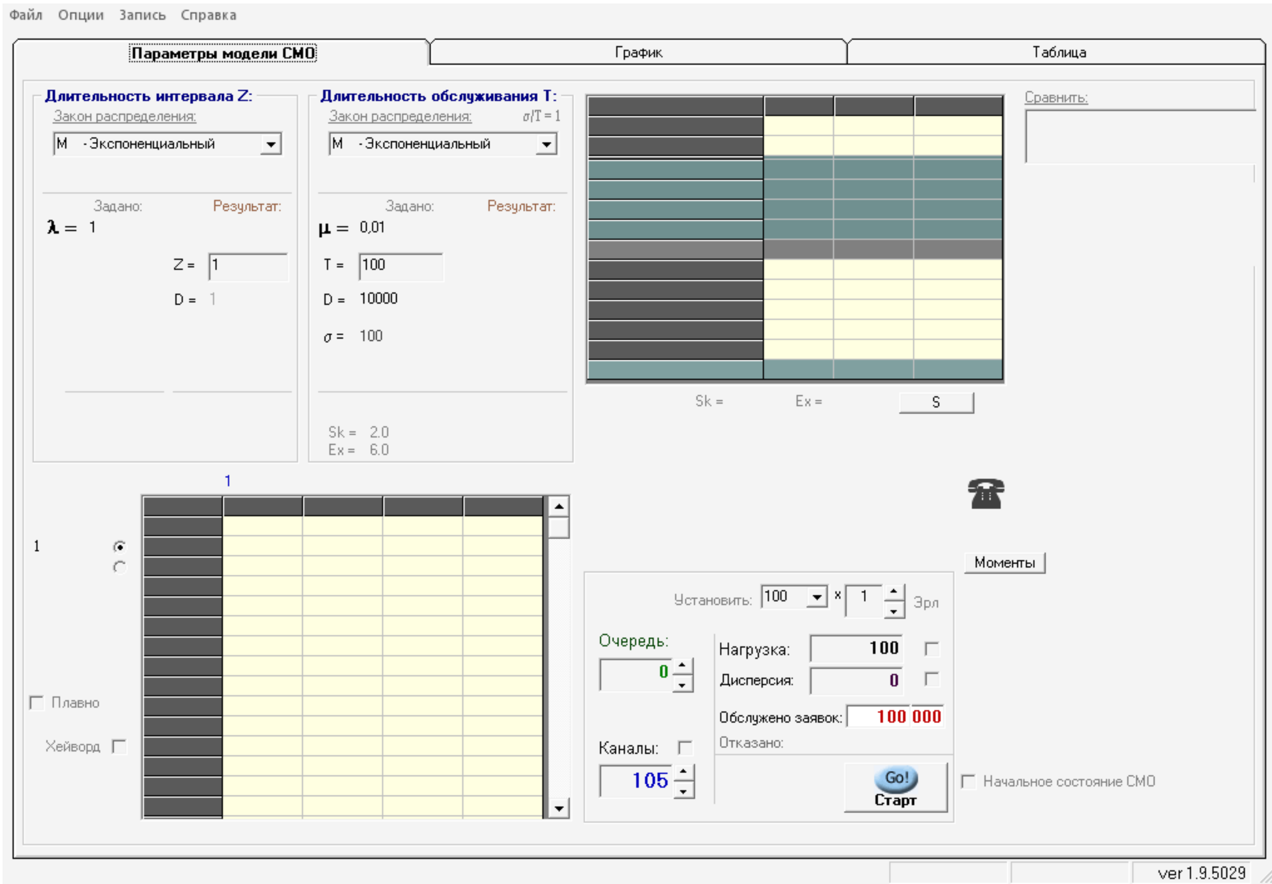

Figure 1 – Working area of program for “Modeling CMO”

Overhead of the main program’s form there is a menu, which consists from the next items: “File”, “Options”, “Record”, “Help”. By choosing of any of these items, there will be shown a list of commands. Some of the commands have correspondent “hot keys” (e.g., F2, F3 etc.). For example, when you select “Record”, there will be shown next list of commands:

– “Record of the flow” – record of an array of time intervals between the queries (flow of calls);
– “Record *Xtay*” – record of the array of time waiting intervals according to the order of each queue;

– “Record *W*” – record of the array of time waiting intervals according to the order of all queues converting;
– “Record *tz*”, F2 – record of the array of time waiting intervals according to the order of each queue.

There is three insets on the working form of the program: “Parameters of queue system”, “Graph”, “Table”.

The inset “Parameters of queue system” can be conditionally divided into some parts:

– “Duration of Z interval”

Here, in this area, parameters of queues’ flow (queues, which arrived to the system for servicing) can be set. With the help of *ComboBox* component we can set the appropriate law of probability distribution function for the value of time duration between queues in the flow. These laws are: “*M* – Exponential”, “*LgN* – Normal logarithm”, “*U* – Uniform”, “*D* – Determined”, “*HM* – Hyper exponential”, “*P* – Pareto *fBM*”, “*W* – Weibull *fBM*”. For “logarithmically normal” law of probability distribution function for value of time durations between queues, it is necessary to set into the field Z parameter of average of distribution (average value) of random value z_i, and into the D field – the value of dispersion (deviation scope of every z_i value from average of distribution *Z*). The value, which equals *1/Z* - is the intensity of queues’ flow λ. For “hyper exponential” law it is necessary to set into the field p_1... p_4 the value of those probabilities, for which “generator” of queues’ flow will choose the average of distribution from fields Z_1 ... Z_4 correspondingly. Below these fields, there will be shown final value Z as the result of queues’ flow modeling, the value of dispersions D and root mean square deviation σ. Here also will be shown the moments of higher order of z_i distribution, such as skewness *Sk* (asymmetry) and excess *Ex*. For setting of “exponential” distribution law, it is enough to set values of probabilities, which equal 1 to any of p_1...p_4 fields.

– “Duration of servicing T”.

In this part of program you can set parameters of servicing and duration of queues’ servicing. With the help of *ComboBox* component, you can also set the appropriate law of probability distribution function for the value of time range between queues in the flow. These laws are: : “*M* – Exponential”, “*LgN* – Normal logarithm”, “*U* – Uniform”, “*D* – Determined”, “*HM* – Hyper exponential”, “*P* – Pareto *fBM*”, “*W* – Weibull *fBM*”. The value, which equals 1/t – is the intensity of queues’ servicing μ.

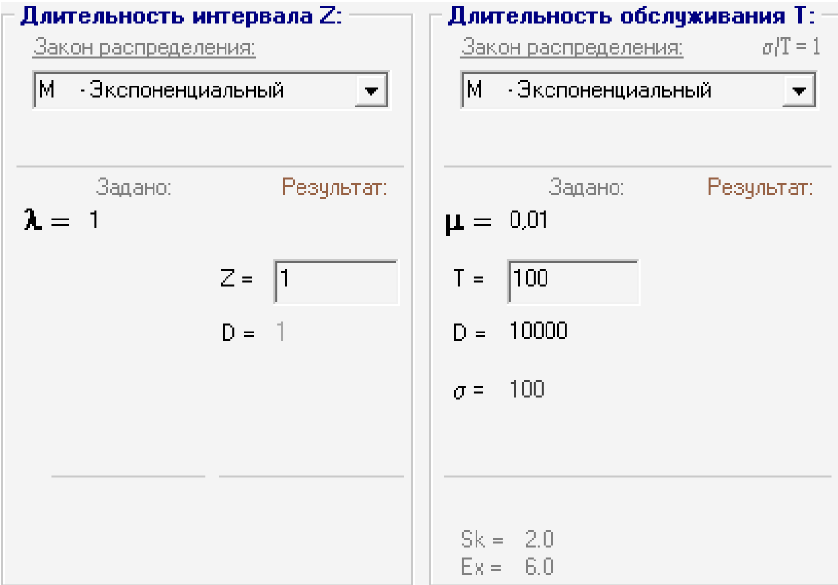

Figure 2 – “Duration of Z interval” and “Duration of servicing T” fields

– “Parameters of the system”

In this part you can set parameters of queue system, namely – quantity of channels in the system *m*, and quantity of waiting places *r*. Here we can also set the quantity of queries, which are modeling within the bounds of 1.000 to 9.999.000. The “Start” button realizes launching of simulation model. Here you can find informational fields, which shows load intensity Y, dispersion of load intensity D, quantity of queries, which were lost, forbidden or set to the queue. The “Initial state of queue system” item allows to mark that the starting of modeling should not be with the “zero” state, but with random quantity of busy channels.

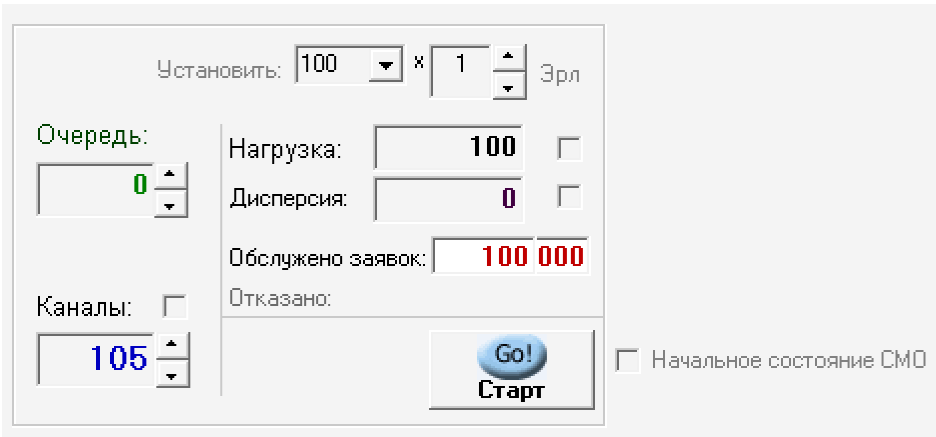

Figure 3 – “Parameters of the system”

– “Results of the modeling”.

This window shows the next data: probability of losses by time P_v (part of time, when all the channels are taken off the system), probability of call loss P_c (part of lost calls), intensity of input load, which is calculated as: $Y=M_t/M_z$, intensity of serviced load: $Y_o=\Sigma t_i/T$ (relation between total time of occupation and total time of modeling), intensity of serviced load, which is calculated as a difference between intensity of input and secondary load ($Y*P_c$), average quantity of busy channels (for systems with losses, it equals the intensity of serviced load), average quantity of queries with average time of occupation (intensity of input load) C, dispersion of average quantity of queries with average time of occupation of t_i intervals, and also the parameter of load intensity density $S=D/Y$.

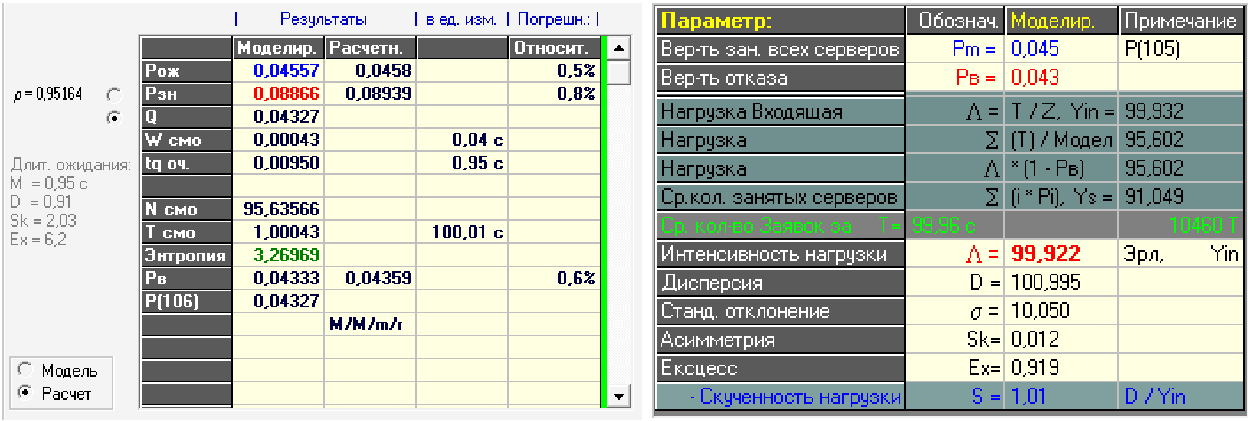

Figure 4 – "Results of the modeling"

In the "Results" window, you can find the main *QoS* characteristics:

- probability $P>0$;
- average duration of occupation of requests in the queue t_w;
- average duration of waiting for every requirement W;
- average length of the queue Q.

Here you can also find average value of miscalculations.

The "Graph" area is shown on the Figure 5. This inset is divided into parts, which are: "Field for graph construction", "Approximation 1 and 2", "Field of graph's selection", "Parameters of graphs" and "Cycle".

Let's consider every part in details:

- "Field for graph construction".

There is a scale on the vertical axis, which is called "Probability of the state", it is possible to set other scale – "Frequency", on on the horizontal axis – "Servers". The field of graph construction work in pairs with field of graph's selection.

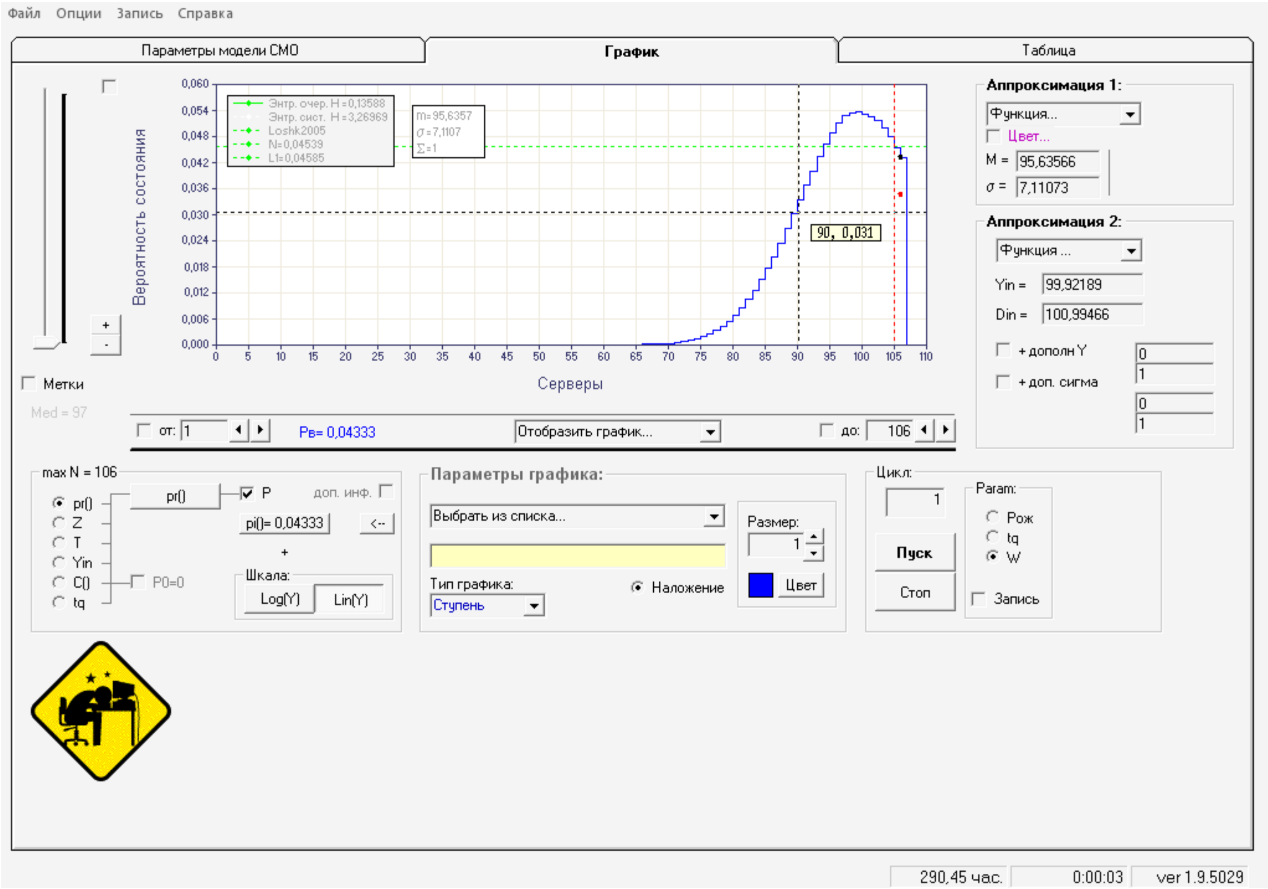

Figure 5 – Field for graphs' construction. "Graph" inset.

In the field of graph selection you can choose distribution functions for values:

- "pr()" – function for distribution of system's states;
- "Z" – distribution function of time intervals between requests z_i in the input flow;
- "T" – function for distribution the time for servicing of requests t_i;
- "Yin" – quantity of requests for the time of average servicing duration of every servicing time interval;
- "C()" – function for distribution of the quantity of arrived requests for average time of servicing duration;
- "tq" – function for distribution of waiting time of requests in the queue.

There is a possibility to change linear scale into logarithmic one.

In the"Parameters of graphs" inset you can choose different parameters: graphs representation, e.g. graph type (step, line, histogram), size of graph line, color of graph, grid representation in the "Field of graph construction", background color etc.

In the "Approximation 1 and 2" inset there is a possibility to choose approximation curves according to the known distribution laws for comparison of obtained curves with the chosen approximation curves.

In the "Cycle" field you can set the cycle for construction of some distribution functions, and also you can record this cycle. With the help of "Start" and "Stop" buttons you can loop the modeling process, where with every new cycle in queue system new channel is added. This allows to investigate parameters according to the capacity of queue system.

3 Control questions

3.1 What is the purpose of program for “Modeling CMO”?
3.2 What is the maximal quantity of requests, which can be input into the system?
3.3 What does QoS mean? Which parameters does it include?

4 Homework

4.1 To study model of system with information distribution according to the references [1].
4.2 Write down answers for the control questions.

5 Description of laboratory work and implementation principles

Start the program for “Modeling CMO” or use the tag “Modeling CMO” on the desktop, or follow the next path: Start – All programs – Modeling CMO. Use the key positions and study program’s interface and capabilities. For starting of first modeling you should enter into the program model of *M/M/m=115* type, where *M* – exponential law of time intervals’ distribution between the queries, secondary *M* – exponential law for distribution of duration of queries’ servicing, *m=115* – quantity of channels (servicing devices). To define: probability of rejection, input load, to build graph of distribution functions for system’s states, to define maximal quantity of loaded channels by graph. To execute analogous modeling for *m=121* channels, when the input load is the same. To clarify how does the increase of channels’ quantity influence on the probability of rejection.

6 Content of report

In the report the student should list: topic, purpose, short description of the program for “Modeling CMO” capabilities, answers for control questions, results of first modeling experiment, graph and make conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

Laboratory work № 2

INVESTIGATION OF QUEUEING SYSTEMS WITH LOSSES *M/M/m*

1 Goal of laboratory work

To model the work of the system with losses *M/M/m* using the program "Modeling CMO". To analyze obtained data by modeling of corresponding systems in the program "Modeling CMO".

2 Key positions

The teletraffic theory doesn't operate with information distribution systems, but with their mathematical models. For full description of information distribution systems it is necessary to show random probabilities, which describe input flow of requests, system's structure and discipline of servicing [1]. Thus, mathematical model of information distribution system contains next elements:

1. Input flow of requests for servicing (traffic) is classified according to the stationary, ordinariness, and overshot features. The main characteristics of requests' flow are its parameter and intensity.
2. Structure of information distribution system – is the data, which shows quantity of servicing devices or servers, their interaction (scheme) and availability for input requests.
3. Discipline of servicing flow of requests – characterizes interaction between the flow and information distribution system. In the teletraffic theory, the discipline of servicing is described by:

– the method of requests' servicing;
– the order of requests' servicing;
– the modes of search of system's outputs;
– the distribution function of servicing duration;
– presence of advantages (priorities) in servicing of some requests;
– availability of boundaries during requests' servicing.

In general case, input flow of requests for servicing is described by the distribution function of time intervals between neighbor requests $A(z)$:

$$A(z)=P(\leq z) \tag{2.1}$$

where $P(\leq z)$ – is the probability which shows if the time between consecutive requests $\leq z$.

The time of request's being at server, is described by the distribution function of probabilities of servicing duration $B(x)$:

$$B(x)=P(\leq x) \tag{2.2}$$

where $P(\leq x)$ – is the probability, which shows if the time of requests' servicing $\leq x$.

For description of the interval between consecutive requests and servicing duration, different distribution functions are used. Those functions, which are represented by corresponding Latin letters, are used more often. They are:

- *M* – exponential (M – Markov's model);
- *H* – hyper exponential;
- *D* – Determined;
- *U* – Uniform;
- *E* – Erlang's distribution;
- *G* – General.

Discipline of servicing flow of requests defines servicing rules and part of requests when they come to the system for servicing:

1. System with losses – requests, which can not find any free server and get reject for servicing, so they are getting lost.

2. System with queue – requests, which can not be serviced right away, as all servers of the system are busy. So, with the help of the discipline, there can be made a decision in which sequence those requests, which are waiting for servicing, will move. The most popular disciplines for queue servicing are:

- *FF* (*FIFO – first in first out*) – when requests are servicing according to the queue;
- *LF* (*LIFO – last in first out*) – priority for those request, which was the last in the queue;
- *SR* (*SIRO – service in random order*) – random choosing of the next request in the queue.

3. Combined systems with queues and losses (queue system with limits).
For example, there can wait only finite quantity of requests, which depend from the quantity of waiting places, which is less than infinity. There is also a probability that the request can be rejected in case, when the time of staying in the queue or system exceeds the limits.

4. Priority systems. If the request has high priority level and all servers are busy at that time, then this request gets one of the first places in the queue or the system temporarily stops servicing of lower priority request and takes it. There is some priority rules, which can be applied:

- absolute priority with breaking – when the high priority exceeds requests with low one. There are: absolute priority with losses, with after service and repeated servicing;
- relative priority – when high priority request takes the first place in queue without breaking.

The main features, which characterize information distribution system:

- quantity of servicing devices (servers, lines, channels, ports);
- quantity of waiting places or maximal queue length (capacity of the memory);

– availability – the method for servers' switching, when for each request all or not all servers are available. The scheme can be fully or partially accessible;
– interconnection (scheme) – is the method for servers' connection, when every request is servicing by one or several servers by stages. The scheme can be single- or multi-stage.

Structural characteristics of the system partially influence on the discipline of flow requests' servicing. For example, when the quantity of waiting places $r = 0$ – it is the system with losses; when $0 < r < \infty$ – combined system with queue and losses; and when $r = \infty$ – system with queue and without losses.

For short notice of investigating system, D. Kendall offered special conditional designation of the basic model, which shows four elements of all parameters of system with information distribution: *A/B/m/r*.

A element characterizes requests' flow and is signed by one of the above-mentioned letters, which represent types of probability distribution functions of time intervals between neighbor requests.

B element characterizes random sequences of servicing duration in separate servers of the system and analogously to the first element, can represent the same distribution lows.

Elements *m* and *r* characterize quantity of servicing places (servers) and waiting places in the system correspondingly.

Besides the above-mentioned elements, the designation of the basic model can include additional data after ":" sign for more detailed signing features of system's.

Thus, the basic mathematical model of queueing system is defined by the sequence of symbols: first shows distribution function of time intervals between requests; second – distribution function of servicing duration; third and next one (is not obligatory) symbols represent the scheme and discipline of servicing.

3 Control questions

3.1 What are the main types of disciplines of queue processing in queue systems?

3.2 What are the main types of queuing systems according to the methods of requests' servicing?

3.3 What are the main rules for servicing requests with priorities?

3.4 What are the main features, which characterize the structure of queue system?

3.5 Explain the structure of conditional representation of basic queue system model according to Kendall's.

4 Homework

4.1 Write down the answers for the control questions.

5 Description of laboratory work and implementation principles

Start the program for "Modeling CMO" or use the tag "Modeling CMO" on the desktop, or follow the next path: Start – All programs – Modeling CMO. Enter input parameters: Z = 1, T = 100, load – 100 Erlang, quantity of channels equal m = 115. Then, it is necessary:

1. To investigate relation between the quality of system's work and quantity of channels. For this purpose, you should execute line of experiments with different quantity of channels (beginning from 115 till 130, if step = 5).
2. To investigate the relation between quality of servicing and law of distribution of servicing duration. For this it is necessary to use the same initial data and execute several modelings with the change of distribution law of servicing duration (exponential, uniform and determined).
3. To build the graph of distribution function of system's states. Then it is necessary to use "Approximation 1" inset and define which law the graph concerns to.
4. To build the graph of distribution function of requests' quantity by average duration of servicing. To define which distribution between time intervals of requests at the input of the system leads to Poisson distribution of requests quantity by average duration of servicing.

To make conclusions for every paragraph of laboratory work.

6 Content of report

In the report the student should list: topic, purpose, answers for control questions, results of laboratory work implementation, graphs and make conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

Laboratory work № 3

ANALYSIS OF QUEUE SYSTEMS WITH ORDER

1 Goal of laboratory work

To model a work of the system with unlimited queue *M/M/m/∞* using the program “Modeling CMO”. To analyze obtained data by modeling of corresponding systems in the program “Modeling CMO”.

2 Key positions

For quantitative evaluation of servicing quality of systems with queue, the next characteristics should be calculated:

– probability of waiting $P_{w>0}$ or average part of loaded requests;
– average length of queue *Q*;
– average time of waiting for loaded requests t_q;
– average time for any request *W*;

The probability $P_{w>0}$ at the time interval (t_1, t_2) is defined as the relation between quantity of requests, which were received in the queue $C_q(t_1, t_2)$ during this period, and general quantity of requests, which were obtained by the system during the same time – $C(t_1, t_2)$:

$$P_{w>0} = \frac{Cq\,(t1,t2)}{C\,(t1,t2)} \quad (3.1)$$

The length of the queue is one of the key qualitative parameters of the system’s servicing (efficiency factor of system’s functioning in general) and it is defined by the quantity of requests, which are waiting for servicing. The length of the queue depends on the quantity and time, when requests were received by the system and how much time was needed for their processing etc. As the length of the queue is random value, then its average of distribution *Q* can be used as the index of the length.

The average time of waiting in the queue t_q is formed by the load of requests there. It depends from the quantity of requests, which are in the queue right now and the time of finishing of servicing of previous requests etc.

The average time of waiting in the system *W* – is the average value of waiting time, which relates to all of the requests – which were and were not slowed. This parameter is needed for the purpose that not all the requests get to the queue and part of already obtained requests are serviced in case of free servers immediately.

The additional *QoS* features are: the average number of requests in the system *N* and average time of being in the system *T*. They are additional and can be calculated by the main characteristics:

– the average number of requests in system N defines the level of system's capacity and when the queue is infinite, it contains the value of the average quantity of requests, which were obtained by the system Λ and those requests, which are in the queue Q:

$$N = \Lambda + Q, \tag{3.2}$$

– the average time of the requests being in the system (response time) T – it is the time, that one request spends in the system and averaged by all of the requests (slowed and not). It contains the values of the average servicing time $\bar{x}$ and average time of requests' waiting in the system W:

$$T = \bar{x} + W. \tag{3.3}$$

For each of the flow model, all the qualitative characteristics of servicing are in the definite functional relation.

3 Check questions

3.1 What are the main features of servicing quality for the systems with the queue?

3.2 What are the features of servicing quality which can be calculated from the main characteristics?

3.3 How can the average part of slowed requests be calculated ?

3.4 How can the average waiting time in the system be defined ?

3.5 What does the length of the queue relate to?

4 Homework

4.1 Write down the answers for the check questions.

5 Description of laboratory work and implementation principles

Start the program for "Modeling CMO" or use the tag "Modeling CMO" on the desktop, or follow the following path: Start – All programs – Modeling CMO. Enter the input parameters: Z = 1, T = 100, load – 100 Erlang, the quantity of channels equal m = 115, number of serviced requests 1 000 000. Then, it is necessary to:

1. Define the parameter which numerically coincides with the probability of loading for all the servers in *M/M/m* model. Build the graph of distribution function for the system's states and show on the graph the maximal value and the value of probability of all servers' occupancy (black point).

2. Convert initial system into the system with infinite queue. For this purpose it is necessary to set "queue" parameter r = 500 (for our system value of the queue = 500 is the same as ∞). Define quality parameters of new system. Define which place in the queue was occupied more often than others.

3. Go back to the initial system and set the "queue" parameter $r = 0$. Execute the experiment, when $m = 110$ and $m = 117$. Define the value of E_m parameter which is in the table with the results. Add 10 places for waiting. Define the quality of servicing. Clarify what the improvement of some parameters leads to. Name the process which results – is the achieving of good quality parameters by minimum resource expenses.

4. Define the influence of waiting places increasing on the values of the average waiting time W and probability of rejects $P_в$.

Make conclusions for every paragraph of the laboratory work.

6 Content of report

In the report the student should list: the topic, purpose, answers for check questions, results of laboratory work implementation, graphs and make conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

2. Крылов В.В., Самохвалова С.С. Теория телетрафика и её приложения. – Спб.: БХВ-Петербург. – 2005. – 288с.: ил.

Laboratory work № 4

RESEARCH OF SINGLE-SERVER SYSTEMS *M/G/1/∞*

1 Goal of laboratory work

Research the single-server system in terms of random traffic.

2 Key positions

In the condition of random flow requirements for calculation of load degree or bandwidth, and *QoS* characteristics performed on the basis of probability distribution functions of the system states, which determine this characteristic. In Poisson flow requirements to determine the stationary state probabilities of the system mathematical apparatus of the Markov process sis used. The state of the system understands the current quantity of requirements in the systems that are served or are waiting in the queue. Changing the state of the system is a random process, which is the result of a joint admissions process and service requirements. The distribution of the system states in contrast to the average numbers of its requirements, are the most relevant to the operation of QS under the influence of random factors in any traffic [1].

In the multi-service packet communication networks incoming information flows can have constant (*CBR*), variable (*VBR*) and the mixed bit rate, so that the mathematical model of the flow can be from the simplest Poisson to the complex model of fractal processes (self-similar traffic). The distribution of the time interval between the requirements of such flows can be arbitrary (*G*). The packet length of each service can be different – for one services it is constant and for another variable. Thus the distribution form of the random variable service time will also be arbitrary (*G*).

Systems with the queue $G/G/m/\infty$ is one of the most important models which are considered in Teletraffic Theory, where during the research various methods are used and numerically approximate results obtained. The selected case is the system with the queue and one server ($m = 1$) is considered in [2], where the only approximate results are obtained.

In most cases good approximation of a single-server system is the exponential distribution function of the service requirements duration. The coefficient of servers system using ρ determines as the relation of the intensity of the incoming flow requirements λ to the served intensity μ. In *m*-servers system all servers provide service intensity $m\mu = m(1/\bar{X})$. So in *m*-servers system $\rho = (\lambda\bar{X})/m$. In a single-server system ρ is in *m* times bigger and coincides with the load intensity Λ.

For any single-server system $\rho = 1 - p_0$, where p_0 is the probability that the system is free (busy 0 servers). So ρ numerically is the same as the probability of occupation P_b. In [1] the dependence table between *QoS* parameters for the system $G/M/1/\infty$ is provided(p.89). The table shows that, with a known parameter, all the other parameters are calculated by the ratio shown in the table.

3 Check questions

3.1 What is meant by the definition of the system state?
3.2 What bit rate can the information flow packet networks have?
3.3 How is the coefficient of server system using determined?
3.4 Which parameter does numerically coincides with $P_{зн}$ for single-server system?

4 Homework

4.1 Answer the check questions in the written form.

5 Description of laboratory work and implementation principles

Run the program «Modeling CMO» using either a shortcut «Modeling CMO» on the desktop, or by clicking the following path: Run – All programs – Modeling CMO. Next:

1. Research the system of type *M/M/m* – blocking scheme QS with $m = 1$ servers, service discipline with losses. The incoming flow of requirements is coming in the system with the intensity Λ=0,7 Erlang. Determine the coefficient of variation $varT=\sigma/T$. Build the graph of the distribution function of the system states, with the selected linear scale. Set the parameters p_0 and p_1.

2. Research the system of type *M/M/*1/∞. The incoming flow of requirements is incoming in the system with intensity Λ=0,7 Erlang. Set the parameters P_w and $P_в$. Then investigate the dependence of the quality parameters from the distribution of the service duration for a single-server system when entering the exponential input flow, $P_{вз} = P_{зн}$. For this it's necessary to fill in the table below:

Table 1 – Dependence of the quality parameters from the distribution of the service duration for a single-server system *M/G/*1/∞

	M/M/1/∞	*M/D/1/∞*	*M/U/1/∞*	*M/Log/1/∞*
P_w				
P_{bs}				
Q				
W				
t_q				
varT				

When the coefficient of variation *varT* is smaller, then QoS ________.
For a system with a queue the distribution of the service duration does not allow ___.

3. Research the system of the type *fBM/M/1/∞*. The flow requirements comes in the system with the intensity Λ=0,7 Erlang. Determine QoS parameters Q, W, t_q , P_w and P_{bs}. Why $P_w > P_{bs}$?

For each part of the laboratory task make the conclusion.

6 Content of report

In the report on the implementation of this laboratory work the student must bring: the topic, purpose, answers to check questions, the results of the laboratory task, graphics, and conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

2. Кениг Д., Штоян Д. Методы теории массового обслуживания. Пер. с нем. – М.: Радио и связь. – 1981. – 128с., ил.

Laboratory Work № 5

RESEARCH OF INFORMATION DISTRIBUTING MODEL *HM/D/m*

1 Goal of laboratory work

Using the “Modeling CMO” program simulate the *HM/D/m* information distribution model work. Analyze the data, derived with modeling of *HM/D/m* type systems in “Modeling CMO” program. Define the flow unevenness influence on the system’s quality characteristics.

2 Key positions

The development of telecommunication technology, the new principles of communication networks, the structural change in the composition of subscribers and the range of services – all that significantly affects the nature of the traffic in modern networks. These factors increase the unevenness (nonuniform) flow intensity requirements. The results of static measurements make it possible to distinguish the three types of the traffic [1]:

I type – in monoservice networks with the homogeneous traffic. These are exactly like telephone networks with the only telephone communication service, that led to the traffic homogeneity. The simplest model of Poisson distribution, intrinsically, satisfies such conditions, and the values of the traffic intensity and its dispersion coincide or are close enough.

II type – in multi-service networks with heterogeneous traffic. Integrated nature of the multi-service network with an expanded range of products and services results in mixed traffic, greatly changing its parameters and mathematical model. Such flows are characterized by the increased irregularity of the traffic, in which the variance of the intensity of the traffic exceeds the math expectation of 2 to 15 times.

III type – in the packet networks with multi-service traffic. Traffic has long-term dependences on the intensity and even more significantly different from the Poisson distribution requirements. In the multi-service packet networks traffic is diverse, with certain quality requirements *QoS*. Flows streaming of different services provides the same network with common protocols and control laws. Since the sources of each service may have different bit rate or change it in the transmission, so the combined stream is characterized by so-called "burstness" traffic (bursty data stream). The burstness causes even more bursty traffic, in which the variance of the intensity of the traffic exceeds its math expectation of 20 to 60 times or more.

Traffic unevenness is characterized by concentration factor (congestion) S, which is defined as the ratio of load invariance D_Λ to its math expectation Λ:

$$S = \frac{D_\Lambda}{\Lambda}. \quad (4.1)$$

The S value is the unit for Poisson distribution, less than the unit for aligned (smoothed) load and more than unit for congested (redundant) load.

3 Check questions

3.1 Which traffic types are defined for telecommunication networks?
3.2 What does the concentration factor show?
3.3 What traffic type is characterized by the irregularity, where does the traffic intensity invariance exceed its math expectation from 2 to 15 times?
3.4 What is the concentration factor value for Poisson stream?

4 Homework

4.1 Answer the check questions in writing.

5 Description of laboratory work and implementation principles

Run the “Modeling CMO” program using either the label “Modeling CMO” on the desktop or click on the following path: Start – All Programs – Modeling CMO.

Research *HM/D/m* system – full-accessible circuit of QS with m = 115 servers, service discipline with losses. The flow requirements comes in the system with the intensity of the traffic offered load Λ = 100 Erlang, in which the interval between the demands of a Hyperexponential distribution, and the discipline of the service has a regular distribution. Then, you must:

1. Click "Start". Research the obtained characteristics of the system. Go to the tab "Graph" and select «Z» and a logarithmic scale, construct the graph. Approximate the constructed graph by the *exponentia*l distribution. Then approximate the same graph by *logarithmically normal* distribution. Draw the graphs and two approximating curves.

2. In the tab "Graph" select «pr()» and switch to a linear scale, draw the graph. Approximate graph by *I^st Erlang* distribution and the distribution of *N Loshkovsky*. Draw the graphs and two approximating curves.

3. In the tab "Graph" select "C" and draw the graph. Approximate the generated graph by two distributions: *Poisson* and *Gauss*. Draw the graphs and two approximating curves. Which of the distributions is best for description of uneven flows?

4. Determine how many times the real flow differs from the Poisson distribution. A definition of the peak factor loads.

5. Determine which the distribution of the service time requirements, characteristics of the service quality is better, and which are worse. To do this, compare the characteristics (P_B and P_m) by changing of the distribution of the service

time (exponential, lognormal, regular), and the interval between the requirements of the input stream has Hyperexponential distribution.

Make the conclusion on each Lab item.

6 Content of report

In a report on implementation of this laboratory work the student must bring: the topic, purpose, answers to test questions, the results of the laboratory assignments, plots, and conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).
2. Ложковский А.Г. Теория массового обслуживания в телекоммуникациях: учебник / А.Г. Ложковский. – Одесса: ОНАС им. А.С. Попова, 2012. – 112 с.: ил., (на русском и украинском языках).
3. Вентцель Е.С., Овчаров Л.А. Теория случайных процессов и её инженерные приложения / Е.С. Вентцель, Л.А. Овчаров. – М.: Наука. Ред. физ.-мат. лит., 1991.– 384 с.
4. Крылов В.В. Теория телетрафика и её приложения / В.В. Крылов, С.С. Самохвалова. – СПб.: БХВ-Петербург. – 2005. – 288 с.: ил.

Laboratory Work № 6

ANALYSIS OF QUEUING SYSTEMS WITH ORDER IN MULTISERVICE TRAFFIC CONDITIONS

1 Goal of laboratory work

Using the “Modeling CMO” program research the queuing system QS by multi-service input flow. Analyze the data, derived with modeling the queuing systems at the “Modeling CMO” program. Define which of the observed systems have the best throughput.

2 Key positions

In multi-service communication networks which are based on the packet data transmission technologies, the same communication path transmits voice streams, data streams, video streams, and others. The transfer of certain types of information requires the provision of various transmission rates. Therefore, depending on the category of the requirements for the provision of a particular service for each of the flow information it is necessary to take a feed from a common channel bandwidth. For example, voice requires a guaranteed rate of 64 kbit/s connection for video codec H.263 – 320 kbit/s, file sharing, for example, 1024 kbit/s. For the distribution of the common channel transmission rate among all these services the channel can be expressed as the number of ports, and the rate of each will correspond to the minimum rate of the services offered. In our case, the port rate for one conditional port will be equal to 64 kbit/s, depending on the category of the requirements for the provision of services performed simultaneous occupation of ports, through which packets are sent to a given bit rate. Thus, the admission requirements for the provision of voice services will be simultaneously occupied one port, to provide communication services for videoconferencing - 5, and data - 16 conventional ports.

By such multi-service traffic service model it's necessary to distinguish the flow of requests on the service rendering and the flow of requests on the port rendering (occupation), because they differ one from another in their characteristics. Obviously, if the flow of requests on the service rendering is ordinary, then the flow of requests on the port rendering will be uncommon, because ports are occupied in groups for the definite connections service. In these circumstances we must distinguish two notions of the load: the load by request and by ports.

3 Check questions

3.1 What is the rate of service rendering for voice transfer?
3.2 What is the difference of the load by request from the load by ports?

4 Homework

4.1 Answer the check questions in writing.

5 Description of laboratory work and implementation principles

Run the program «Modeling CMO» using either label «Modeling CMO» on the desktop, or by clicking the following path: Start - All Programs - Modeling CMO. Next, you must:

1. Investigate the system *M/M/m* – full-accessible scheme QS with m = 115 servers, service discipline with losses. The flow of requirements comes in the system with the intensity of the input load Λ = 100 Erlang. Define: quality parameters P_B and P_m, and the average length of the intervals between applications Z and average service time T, the dispersion coefficient D and coefficient of concentration S, the standard deviation σ. Determine the coefficient of variation $varZ = \sigma / Z$.

2. Explore the type system *HM/M/m* – queuing system QS with m = 115 servers, service discipline with losses. The system comes with the intensity of the flow requirements of Λ = 100 Erlang. Set the concentration factor of 4, double-check the value of the intensity of the input load Λ. Define: quality parameters P_B and P_m, and the average length of the intervals between applications Z and average service time T, the variance of D, the standard deviation σ. Determine the coefficient of

variation *varZ*. Conduct a similar experience when S = 16. Record obtained characteristics QoS.

3. Restore the model investigated in paragraph 2. Draw the plot of the distribution function of the number of claims received during the average service time. Note that in the Poisson formula is the average value, and Gauss - Λ and σ.

4. Change the distribution of the service time on the regular. Draw the graph of the distribution function of the system states. Approximate by two distributions: *I Erlang* distribution and the distribution of *N Loshkovsky*. Can I use *I Erlang* distribution with $S>1$?

5. Explore the type system *HM/D/m/∞* - full-accessible scheme QS with m = 115 servers, service discipline without loss. The system comes with the intensity of the flow requirements of Λ = 100 Erlang. Write down obtained characteristics. Draw the plot of the distribution function of the system states, approximate it by a Gaussian function.

6. Investigate systems *HM/D/m* and *HM/D/m/∞*. Determine the average number of busy channels. What systems have better bandwidth? What settings affect the bandwidth?

7. Explore the type system *HM/D/m/∞* – full-accessible scheme QS with m = 140 servers, service discipline without loss. The flow requirements comes to the system with the intensity of the input load Λ = 125 Erlang. Draw the plot of the distribution function of the system states. Approximate by two distributions: the Gauss and normal Hdop1 (tick the box in front of additional parameters: *Y* and σ).

Make the conclusion on each laboratory item.

6 Content of report

In a report on implementation of this laboratory work the student must bring: the topic, purpose, answers to test questions, the results of the laboratory assignments, plots, and conclusions.

7 References

1. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

Laboratory Work № 7

INVESTIGATION OF QUEUING SYSTEMS WITH INFINITE QUEUE *fBM/D/1/∞*

1 Goal of laboratory work

To research the packet traffic influence on the quality of service parameters *QoS*. To research the packet traffic peculiarities.

2 Key positions

The traffic of multiservice networks with packet switching is characterized by long-term relationships in the intensity of the load and the significant difference between the statistical properties of packet flows from the Poisson stream. Adequate model of the flow in such networks is considered self-similar (self-similarity) processes, where the input stream is described by the fractal Brownian motion (model *fBM*). However, the study of the characteristics of service quality information distribution systems in these conditions is a very difficult mathematical problem. The reason for this is the weak formalized model of the self-similar flows, so that can not be obtained analytically based results to estimate the *QoS* parameters in the information distribution systems.

The most perspective method is the method for estimating the parameters of service quality of the self-similar traffic, in which the proposed use of the methods of calculation known classical distributions, the entropy of which is the closest to the entropy of the system states under the conditions of service of the self-similar traffic [1]. Then it becomes possible to calculate the characteristics of QoS models with the self-similar traffic under any law of the distribution of the service time for Polyachek-Khinchin formula [2].

The random process of packets arrival at the information distribution systems for service, creates a flow of packets (traffic), which is characterized by a the certain distribution, which establishes a relationship between the value of a random variable (number of packets) and the probability of occurrence of the value. In most cases, for the calculation of *QoS* parameters it's necessary to know about the distribution only some numerical data - different orders of distribution moments. For the calculation of the Poisson distribution in sufficient expectation Λ, and for normal distribution - expectation and variance Λ, D requires. The main characteristics of the random process Λ and D, although are very important, at the same time are not exhaustive, and sometimes they are useless for predicting the value of a random variable. Sometimes a random process is characterized by the same values of Λ and D, but the internal structure of these processes is different. Some of them may have a smoothly varying implementation, and others - a pronounced oscillating structure with an abrupt change in the individual values of the random variable (e.g., a sharp increase in the number of packets in the network, which leads to the "burstness" of traffic). For the "smooth" processes high predictability of implementations is typical, and for "burstness" - a very small probability dependence between two random variables. In such cases, the distribution, which characterizes the random variable, carries some uncertainty and allows with more or less reliability to predict the value of a random variable.

Thus, the probability distributions, which are used to describe the traffic in packet networks do not provide a quantitative assessment of the uncertainty of the queuing system, the entropy distribution. The entropy does not depend on the values of which gets a random variable, but only on their probabilities. Estimation of the parameters of service quality of the self-similar traffic can be entropy method, which amounts to the use of calculation methods known distributions, the entropy is equal to or close to the entropy of the system states for maintenance of the self-similar traffic [1].

3 Check questions

3.1 What is the traffic in the multi-service packet switching networks characterized by?
3.2 What does estimation of *QoS* of self-similar traffic method consist of?
3.3 Name the main characteristics of the normal distribution random process.
3.4 What is typical for «smooth» and «burstness» processes?
3.5 What does the entropy of random variable distribution depend on?

4 Homework

4.1 Answer the check questions in writing.

5 Description of laboratory work and implementation principles

Run the “Modeling CMO” program using either label “Modeling CMO” on the desktop, or by clicking the following path: Start – All Programs – Modeling CMO. Then, you must:

1. Investigate the system type *fBM/D/m* – full-accessible circuit with $m = 1$ and 115 servers, service discipline without loss (set all of 1500). The system comes with the intensity of the flow requirements Λ = 0,7 and 100 Erlang. Set the parameter “number of serviced requests” to 2 000 000. Define quality parameters *Q*, *W*, *tq, Pw* and *Pv*. Determine the coefficient of variation $varZ = \sigma / Z$. Set the parameters α = 1,3; β = 0,1; H = 0,85. Construct a graph of the distribution of the system states, with the logarithmic scale, approximate by an exponential distribution.

2. Investigate the same system, but the parameter “number of serviced requests” set to 5 000 000. Draw the graph of the distribution function of the number of claims for the average service time selecting the linear scale.

3. Set the parameters α = 1,9; β = 0,1; *H* = 0,55. Set up a queue of 300. Set the peak factor load to 4. Set the parameter "number of serviced requests" to 5 000 000. Determine the coefficient of variation *varZ*. Define quality parameters *Q*, *W*, *tq, Pw* and *Pv*. Draw the graph of the distribution function of the number of claims for the average service time.

4. Construct the graph of the distribution of the system states, with the logarithmic scale. What are the accounts for the void in the previous graph? Grouped as a single application of vacuum to the other?

5. Which distributions can be used to describe the packet traffic, and why? What are the numerical characteristic distributions, which can serve as the degree of inequality? Draw the graph of the distribution function of the system states, with selected linear scale, before plotting put a tick in the box to the value $P_B = 0$. Approximate by the Gaussian distribution function.

Make the conclusion on each Lab item.

6 Content of report

In a report on implementation of this laboratory work the student must bring: the topic, purpose, answers to test questions, the results of the laboratory assignments, plots, and conclusions.

7 References

1. А.Г. Ложковський, Ганифаев Р.А. Оценка параметров качества обслуживания самоподобного трафика энтропийным методом // Наукові праці ОНАЗ ім. О.С. Попова. – 2008. – №1. – С. 57-62.

2. Loshkovskii A.G. Queuing systems in telecommunications – Odessa: ONAT, 2010. – 112 p. (in Russian and Ukrainian).

Учебно-методическое издание

Анатолий Григорьевич Ложковский

Татьяна Рудольфовна Шмелёва

ТЕОРИЯ ТЕЛЕТРАФИКА

Методические указания к выполнению цикла лабораторных работ
по курсу
«Теория телетрафика в телекоммуникациях»

на английском языке

Редактор *Чепелюк Н.И.*
Компьютерная верстка *Гардыман Ж.А.*

Здано в набір 11.11.2013. Підписано до друку 21.11.2013
Формат 60х90 1/16. Зам. №
Тираж 50 прим. Обсяг 2,2 друк. арк.
Віддруковано на видавничому устаткуванні фірми RISO
у друкарні редакційно-видавничого центру ОНАЗ ім. О.С.Попова