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SOLVING THE PROBLEM OF CHANNEL VOLUME'S DISTRIBUTION IN 3-TIER NETWORK TAKING INTO ACCOUNT FUZZY CONSTRAINTS ON CONSUMPTION VOLUMES

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Abstract. *The article proposes a method for solving the problem of rational distribution of the power of data transmission channels, taking into account fuzzy restrictions on consumption volumes. A feature of such tasks is the inability to meet the needs of the end user at the expense of the resources of different suppliers. Methods for solving the problem with fuzzy restrictions on the consumption volumes of end users are investigated. A fuzzy optimization problem is formulated, which allows taking into account the interval specified volumes for the connection values. A variant of solving fuzzy optimization problems in the case of using fuzzy numbers is proposed. A multi-criteria problem of efficient distribution of communication channel powers with fuzzy restrictions is formulated. A variant of the algorithm with a return is proposed, which allows solving the obtained problem. The approach is illustrated by a number of numerical examples for the problem of forming a network structure with a given number of end users and different allowable bandwidths of communication servers.*

Key words: *data transfer, volume distribution, fuzzy constraints, optimal solution, backtracking algorithm*

Introduction.

The tasks of finding optimal solutions arise in the process of development and practical implementation of methods for effective management of various organizational, technological and information systems.

An important characteristic of optimization problems is the desire to find the optimal solution (optimality principle). In practice there are a number of constraints that do not allow finding such a solution. In these cases, the question is raised of finding not optimal, but rational (compromise, effective) solutions that satisfy the problem statement. It is often necessary to find a compromise between the effectiveness of solutions and the cost of finding them. Serious difficulties arise when solving optimization problems under conditions of incomplete information, as well as in the case when random or subjective factors (parameters) play a significant role.

One of the applied problems in which there can be uncertainty in setting the parameters is the problem of distributing the limited capacities of data transmission channels between different nodes of the Internet providers network. Suppose that there is a local computer network of an enterprise (organization, educational institution) that provides users with access to the Internet. User access to the global network and obtaining the necessary information is carried out using several communication servers located on the territory of the information and computer center of the enterprise and connected by high-speed external communication channels with Internet providers. The bandwidth levels of the servers are within the bandwidth (bandwidth) of the local network (for example, 1Gb per second).

The solution of the formulated problem was considered in [1-7] on the basis of solving problems of optimal resource allocation. The problems of efficient use of a homogeneous resource were considered using the example of time distribution in the form of a classical problem of distributing resources of a given volume over a set of categories (works) [4]. The setting of such tasks consists in finding a cost plan for the available resource (such a resource is most often considered time) for the execution of a group of tasks, in which the total (final) use of the resource is optimal.

Problem statement

An information and computer network is considered, including N_1 data transmission channels (global network providers), N_2 communication servers and N_3 end users (subscribers). We denote by A_i^+, $i=\overline{1,N_1}$, the values of the maximum bandwidth of the data transmission channel that provider *i*, $i=\overline{1,N_1}$, is able to provide; B_j^+, $j=\overline{1,N_2}$, – the value of the maximum bandwidth of the data transmission channel that the communication node *j*, $j=\overline{1,N_2}$, can provide; ; C_k^-, C_k^+, $k=\overline{1,N_3}$, – values of the minimum and maximum bandwidth of the data transmission channel, which must be provided to the subscriber *k*, $k=\overline{1,N_3}$; t_k – throughput of the *k*-th subscriber station, $k=\overline{1,N_3}$. Then, assuming that the power distribution of communication channels satisfies the conditions of additivity and proportionality, we can consider the problem of distributing a limited homogeneous resource (bandwidth of communication channels) with transport-type constraints in order to find the optimal data transmission plan. This ensures the effective functioning of the system for providing users with Internet access, which consists in finding the optimal values of data transmission bandwidths T_i of the *i*-th information provider (provider), $i=\overline{1,N_1}$, and the optimal values of the bandwidths t_k of using local communication channels of the *k*-th user, $k=\overline{1,N_3}$.

Formally, the statement of problem can be written as

$$\max t_1;\ \max t_2;\ \ldots \max t_{N_3}, \tag{1}$$

with the following constraints

$$\begin{gathered}\sum_{k=1}^{N_3} t_k \le \sum_{i=1}^{N_1} A_i^+; \\ t_k \le B_j^+,\ j=\overline{1,N_2},\ k=\overline{1,N_3}; \\ C_k^- \le t_k \le C_k^+,\ k=\overline{1,N_3}; \\ \sum_{j=1}^{N_2} B_j^+ \le \sum_{i=1}^{N_1} A_i^+ \le \sum_{k=1}^{N_3} C_k^+ .\end{gathered} \tag{2}$$

Let's assume that the needs of network subscribers to increase the speed of obtaining one or another amount of information are known. The wishes (preferences) of subscribers are set regarding a possible increase in consumption volumes (bandwidths) for transmitting information from the provider to the user node. To implement the changes, it is necessary to update the capacities of the switching servers of the network by deploying new, more powerful computers or by increasing the number of existing servers. In other words, it is necessary to conduct a study on updating the resources of the server park of the information and computing center, which makes it possible to increase the total bandwidth of a group of switching servers. At the same time, the value of the total capacity of servers, both in the case of an increase in the capacity of the existing fleet of computers, and in the case of an increase in the number of servers, is assumed to be the same.

If the values of consumption parameters are random variables with known distribution functions, then it can be solved by stochastic programming methods. However, in practice these parameters are often unknown and only the range of possible values can be determined for them. A problem of this type can be called a problem with multiple values of the coefficients.

The next step on the way of detailing and refining the model considered here is the description of the problem parameters in the form of fuzzy sets (numbers) [8]. Additional information is introduced into the model in the form of a membership function of these fuzzy sets. These functions can be considered as a way for an expert to approximate his unformalized idea of the real value of a given parameter.

Fuzzy sets are a mathematical model of object classes with fuzzy or blurry boundaries. In other words, an element can have some degree of membership in the set, and it is intermediate between full membership and complete non-membership.

Let us assume that in the formulation of the problem of distributing the power of data transmission channels, the current values of the throughput of communication channels of each subscriber k, $C_k, k=\overline{1,N_3}$, are known, and the values of $C_k^+, k=\overline{1,N_3}$ determine the values of the bandwidths that are planned by users as a result of updating communication equipment. Obviously, it is possible to fully satisfy the expansion of the bandwidth of subscriber channels only under the condition $\sum_{j=1}^{N_2} B_j^+ \geq \sum_{k=1}^{N_3} C_k^+$.

Formally, the statement of problem can be written in the form of optimization of criteria (1) with the following constraints

$$t_k \in supp\ \tilde{t}_k = [C_k, C_k^+],\ k=\overline{1,N_3}; \tag{3}$$

$$\sum_{k=1}^{N_3} t_k \leq \sum_{i=1}^{N_1} A_i^+;$$

$$t_k \leq B_j^+,\ j=\overline{1,N_2},\ k=\overline{1,N_3}; \tag{4}$$

$$\sum_{j=1}^{N_2} B_j^+ \leq \sum_{i=1}^{N_1} A_i^+ \leq \sum_{k=1}^{N_3} C_k^+ .$$

We will assume that the capacities of communication channels available to users satisfy the conditions $\sum_{k=1}^{N_3} C_k \le \sum_{k=1}^{N_3} t_k \le \sum_{i=1}^{N_1} A_i^+$, and the values of the possible expansion of the channel capacity are determined by right-hand fuzzy triangular numbers in the form (C_k, C_k, C_k^+), $k = \overline{1, N_3}$, with linear membership functions [9].

This problem is a multiobjective fuzzy optimization problem [10]. To solve it, methods are used that allow finding a compromise (effective) solution by reducing the problem to a single-criterion one in the form of a convolution of criteria or to a sequence of single-criteria optimization problems [11]. In the case of fuzzy constraints, each such problem can be reduced to an optimization problem of the form of Bellman-Zadeh [12] with subsequent solution by the one of known method.

Taking into account the specifics of the obtained problem, the most rational method is the sequential introduction of constraints [11]. A characteristic feature of this method, which makes it possible to use it to find an effective solution, is the sequential (at each step) introduction of constraints on the width of the communication channel, at which unsatisfactory values of the criteria are achieved.

Following the search methodology, at each algorithm's step $p = 1,2,...$, an "ideal assessment" $t^{*(p)} = (t_1^{*(p)}, t_2^{*(p)}, ..., t_{N_3}^{*(p)})$, $p = 1,2,...$, is formed, where $t_k^{*(p)}$, $k = \overline{1, N_3}$, are the optimal values of each of the criteria (19) $\max t_k$, $k = \overline{1, N_3}$, on a given range of acceptable values G_p, $G_1 = \{t_k = C_k^+; k = \overline{1, N_3}\}$, $G_{p+1} = \{t_k \in G_p; k = \overline{1, N_3} \mid t_s \ge \xi_s\}$, $s \in \{1,2,...,N_3\}$, is the number of the criterion, the value of which is the least consistent with the compromise solution. It is clarified to what level ξ_s the value of this criterion should be changed, and a search for a new solution is performed, taking into account the additional constraint.

This method allows solving the problem of efficient distribution of channel capacities, taking into account fuzzy constraints on consumption volumes, however, to use it at each step, it is necessary to evaluate the compliance of the current solution with a certain "ideal" solution, which, as a rule, is formed with the participation of an expert. In addition, the solution procedure turns out to be cumbersome, leading to the multiple solution of optimization Bellman-Zadeh fuzzy tasks.

Additionally it is easy to formalize this process by applying the back tracking solution search procedure [13].

From the condition of the problem of optimizing the distribution of channel powers, taking into account fuzzy constraints on consumption volumes (3)-(4), it follows that

$$\sum_{k=1}^{N_3} C_k^+ \ge \sum_{j=1}^{N_2} B_j^+ \ge \sum_{k=1}^{N_3} C_k \quad . \tag{5}$$

Obviously, in this case, it is impossible to allocate the maximum expected power of communication channels to all subscribers. We will look for a solution on rational distribution based on the scheme of the back tracking algorithm.

Algorithm.

Step 0. Without loss of generality, we will assume that the order of users is ordered in non-increasing order of the planned capacities of communication channels.

We put the required values in the initial solution $t_k = C_k^+$, $k = \overline{1, N_3}$.

Step s=1,2,... We check the fulfillment of condition

$$\sum_{k=1}^{N_3} t_k \le \sum_{j=1}^{N_2} B_j^+ . \qquad (6)$$

If inequality (6) is satisfied, the algorithm terminates, otherwise:

a) determine the q, $q \in [1, N_3]$, largest (first of N_3) values t_k, $k = \overline{1, N_3}$.

b) decrease the values t_k, $k = \overline{1, q}$, by $\Delta t > 0$: $t_k = t_k - \Delta t$, $k = \overline{1, q}$.

Obviously, the total demand in this case decreases.

Change $s = s + 1$ and move on to the next step.

Experiments

The algorithm proposed above for finding a solution in the problem of rational distribution of the power of communication channels, taking into account fuzzy constraints on consumption volumes (3)-(4), was used to calculate the values of throughput resources in a network with 1 Internet provider, 2 (3, 4) routers (communication servers) and 17 end users (collective subscribers).

The bandwidth of user connections to communication servers was initially 350, 250, 250, 245, 180, 180, 165, 165, 160, 145, 140, 140, 140, 120, 110, 80, 80 Mb/s (total capacity 2900 Mb/s). In order to expand consumer traffic, it is proposed to upgrade equipment in the form of a possible increase in the number of servers or/and increase their capacity. The bandwidth of the communication channel with the provider remains constant and equals 10 Gb/s. The total throughput capacity of communication servers after the upgrade is planned to be 3 Gb/s.

To determine the rational distribution of the size of communication channels, consumers were asked to determine the required size of connections to communication servers. Based on the given amount of traffic, it was planned to use 2, 3 or 4 servers with a total capacity of 3 Gb/s.

Computational experiments on the efficient distribution of the power of communication channels were carried out using the above algorithm for the classical solution of optimization problems with fuzzy constraints on consumption levels (fuzzy approach) and the algorithm using the backtracking approach. In the latter case, both a consistent uniform decrease in consumer requests by the value $\Delta t > 0$ (*app1*) and a proportional decrease in the values of requests were applied, taking into account the required volumes of traffic increase (*app2*).

Results

The results of the numerical experiments performed are shown in Table 1.

As follows from the results obtained, the application of the proposed algorithm made it possible to obtain the most efficient (close to optimal) solutions in the considered distribution problem for a configuration with two communication servers with a maximum bandwidth of 1500 Mb/s. The best solution to the problem using the method of efficient channel power distribution, taking into account fuzzy constraints, was obtained for the connection option with 3 routers. At the same time, it slightly differs from the solution with two servers, which suggests that the best option in the considered distribution problem is the variant with two communication servers. It should also be noted that the solution based on the algorithm using the return scheme does not require significant computational resources, which allows us to speak about the constructiveness of the method.

Table 1 – The results of numerical experiments on the efficient distribution of the power of communication channels

Consumers																	
p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	p15	p16	p17	Sum
Init Power, Мб/с (*Max Sum Power*=2900 Мб/с)																	
350	250	250	245	180	180	165	165	160	145	140	140	140	120	110	80	80	2900
Plan Power, Мб/с (*Max Sum Power*=3000 Мб/с)																	
370	275	275	260	195	185	180	175	165	155	150	150	145	125	115	90	90	3100
Results for K communication servers, Мб/с																	
Approuch: ***app1***																	
CommunicationPower × *K*=1500×2																	
363	268	268	253	188	183	173	168	158	148	143	143	138	118	108	85	90	2995
CommunicationPower × *K*=1000×3																	
359	264	264	249	184	179	169	164	154	144	139	139	134	114	105	83	90	2934
CommunicationPower × *K*=750×4																	
357	262	262	247	182	177	167	162	152	142	137	137	132	112	107	89	90	2914
Approuch: ***app2***																	
CommunicationPower × *K*=1500×2																	
354	254	254	254	184	184	174	169	164	149	149	149	144	124	114	89	90	2999
CommunicationPower × *K*=1000×3																	
352	252	252	252	182	182	172	167	162	147	147	147	142	122	112	87	90	2967
CommunicationPower × *K*=750×4																	
350	250	250	250	180	180	170	165	160	145	145	145	140	120	110	85	90	2935
Approuch: ***fuzzy***																	
CommunicationPower × *K*=1500×2																	
361	266	266	251	186	181	171	166	160	150	146	144	141	121	110	83	82	2985
CommunicationPower × *K*=1000×3																	
362	267	267	252	187	182	173	167	160	150	147	142	140	120	110	82	81	2989
CommunicationPower × *K*=750×4																	
355	260	260	245	180	175	165	160	150	150	145	140	135	118	108	79	75	2900

Summary and conclusions.

The problem of optimal power distribution of communication channels in information-computer networks with a three-level architecture is considered. Approaches for its solution are studied, the problem statement with fuzzy constraints on the consumption volumes of end users is considered. A fuzzy optimization problem is formulated, which allows taking into account the interval specified volumes for the connection values. A variant of solving fuzzy optimization problems in the case of using fuzzy numbers is proposed. A multi-objective problem of efficient power distribution of communication channels with fuzzy constraints is formulated. A variant of the algorithm with a return is proposed, which allows solving the obtained problem. The approach is illustrated by a number of numerical examples of a problem with a given number of end users and different allowable bandwidths of communication servers.

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