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ANALYTICAL SIMULATION METHODS DETERMINING THE BASIC CHARACTERISTICS OF A TELECOMMUNICATION NETWORK WITH DIFFERENT COMMUNICATION CHANNELS AND A CHANGING STRUCTURE

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Abstract. The article deals with the problems of determining the main quality indicators of a telecommunications network with different types of communication channels and the time-varying structure of their functioning to ensure the specified reliability and time of delivery of protected messages to information consumers. The main method of solving this problem is using analytical and simulation methods on personal computers. Comparison of the obtained simulation results with the results of analytical models are also given.

The developed algorithms for simulation of the process of transmitting messages in various transmission modes allow obtaining distribution of time for message delivery in the system, waiting times for messages in the communication center and many other benefits.

Keywords: telecommunication networks, different types of communication channels, networks with a changing structure, algorithms for simulation.

Introduction

In the world, there is currently an intensive development and implementation of reliable and secure information and communication technologies for data exchange between various consumers of information, especially with the rapid development of high-speed mobile communication systems of various cellular companies. The construction of such systems is based on the use of the existing both wired and wireless telecommunication networks for organizing data exchange between different subscribers of a heterogeneous network.

The modern telecommunications network is a complex system with a large number of different points and nodes connected by numerous channels of various types, purposes and capacity. Complex multimedia streams of heterogeneous information intended for processing and delivery to numerous consumers pass through communication channels. At the same time, the mode of operation of the network is constantly changing, reflecting various random or regular changes in modern activities, and such changes lead to certain difficulties when trying to provide reliable communication for optimal control of various objects that are consumers of information.

The creation of scientific foundations for the study and construction of secure protected telecommunication networks is impossible without the development and use of models for the functioning of networks with sufficient adequacy reflecting the basic structural and functional relationships of network systems.

There are a large number of works devoted to the definition of various characteristics of telecommunication networks. Mostly, these works are focused on the study of a network with wired communication channels [1 - 6].

A specific feature of the construction of modern integrated information and communication technologies (ICT) is the diversity of the channels used and the dynamism (variability) of the network structure, i.e. this applies to telecommunication networks with different types of communication channels and changing structure. This refers to the use of wired, fiber-optic, and wireless mobile cellular radio communication channels [7-10].

An additional feature of such systems is the need to take into account the priorities of messages according to their importance and urgency, as well as the modes of transmission and reception, which can be very different.

To determine the main qualitative characteristics of communication networks with wired and wireless communication channels with a changing structure and to identify the effectiveness of their functioning, analytical methods and methods of statistical (simulation) modeling on personal computers (PCs) can be used as research tools. Under the changing structure, we mean mobile (in particular, cellular) or satellite communications, although the base stations are stationary, but the subscribers can be in motion, which leads to a change in the structure of the network at a given time.

The efficiency of functioning of secure information and communication technologies (ICT) with a changing structure depends not only on the quality indicators of the components, but also on the control algorithms and adaptation of individual network components to the existing operational situation. Therefore, the development of methods and adaptive control algorithms for data transmission networks with a changing structure is important in scientific and practical terms [9, 10].

The data exchange in modern information and communication technology is carried out on the basis of conventional telecommunication telephone and wireless mobile (cellular) communication network.

Main part

The object of the research is a telecommunication network with wired and wireless radio communication channels and a time-varying structure, designed to ensure reliable and secure communication between senders and recipients of information (IAS).

The efficiency of the functioning of networks, their cost, throughput, noise immunity, reliability and other parameters are determined by the choice of a set of technical means and network structure [11-14].

Usually, the construction or development of telecommunication networks begins with a preliminary analysis of the characteristics of information circulating in the system being developed and the study of the properties and interconnection of sources and consumers of information. All this influences the choice of structure, topology, procedures and the composition of the components of the telecommunication network. The advantages of building or developing a telecommunications network using switching centers in comparison with networks, the structure of which repeats the structure of the serviced control system, are:

- a significant reduction in the total number of communication channels and their length due to the fact that there is no need to organize numerous direct routes between different objects or subscribers;

- high efficiency of using the bandwidth of communication channels, due to the use of the same channels for the transmission of many and different types of information between different users of the mobile communication network;

- the use of one complex telecommunication network for the exchange of information in the interests of many large control systems.

The main parameters characterizing the communication network and the clientele served are following:

a) the number and type of communication channels between the switching nodes of the wired network or base stations of mobile communication;

b) the intensity of the incoming load flows;

c) speed of information transfer;

d) the probability of errors;

e) information delay time;

f) the bandwidth of the network branches;

g) security of transmitted information.

There is a certain interdependence between the listed variable parameters that characterize the information network.

As a criterion for optimizing the construction of a reliable secure telecommunication network, it is advisable to use minimization of the amount of time delays leading to a delay in bringing information to the recipient. Also, the probability of errors per information symbol, as well as capital and operating costs for increasing security, reliability of delivery, ensuring the specified delivery speed and delivery time to the consumer of information [1, 3]:

$$C_{\Sigma} = min\ \Sigma\ t_{d,m} + min\ \Sigma\ P_e + min\ \Sigma\ C_{cost}$$

where:

t_d - time delay in delivering information to the consumer,

P_e- error probability per symbol of transmitted information,

C_{cost} - capital and operating costs (costs of improving the system by improving noise immunity, system reliability, transmission speed and reducing message delivery time, etc.).

The reducing information latency can be achieved by increasing the speed of information transfer through the communication channel and reducing the latency in communication nodes. Moreover, reducing the number of errors in communication channels can be achieved by increasing the noise immunity of data transmission systems, which is possible with the introduction of informational or procedural redundancies (leading to reducing the transmission speed), increasing the power and complicating the technical means of data transmission, as well as increasing the cost of building such systems. The use of more powerful and more complex technical means to increase noise immunity leads to additional material costs, which are determined by cost estimates.

Application of the above criterion for the functioning of the network makes it possible to take into account the technical and economic indicators of objects that are consumers of information.

Considering these factors when operating networks allows more objective and realistic determination of the modes of use of the existing telecommunication network.

The proposed approach for ensuring information security in telecommunication networks and systems is that when developing and constructing any information systems and information protection tools, it is necessary to take into account information delays, taking into account their importance, determined by the recipient of this message.

The importance of information is determined by the material effect of saving the generalized labor costs of the recipient object to achieve the goal. In general, goal achievement is described by the expression [3]

$$P = P_{in} – C_{cost},$$

where P - an indicator characterizing the operation of the integrated system (profit, productivity, quality and quantity of products, degree of completion of the task, etc.); P_{in} - indicator P, taking maximum values with absolutely accurate and reliable functioning of the information system. C_{cost} – cost costs for improving the telecommunications system. The advantage of this expression is the fact that P synthesizes cost changes not only to create a secure telecommunication network, but also the total costs of the system as a whole.

In the process of designing or developing existing networks with heterogeneous channels and a changing structure, one has to solve the following problems:

- an analysis task when a set of external and internal network parameters is given and it is required to evaluate the quality (indicators) of its functioning;

- The optimization task, which consists in determining the internal parameters of the network that ensure the transmission of predetermined information flows with the required quality (according to a given criterion).

Basically, the solution of the problems of analysis and synthesis of various telecommunication networks is reduced to the tasks of assessing probability-time characteristics (PTC).

To evaluate the PTC network with heterogeneous channels, a combined use of analytical and static models is proposed. At the same time, the choice of method and models for assessing PTC is determined by the characteristics and parameters of message flows transmitted over the network, as well as various laws of message service.

The study of the structure and laws of distribution of message flows is a prerequisite for assessing probabilistic and temporal characteristics (PTC) and solving the problems of analysis and synthesis of networks with different types of channels and a varying structure.

Messages of each priority are characterized by:

- the nature of the flow, determined by the distribution function (DF) and the density function (DF’) of the lengths of the intervals between messages - F (τ), f (τ);

- intensity or flow parameter - λ

- DF and DF’ capacitance message lengths - F (l), f (l),

- message parameters (average message length, sometimes length dispersion) –

$$\bar{l}, D^2(l)$$

In some cases, it is necessary to know the magnitude of the load of various priorities, the characteristics of unevenness, etc. The choice of the method for estimating PTC is determined mainly by the probabilistic characteristics and structure of message flows, transmission methods and message processing algorithms, structure of transmission paths, etc.

One of the most effective methods for improving the quality of the functioning of telecommunication networks and systems is the organization of priority message service, which consists in providing advantages to messages with a higher priority or messages with large cost losses from delivery delays. It is quite natural to expect that: if during the transmission process we give preference to service for rapidly aging messages, then the overall flow of timely delivered messages will increase, if we give preference to the most valuable messages, the total value of the delivered messages will increase or the total information delay time will decrease.

The optimal priority system should take into account the characteristics of each individual message. However, the implementation of such a system is practically impossible due to technical difficulties and because it is impossible to accurately establish the value of each message on a single scale, especially when you consider that they can be sent by different subscribers. Therefore, usually the entire stream is divided into several groups, and all messages in one group are given the advantage of serving over all messages in another group. Within one group, messages are considered "peer to peer."

Thus, the general task of synthesizing the optimal priority system can be formulated as follows: to divide the total message flow into n flows and organize such a transmission so that to maximize the value [3]:

$$W_E = \frac{\sum_{k=1}^{n} L_k M_k Q_k}{\sum_{k=1}^{n} L_k M_k} \quad (1)$$

where: - W_E network performance indicator characterizing the value of transmitted messages;

- L_k the relative share of the stream of the K-th priority;

- Q_k probability of timely transmission of messages of the K-th stream. To assess the degree of influence of each of the parameters of message flows, we consider separately priority systems according to the value or time of message aging.

Consider organizing priorities for message value. Let the total message flow be characterized by the density distribution of the message value f (C_0). The first priority will be messages with $C_0 \geq C_1$, the second - with $C_2 \leq C_0 \leq C_1$, etc. The task is to find such values of C_k (k=1, n=1) at which the maximum value of WE is ensured. In this case, it is more convenient to use a slightly different expression for WE (without normalizing message values):

$$W_E = \frac{\sum_{k=1}^{n} L_k (C_0) Q_Э}{\sum_{k=1}^{n} L_k M_k (C_0)} \quad (2)$$

It is easy to show that

$$L_1 M_1 (C_0) = \int_{C_1}^{\infty} C_0 f(C_0) dC_0 \, , n \quad (3)$$

$$L_k M_k (C_0) = \int_{C_k}^{C_{k-1}} C_0 f(C_0) \, dC_0 \, , k = \overline{2, n} \; (4)$$

$$\sum_{k=1}^{n} L_k M_k (C_0) = \int_{0}^{\infty} C_0 f(C_0) dC_0 = M(C_0) \; ; \; (5)$$

$$Q_k = Q_\infty \frac{1 - \rho^{k+1} Q_m^{K+1}}{1 - \rho^{k+1} \rho} \quad (6)$$

To find Q_k, we use expression (6) to study the influence of only the value of messages, we set $\mu_k = \mu_1$,

$$\nu_k = \nu (k = \overline{1, n})$$

Then you can write:

$$Q_k = \frac{1 - \sum_{i=1}^{k} \rho_i}{\nu \left[\mu^{-1} + (\nu + 6_{k-1} \prod_{k-4}(\nu)^{-1}\right] - \rho_k} \; ; \; (7)$$

Where: $\rho_i = \frac{\lambda_i}{\mu} = \frac{\lambda \cdot L_i}{\mu} = \rho L_i$;

$$\prod_{k-1}(\nu) = \sum_{i=1}^{k-1} \lambda_i \mu 6_{k-1}^{-1} \left(\nu + 6_{k-1} - 6_{k-1} \prod_{k-1}(\nu) + \mu\right)^{-1} \quad (8)$$

Given that $\prod_{k-1}(\nu)$ should be less than 1, and replacing $6 = \frac{\nu}{\mu}$ we get:

$$\prod_{k-1}(6) = \frac{1 + \delta + \rho \sum_{i=1}^{k-1} L_i}{2\rho \sum_{i=1}^{k-1} L_i} - \sqrt{\left(\frac{1 + \delta + \rho \sum_{i=1}^{k-1} L_i}{2\rho \sum_{i=1}^{k-1} L_i}\right)^2 - \frac{1}{\rho \sum_{i=1}^{k-1} L_i}} \; ; (9)$$

$$Q_k = \frac{1 - \rho \sum_{i=1}^{k-1} L_i}{\delta \{1 + [\delta + \rho \sum_{i=1}^{k-1} L_i (1 - \prod_{k-1}(\delta))]^{-1}\} - \rho L_k} \quad (10)$$

$$Q_k = \frac{1 - \rho\sum_{i=1}^{k-1} L_i}{\delta\left\{1 + \frac{1}{\delta + \rho\sum_{i=1}^{k-1} L_i\,(1 - \prod_{k-1}(\delta))}\right\} - \rho L_k} \quad (11)$$

As an example, consider the two simplest comparing densities distribution of message value f (C_0).

The law of uniform density:

$$f(C_0) = \begin{cases} \frac{1}{C_{max}} & 0 \le C_0 \le C_{max} \\ 0 & C_0 < 0, C_0 > C_{max} \end{cases} \quad (12)$$

In this case

$$L_k = \frac{C_{k-1} - C_k}{C_{max}} - b_{k-1} - b_k \quad (13)$$

where $b_k = \frac{C_k}{C_{max}}$, $k = \overline{1, n}$

In accordance with (2):

$$L_k M_k(C_0) = \int_{C_k}^{C_{k-1}} C_0 f(C_0) d(C_0) = \frac{1}{C_{max}} \int_{C_k}^{C_{k-1}} C dC =$$

$$= \frac{C_{k-1}^2 - C_k^2}{2C_{max}} = \frac{C_{max}}{2}\left(b_{k-1}^2 - b_k^2\right); (14)$$

$$M(C) = \frac{C_{max}}{2}\sum_{k=1}^{n} Q_k\left(b_{k-1}^2 - b_k^2\right); \ (15)$$

where given (11)

$$Q_k = \frac{1 - \rho(1 - b_k)}{\delta\{1 + [\delta + \rho(1 - b_k)(1 - \prod_{k-1}(\delta))]^{-1}\rho(b_{k-1} - b_k)}; \ (16)$$

With a uniform distribution law,

$$W_E = \sum_{k=1}^{n} \frac{1 - \rho(1 - b_k)(b_{k-1}^2 - b_k^2)}{\delta\{1 + [\delta + \rho(1 - b_k)(1 - \prod_{k-1}(\delta))]^{-1}\rho(b_{k-1} - b_k)} \quad (17)$$

Obviously, the maximum is reached at some values W, which do not depend on the absolute value of W_E. Therefore, with a uniform law of distribution of message values, for any given number of n priorities, it is possible to determine the optimal values of bk, that provide a maximum of W_E.

Research results.

In fig. 1 shows the dependences of the average message delivery time in the system on the message arrival rate λ for the service parameter values μ = 60 and μ = 20 m / h (see Table 2). As can be seen from the graph, at μ = 60 m / h, the average message delivery time in the system increases linearly with increasing intensity λ.

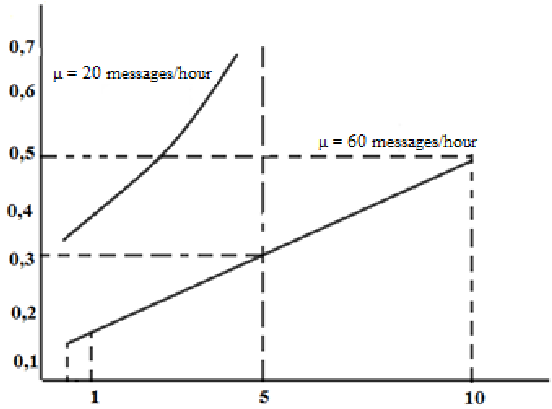

Figure: 1. Dependence of the average delivery time of the message on the intensity of receipt

With a decrease in the service parameter, i.e. at μ = 20 m/h, the increase in the average time of delivering requests in the system increases rather sharply with an increase in λ at values starting at λ = 2 m/h.

The experimental calculation results are shown in Tables 1 and 2.

Also obtained are histograms of the distribution of the message delivery time at λ = 0.5 m/h and μ = 20 m/h; λ = 5; 10 m/h at μ = 60 m/h.

Verification of the experimental distribution according to the criterion of goodness x2 at λ = 5 m/h and μ = 20 m/h showed that the distribution has the character of a uniform law, which can be assumed for the case λ = 5; 10 m/h, μ = 60 m/h.

Table 1.

No.	λ	μ	Poisson exponent	Poisson uniform	Uniform exhibitor	Exhibitor uniform
1	0,5	20	0,317	0,221	0,339	0,219
		60	0,193	0,191	0,191	0,165
2	1	20	0,361	0,230	0,364	0,229
		60	0,197	0,166	0,198	0,165
3	5	20	3,491	0,383	-	0,803
		60	0,262	0,174	0,325	0,178
4	10	20	-	1,554	-	51,0
		60	0,417	0,220	15,149	0,227

Table 2.

t_g (hour)	0,1	0,16	0,26	0,30	0,36
λ m/h (messages/hour)	-	0,36	0,88	0,94	0,97
λ = 1	0	0,309	0,88	0,93	0,97
λ =5	0	0,202	0,66	0,75	0,82
λ=10	0	0,104	0,41	0,46	0,53

The presented simulation results show that using the developed statistical model, various probabilistic - temporal characteristics and parameters of a telecommunication network with wired and wireless communication channels of a given structure can be obtained. Comparison of the obtained simulation results with the results of analytical models showed their good agreement.

The histograms of the distribution of the delivery time of requests in the system at different rates of arrival λ = 0.5 were obtained; 5; 10 messages/hour and at μ = 60 m/h. It was revealed that the distribution law of the time for bringing the requirements in the system has an exponential character.

When using analytical models, in each case there are limitations imposed on the nature of the flow and service, the number of phases, service disciplines, priority system, etc.

When studying a telecommunication network in conditions close to real ones, the method of simulation modeling on personal computers can be used to assess the main qualitative characteristics of the network. The ultimate goal of studying the principles of construction and modes of operation of multilink priority data exchange systems is to determine the main indicators of the quality of functioning of a multi-level hierarchical network with different types of communication channels.

Conducting an analytical study presupposes the presence of a sufficiently complete and accurate analytical description of the system as a whole, the creation of which is mostly difficult due to the complexity of the processes occurring in networks with different types of channels.

Therefore, the use of only analytical methods turns out to be possible only with significant simplifications, which, as a rule, leads to obtaining probabilistic characteristics of some simplified network model.

Computer simulation is a general method without any theoretical limitations. Modeling the messaging process in a communication network with different types of channels and a given structure has a number of specific features, the main ones of which are as follows:

1. To model a network (more precisely, the processes occurring in it), it is required to develop software generators or their corresponding algorithms. Programs of this type are not only associated with a specific type of simulation system (in this case, a network), each such program is based on a specific mathematical model. Of course, this narrows the scope of their application, however, the presence of a general methodological concept successfully incorporated into the complex of programs can significantly reduce the labor intensity and time consumption at the initial stages of programming.

2. An important problem in the algorithmic and software development of a network with wired and wireless communication channels is the overall complexity of the entire simulated system. In this regard, the expediency of dividing (decomposing) the general model into private sub-models and the transition from them to common.

3. Having the possibility of direct application of the existing assortment of programs, you cannot do without creating your own programs that complement standard software tools. In the most favorable case, you can limit yourself to the modification of standard programs, coordinating them with the specific conditions of use and needs. The use of existing programs depends on their adaptability.

For modeling a complex multi-level radial-nodal network with a time-varying structure and different types of communication channels in order to determine its main qualitative characteristics of functioning, it is convenient to start with considering the general structure in the form of substructures of various configurations.

Determining the required estimates of the functioning of the structure under consideration reduced to calculating the characteristics of a multiphase queuing system.

Conclusion

In this article, the tasks of determining the main quality indicators of a telecommunication network with different types of communication channels and the time-varying structure of their functioning were considered to ensure the specified reliability, reliability and time of bringing protected messages to information consumers. The main method of analytical and simulation methods on personal computers was used for solving this problem.

The developed algorithms for simulation of the process of transmitting messages in various transmission modes allow to obtain the following characteristics:

- the dependence of the average time of message delivery t_g to the system on the intensity of the arrival of λ at fixed values of μ and the laws of distribution of the service parameter for different laws of receipt of messages;
- the dependence of the average waiting time for messages to the communication center (CC) on the intensity of message arrival λ for fixed values of μ and given laws of service and receipt of messages;
- distribution of time for message delivery in the system;
- distribution of waiting times for messages in the communication center;
- the probability of timely delivery of messages $P_g(t \le t_g)$;
- the dependence of the probability of timely delivery of messages P_g from the allowable time (delay) for bringing applications in the system (t_g);
- quantitative indicators of served and not served messages in each node of the telecommunication network;
- the number of retransmissions;
- the number of messages that reached the consumer information during the first transmission and one, 2, 3 or more retransmissions;
- distribution of the memory capacity of network nodes, recipients of information, and others.

The obtained simulation results show that, using the developed statistical model, various probabilistic-temporal characteristics and parameters of the telecommunication network of a given structure can be obtained. Comparison of our simulation results with the results of analytical models showed their good agreement.

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