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Designing Information and Communication Networks

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ABSTRACT:The purpose of this study is to increase the efficiency of designing infocommunication networks through the use of the method of penalty functions with restrictions on the probabilistic-temporal characteristics of information flows. The method of penalty functions is a powerful computational tool of the theory of optimization and is convenient because the structure of constraints, their nonlinearity or linearity, smoothness or non-smoothness, do not play a fundamental role in solving the design problem. In addition, the method of penalty functions is easy to calculate, it is possible to take into account many structural parameters. An important task of effective design of info communication networks is to find the optimal structure, according to the criterion of network-wide costs, taking into account the limitations on the quality of transmitted many product flows of information. The results showed that in the area of small sizes of the territory of 3x3, 4x4 and 5x5 km networks, the above costs change little, which is explained by the fact that in a limited area the bulk of the costs are the cost of nodes, the number of which does not depend on the size of the territory, but is determined only by the capacity of the network. It has been determined that at network levels R=2,3,4,5 the most optimal, regardless of topology, are networks with layers 2 and 3 compared to networks with layers 4 and 5. It was revealed that the radial structure was 5 (five) times more economical than the fully connected structure, 3 (three) times compared to the ring structure and 2 (two) times more economical than the lattice structure. The proposed method allows you to take into account all the technical parameters of the network, as well as the integration of information resources located in different geographical locations and does not require that the starting point belongs to an acceptable area. Based on the above method of designing infocommunication networks, a computer program in the Python language was developed, and a certificate was obtained from the Intellectual Property Agency of the Republic of Uzbekistan.

KEY WORDS: Info communication network, network design, penalty function, network-wide reduced costs, optimal structure.

I. INTRODUCTION

Improving the efficiency of the design of infocommunication networks largely depends on many factors, in particular, on properly developed mathematical models and methods. In turn, the development of mathematical models and methods for designing infocommunication networks is a complex task, where it is necessary to solve a number of interrelated topological optimization problems, taking into account the characteristics of the incoming many product flows of information. Infocommunication networks are built as a multi-level structure that include various endpoints, nodes with different performance and communication channels with different bandwidth. Each level is built on the basis of various arbitrary topological constructions, for example, a fully connected, circular, lattice and radial structure. Such networks are difficult to design, so to properly solve the design problem, it is necessary to use new methods and models that give accurate and adequate results. Their main content is determined by the design methodology, when a topological structure of the network is formed that meets the requirements for its characteristics, technical means are selected, and software is developed. It is determined which control devices and protocols for managing the processes occurring during the operation of the infocommunication network will be selected. How to improve the efficiency of the design of infocommunication networks and how can you determine the optimal structure? Which design method is more effective? These complex questions were partially answered in the following works, for example, in the work [1,2] the issues of optimizing the structure of the content delivery network were considered, the criteria for optimization by latency, restrictions on the values of incoming flows and the conditions for preserving redistributed flows were formulated. The proposed technique allows to distribute the load between the nodes according to the criterion of

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average latency and choose the optimal structure of the network nodes. It also takes into account the conditions for maintaining load flows to the nodes. However, this work does not take into account the heterogeneity of incoming flows and does not solve the problems of designing a multi-level infocommunication network depending on the cost indicators of the network. The most widespread method of branches and boundaries [6], which is based on the idea of sequential partitioning of many permissible solutions. At each stage of the method, the elements of the partition (subset) are analyzed whether this subset contains an optimal solution or not. The process continues until all partition elements have been reviewed. This method does not make it possible to take into account many structurally network parameters of the infocommunication network, the method is based on the tree-like decomposition of the space of permissible solutions, other topological constructions of networks are not taken into account, such as the ring structure, fully connected structure, lattice structure, etc. In the work [7] a model of structural and functional synthesis of the transport telecommunication network is proposed. It does not require a preliminary solution to the problem of distributing capital investments between the design stages, i.e. the model itself provides for the possibility of solving the problem of structural and functional synthesis of the telecommunications network: choosing a topology, choosing the bandwidth of transmission paths, distributing flows (routing) and limiting traffic coming from networks to access to the transport network. However, given the multi-level structure of the telecommunications network, they are insufficient for a complete analysis and calculation of the following structural and network problems: network-wide costs, taking into account the topological structure of networks, the average delay time of packets, the length of communication channels, and ultimately the determination of the optimal structure of networks. The works [3,12,13] consider algorithms for descending coordinates to solve the problem of optimizing the structural parameters of a telecommunications network by sequentially performing approximate minimization along the coordinate directions or hyperplane coordinates. These are essentially iterative methods in which each iteration is obtained by fixing most of the components of the variable "x" vector in their values from the current iteration and approximately minimizing the goals relative to the remaining components. Each such subtask is a low-level minimization (even scalar) problem and thus can usually be solved more easily than a complete problem. However, this optimization method does not make it possible to calculate the network-wide reduced costs of networks and it is not possible to determine the optimal structure of networks, only limited to finding certain points in the coordinate plane. In order to increase the efficiency of designing infocommunication networks, the method of penalty functions (MPF) is proposed [8,9,10].

In the subsequent sections of this work are devoted to a detailed presentation of the essence of the MPF, the calculation of network-wide costs, the definition of the optimal structure of infocommunication networks.

II. LITERATURE SURVEY AND METHODOLOGY

The task of effective design of infocommunication networks with the use of (MPF) is a procedure for a complex optimization task focused on the application of the tasks of designing and forecasting the technical and economic indicators of infocommunication networks with a multi-level structure. Methods of designing infocommunication networks, based on the MSF, involve the consideration of simple and convenient for calculation structural parameters and weakly tied to the classical concept of analysis and synthesis of networks. The general task of designing infocommunication networks is reduced to the search for components of the vector X, which delivers a minimum of the functions of network-wide reduced costs and includes [9]:

$$X = \lfloor R, W_r, W_{r-1,r}, n_{ir}, m_{jr}, m_{jr-1,1} \rfloor, \quad (1)$$

where: R - is the number of hierarchy steps; $W_r, r = \overline{1,R}$ -topology of subnets of the r th stage of the hierarchy; $W_{r-1}, r = \overline{2,R}$ - topology of interlevel subnets; n_{ir} is the number of switching nodes (concentrates and centers of switching nodes) of the i-th type at the k-th stage of the hierarchy; $m_{jr-1,r}$ is the number of communication channels of the j–type in the interlevel subnet with the index (r -1 ,r). The purpose of the design task to be

$$\Pi(X) \to \min \quad (2)$$

When the standards for the quality of service for users of infocommunication networks are met, that is, the norms for the average delivery time T_k of a data packet of the k-th priority and the probability $P_k\{T \le t\}$ of delivery of a speech packet in a random time T, should not exceed the specified t.
The average delivery time T_k of a package is calculated using the following formula:

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$$T_k = \frac{1}{\mu_э - \lambda}(1 + \frac{\mu_э \kappa_Г}{d}), \quad (3)$$

where: $\mu_э -$ is the effective intensity of package maintenance; $\lambda -$ is the intensity of packet receipt; $\kappa_Г$ - the availability coefficient of the communication channel; $d = 1/T$ -is the intensity of channel recovery. The average time T_k delays of the data packet of the k-th priority T should not exceed the specified *t*.

For a multi-level infocommunication network, the network-wide reduced costs P(X) are calculated using the following formula, which consists of capital and operating costs [10]:

$$П(X) = \sum_{r=2}^{R}\left[E_H \sum_{i=1}^{I} W_{ir} * C_i^y * n_{ir} + \sum_{j=1}^{J} W_{jr} * C_j^k * m_{jr} + \sum_{j=1}^{J} W_{jr-1,r} * C_{jr-1,r}^k * m_{jr-1,r}\right] + \sum_{r=1}^{R} e_r s_r, (4)$$

where: $E_H = 0{,}15$ is the standard coefficient of economic efficiency of capital expenditures; $I -$ number of node types (gateways, switches, servers, workstations); $C_i^y = \{G_i^y(K_{гi}^y, d_i^y)\} -$ cost function; $G_j^Y -$ performance of switching nodes; $K_{Гi}^Y$ –readiness coefficient; d_i^Y –channel recovery intensity; $i = \overline{1, I}$; $n_{ir} -$ the number of i-type switching nodes on the r-hierarchy; $J -$ number of types of communication channels (CC); $C_j^k = \{V_j, l_j\} -$ cost function; $V_j -$ speed in the communication channel; $l_j -$ the length of the communication channel; $m_{jr} -$ the number of j-type communication channels at the r-th stage of the hierarchy; $J -$ number of types of inter-level communication channels; $V_{jr-1,r} -$ speed in inter-level communication channels; $l_{jr-1,r} -$ length of communication channels of the inter-level hierarchy; $m_{jr-1,r} -$ the number of j-type communication channels on the (r–1)th and r-th levels of the hierarchy. $W_{ir} -$ type of topology of the infocommunication network of the i-th type at the step r; $W_{jr} -$ type of topology of an infocommunication network of the j-th type on the step r; $W_{jr-1,r} -$ type of topology of the infocommunication network of the j-th type between the (r-1) and r-th stages of the multi-level network;

To solve the problem of designing the structure of infocommunication networks, a method is proposed based on the additive convolution of the objective function and constraint functions using the penalty function method (PFM), which allows reducing the original problem with constraints to a sequence of problems of unconditional minimization. This approach contributes to the unification of the process of solving design problems, since it does not associate the solution method with a specific structural problem with a specific interpretation or context, and the structure of constraints, their linearity or non-linearity, smoothness or non-smoothness, as well as whether the starting point belongs to the admissible region are of no fundamental importance when minimization of the penalty function. Preliminary fixation of the topology is not a significant limitation of the optimization method, since in the process of optimization, not only the numerical values of the variables being optimized change, but also the type of topology. With the penalty function method, the original objective function becomes more complicated, which is replaced by the generalized objective function F(X, h) and has the form [8]:

$$F(X, h) = П(X) + P(h)\Psi(X) \rightarrow \min, \quad (5)$$

where: Ψ(X) is a function of the vector "X", and at Ψ(X) = 0, if the constraint is satisfied (i.e. the desired point is inside the valid region or at its boundary) and Ψ(X) 0 - in the opposite case; P(h) is a monotonically increasing function of the variable h. The value of F(X, h) in the allowable region coincides with P(X), and outside the allowable one is determined by the penalty term P(h)Ψ(X). This function grows rapidly as the X-point moves away from the allowable area. When solving the problem of designing infocommunication networks, a penalty function of the following form is adopted:

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$$F(X,h)=\Pi(X)+\frac{h}{2}\sum_{i=1}^{m_0}\left\{[\varphi_i(X)+\frac{\lambda_i}{h}]^+\right\}^2, \qquad (6)$$

where: m- is the number of constraints;h, λ_i - algorithm parameters $h>0$, $\lambda_i>0$, $i=\overline{1,m_0}$; $[\bullet]^+$ - function $\Psi(X)$; $\varphi_i(X)$- constraint function. The presented method of designing infocommunication networks allows to simplify the process of calculating the structural and network parameters of the network, and it also becomes possible to compile an algorithm for calculating the optimized parameters and obtain more accurate calculation results.

III. EXPERIMENTAL RESULTS

Numerical studies were carried out according to the formula (4) by repeatedly solving the problems of designing infocommunication networks according to the criterion of network-wide costs given, taking into account the limitations on the average delay time and possible topologies by a set of basic structures (Table 1). The spectrum of possible topologies is characterized by a set of basic structures comprising a "fully connected network" (FCN), a "radial network" (RN), a "ring communication network" (RCN) and a "lattice network" (LS). For basic structures, analytical relationships are given that relate the main structural parameters: the number of edges m and the number of vertices n, the average length of the channel (Table 1).

Table 3.1. Analytical relation for basic structures of infocommunication networks.

Types of networks	Number of ribs	Average channel length, l	Note
FCN	$\frac{n(n-1)}{2}$	$\frac{(0,32Z_1+0,13Z_2)n-(0,32Z_2+0,13Z_1)}{n-1}$	$Z_1 \geq Z_2$
RN	n-1	$\frac{0,24Z_1(np-1)\sqrt{\frac{n}{p}}+Z_2(n-p)(0,1\sqrt{np}+0,15)}{\sqrt{np}\quad(n-1)}$	$p=\frac{n_g}{n_v}$ $Z_1 \geq Z_2$
RCN	n-1	$\sqrt{\frac{Z_1Z_2}{n}}$	
LS	$m=(n_g-1)\cdot n_v+(n_v-1)\cdot n_g$	$\sqrt{\frac{Z_1Z_2}{n}}$	

Source: "Compiled by the authors"

Now it is necessary to determine how much the geographical location of the structurally network components of networks, i.e. nodal and channel equipment, affects costs? Why do design costs increase when new infocommunication nodes are added to network equipment? The authors tried to answer these questions using the results shown in Figure 1. From the graph it can be seen that with an increase in the size of the network, the costs of node and channel equipment increase synchronously, regardless of the topological construction of networks. The largest design cost of a network with a fully connected structure, the lowest design cost of a network with a radial structure. Other networks also experience an increase in these costs with an increase in the size of the network, regardless of the topological construction of infocommunication networks. What does that mean? The authors believe that in a limited area, the bulk of the costs (function 3) are the cost of nodes, the number of which does not depend on the size of the territory and on the topology of the networks, but is determined only by the capacity of the network.

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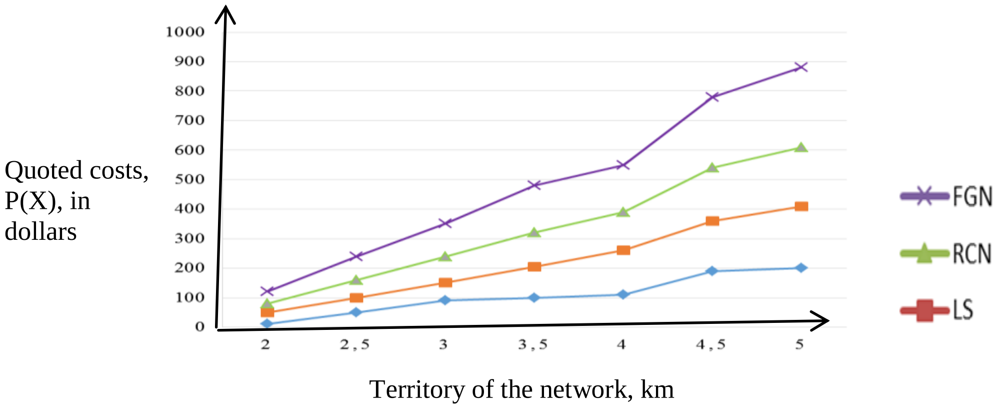

Fig.3.1 Graph of the dependence of network-wide costs on the territory of networks.
Source: "Compiled by the authors".

Now it is necessary to determine the optimal structure of infocommunication networks according to the criterion of network-wide costs. How to determine the minimum costs, how do the number of steps of the hierarchy affect the given costs, with different topological structures? Indeed, how to determine the optimal structure if the infocommunication network is built as a multi-level structure? Each level is built on an arbitrary topology, the location of nodes and communication channels is also on an arbitrary principle. At each level, the nodes are connected to each other using digital channels that differ in different bandwidths. In Fig. 2. a graph of the dependence of network-wide costs on the number of steps of the hierarchy of the infocommunication network is presented.

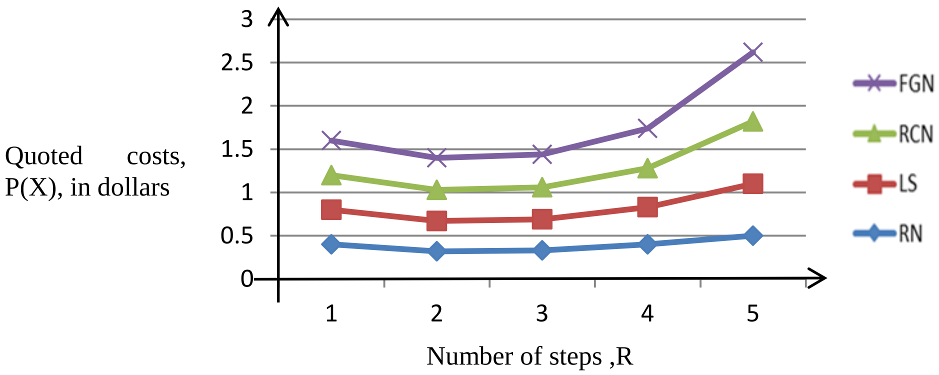

Fig.3.2 Dependence of network-wide costs on the number of hierarchy levels in different network topologies.
Source: "Compiled by the authors".

The authors conducted multivariate numerical studies, with different initial data, with different topological structure of the infocommunication network. The results are shown in Figure 2. Figure 2 shows that as the number of steps in the hierarchy increases, these costs gradually increase, regardless of the type of network topology. In the area of 1 to 2 stages, all networks have reductions in these costs, from 2 to 3 stages there is an optimum of the indicated costs. Already from 3 to 5 stages and beyond, the values of network-wide reduced costs for all types of network topologies gradually increase. From this it should be said that the 1st and 2nd stages correspond to the terminal network, which includes terminals, hubs and communication channels connecting the terminals to the hubs. To the 3rd and 4th stages corresponds the backbone network, which includes the switching nodes and their connecting communication channels, as well as the backbone network management system. Thus, it can be argued that all network topologies have an optimum of network-wide reported costs in the area of 2 and 3 stages, and the subscriber network (from 1 to 2 stages)

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in all topologies is more economical than the other stages. It has been determined that in economic terms 2-3 layer networks (backbone networks) are much preferable than 4-5 layer networks. At the same time, it should be noted that the most economical is the radial network than other networks. This gives us the opportunity to assert that in the long term for the effective design of infocommunication networks, it is necessary to build 2 or 3 layer networks. Because, such networks are not only economical, compared to other networks, but also they are easy to design and in such networks channel and network resources are effectively used.

IV. DISCUSSION

The proposed method of penalty functions was used in the work [1,4,5] to optimize the physical structure of hierarchical digital networks of integral service, numerical optimization results were obtained, but they were suitable only for networks with packet and circuit switching. Comparative characteristics were made between packet and circuit switching, and optimal network structures were not determined. The effectiveness of these methods was assessed by the rational use of channel bandwidth. In [11,14,15], the calculation of network-wide costs was carried out only for individual networks with a smaller dimension and with a small number of switching nodes, the optimal structure of the network was not determined, and the heterogeneity of incoming information flows was not taken into account. The authors of this article propose a method of penalty functions to improve the efficiency of designing infocommunication networks. Using this method, it became possible to reduce the amount of calculations of function (4), taking into account the heterogeneity of incoming information flows, with different topologies, and the optimal structure was determined according to the criterion of network-wide given costs.

V. CONCLUSION

As a result of the research, it has been revealed that when designing an infocommunication network with a multi-level structure, the total length of its channels is reduced, nodal equipment and network channels are effectively used, the network management procedure is simplified and a certain saving of its resources is achieved. To improve the efficiency of the design of infocommunication networks, a method of penalty functions is proposed, which made it possible to calculate the network-wide costs, determine the optimal structure of the network, taking into account the stages and its topological construction, as well as take into account the number of stages, nodes, reliability and bandwidth of communication channels and reduce the cost of its design by 3-4%.

In the future, further research in this area will be aimed at improving the efficiency of the design of mobile communication networks, as well as optical infocommunication networks using the penalty functions method

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