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Multicriterion Optimization of Management of the Packet Switching Network*

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ABSTRACT: The particularities of application of the methods of multicriterion optimization at operation management of the packet switching network are considered. The investigation results are provided on the example of solving of a particular management problem considering the time period for the delivery and package loss probability at the datagram transmission of messages.

INTRODUCTION

Organization of integrated management of the present-day telecommunication networks requires use of the relevant hardware-software platforms providing for the necessary level of the quality of service (QoS) of the rendered telecommunication service at any time and with minimum operation costs [1,2]. The unified standard solutions related to management issues are either too complicated and for this reason hardly realizable (TNP CMIP protocol) or underdeveloped and imperfect (COBRA+Java technology), or they are designated for more simplified missions (SNMP Internet-protocol) [2]. There are also existing no uniform approaches to the analysis of the management data and to the development of the process of telecommunication networks management.

The main objective of the management system is to establish the structure and the parameters of the network, software and technical means, sharing flow and variation of the request-servicing discipline in order to secure provision of telecommunication services at the required level of QoS. As a rule, telecommunication networks are estimated based on a certain set of technological and economic parameters (transmission rate, throughput, delay time, probability of delivery, quality of transmission, costs of transmission etc.), which are closely related to and contradict with each other. Therefore, in order to consider these quality parameters under the condition of prompt

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telecommunication network management it is reasonable to apply the methods of multicriterion optimization [3-5].

This paper considers the particularities of application of the methods of multicriterion optimization at operation management of the telecommunication systems with package switching. The investigation results are provided on the example of solving of a particular management problem considering the time period for the delivery and package loss probability at the datagram transmission of messages. This problem is actual for the applications operating in a real time scale and being critical in terms of time limits for delivery of messages, i.e., within the systems of video and voice messages transmission, banking terminals systems; systems of signalization; telecommunication networks troubleshooting management systems.

METHODS FOR SELECTION OF THE SOLUTIONS OPTIMAL IN TERMS OF THE VECTOR CRITERION

In the most general case the telecommunication network is a system that can be regarded as an ordered set of elements, interrelations and their properties. Their unambiguous purpose determines the system, i.e., the purpose of its operation, its structure and efficiency. The basic objective of the management process is to develop the management influences providing for the best efficiency of the telecommunication network operation considering the aggregate of technical and economic parameters of quality. Under such an organization of the processes of optimal management of the telecommunication network there should be applied the basic provisions for the theory of multicriterion (vector) optimization. We determine the main categories and meanings occurring at solving of the problems of selection of the optimal on the basis of vector criterion structure options and network parameters.

Solving of the above optimization problem includes determining of the initial set of options of the system, forming up of a subset of the allowable options, setting of the aggregate of the quality parameters and the criterion for the optimality of the system as well as selection of the structure options, which are optimal in terms of the set criterion. In fact, this is the problem of the general decision-making theory reduced to realization of some function of selecting the best (the most optimal) system $\Phi^{(opt)}$ serving as the reflection operator $\Phi^{(opt)} = C(\Phi_{allow})$ upon the set of the allowable options Φ_{allow}.

In order to formalize the setting of the management problem there has to be formulated the mathematical description of the operating conditions, structure, quality indicators and the network optimality criterion. The formalized setting of the problem provides for the possibility of using the mathematical methods of modeling and multicriterion optimization of the systems at selection of the optimal solutions.

The selection of the optimality criterion is related to formalization of the representation of its optimality. Here, two approaches are possible – the ordinalistic and the cardinalistic ones. The ordinalistic approach appeals to the order (better or worse) and is based on introduction of some of the binary correlations upon a set of allowable alternatives. The preference in this case is the binary correlation R upon the set Φ_{allow} reflecting the representation of the fact that the alternative ϕ' is better than the alternative $\phi'' : \phi' R \phi''$. The cardinalistic approach to the description of preferences prescribes to each alternative $\phi \in \Phi_{allow}$ a number U, which is interpreted as the usefulness of the alternative ϕ. Each usefulness function is determining the respective order (or preference) R upon the set $\Phi_{allow}(\phi' R \phi'')$ then and only then when $U(\phi') \geq U(\phi'')$. This case argue into that the use fulness function $U(\bullet)$ is determined as an indicator of the preference R.

However, at setting of the problem the scalar criterion resulting in the sole solving of $\phi^{(opt)} = \underset{\phi \in \Phi_{allow}}{opt} \left[U(\phi)\right]$, has not met with success often owing to the insufficient determination of the system optimality. Therefore, at the initial stages the system is characterized by the aggregate of quality parameters and the target function related therewith:

$$\vec{k}(\phi) = \left(k_1(\phi), ..., k_i(\phi), ..., k_m(\phi)\right), \qquad (1)$$

which determines the dependence of the quality parameters upon the structure s and the parameters $\vec{\beta}$ of the system $\phi = (s, \vec{\beta})$.

Here, there occur the problems of optimization of the solutions upon the aggregate of the quality parameters. They are also called the problems of multicriterion or vector optimization [3-5]. As the result of that it is found a subset of efficient (Pareto-optimal) options of the system, which, in a general case, contains not one but several options not dominated upon the introduced strict preference relation.

The above Pareto-optimal solutions can be found both directly upon the set Φ_{allow} using the introduced binary preference relationships and within the space of the drawn quality parameters (1), which is also called the criterion space of estimates. At that, each option of the system ϕ is reflected from the set of the allowable options Φ_{allow} into the criterion space:

$$V = \vec{K}(\Phi_{allow}) = \left(\vec{v} \in R^m \mid \vec{v} = (k_1(\phi), k_2(\phi), ..., k_m(\phi)\right), \ \phi \in \Phi_{allow}). \qquad (2)$$

Here, each of the project solutions ϕ is matched with its own estimate of the selected quality parameters $\vec{v} = \vec{k}(\phi)$ and, vice versa, each estimate is matched with a project solution (in the general case it is not obligatory one).

For the network user it is desirable to obtain the best possible solution for each criterion. However, practically, this case can be rarely found. Here it is worth mentioning that the parameters of quality (target functions) (1) can be of three types – neutral, coordinated and competitive with respect to each other. In the first two cases the system optimization can be performed separately upon each of the quality parameters. In the third case it is impossible to attain the potential value of each of the parameters taken separately. At that, there can be achieved only the coordinated optimum of the introduced target functions – the optimum based on the Pareto criterion, which means that subsequent improvement of each of the parameters can be attained exclusively at the expense of worsening of the remaining quality parameters of the system.

The optimum based on the Pareto criterion is matched in the criterion space by a set of Pareto-optimal estimates corresponding to the non-dominated options of the system:

$$P(V) = opt_{\geq} V = \left(V^{opt} \in R^m \mid \forall \vec{v} = \vec{k}(\phi) \in V : \vec{k}(\phi) \geq \vec{k}(\phi'')\right). \qquad (3)$$

Finding of the optimum on the basis of the Pareto criterion can be performed either directly according to (3) using the search among all of the allowable options of the system Φ_{allow} or by means of applying special methods like the weight method and the method of operation characteristics [4,5].

In particular, while applying the weight method the Pareto-optimal project solutions are found by means of optimization of the weighed amount of particular target functions:

$$\underset{\phi \in \Phi_{allow}}{opt} \left[k_p(\phi) = \lambda_1 k_1(\phi) + \lambda_2 k_2(\phi) + \ldots + \lambda_m k_m(\phi)\right], \qquad (4)$$

from which different allowable combinations of weight coefficients $\lambda_1, \lambda_2, \ldots, \lambda_m$ are selected from the condition that $\lambda_i > 0$, $\sum_{i=1}^{m} \lambda_i = 1$. The Pareto-optimal solutions are those options of the system satisfying the condition (4) at different allowable combinations of weight coefficients $\lambda_1, \lambda_2, \ldots, \lambda_m$.

The operation characteristics methods consists of the fact that all of the target functions except for one, the first, for example, are transferred into the rank of limitations of the type of equality and its optimum is determined upon the set of allowable alternatives Φ_{allow}:

$$\underset{\phi \in \Phi_{allow}}{opt} \left[k_1(\phi)\right], \quad k_2(\phi) = K_{2\phi}; \quad k_3(\phi) = K_{3\phi}, ..., k_m(\phi) = K_{m\phi}. \qquad (5)$$

Here $K_{2\phi}, K_{3\phi}, ..., K_{m\phi}$ are some fixed although arbitrary values of the quality parameters.

While solving the optimization problems (4), (5) within the criterion space a certain multidimensional operation surface is established, which is a match to the Pareto-optimal surface under specific conditions. It is worth mentioning that each point of the Pareto-optimal surface possesses the property of an m-fold optimum, i.e., this point has a match of a potentially allowable value of one of the parameters k_{iopt} at the fixed (being a match to this point) values of the remaining (m – 1) quality parameters. The Pareto-optimal surface connects the potentially allowable values of the quality parameters and represents a coordinated optimum upon Pareto in the general case of dependent upon and competitive with each other quality parameters. Therefore, while obtaining the Pareto-optimal surface within the criterion space we find at the same time the multidimensional potential characteristics (MDPC) and related to them multidimensional exchange diagrams (MDED). By analyzing the MDED we can find out how we have to vary the values of some of the system quality parameters in order to improve the other parameters as well as in what way we need to change the structure and the parameters of the relevant networks.

If the found great number of the Pareto-optimal options of the system appeared to be narrow then we can use any of them as the optimal one. In this case it can be considered that the strict preference relation $\succ$ is a match with the relation $\geq$ and, therefore, $opt_{\succ} V = P(V)$. However, practically, the set $P(V)$ turns out to be rather wide.

For the above reason there occurs the problem of narrowing of the found set of the Pareto-optimal solutions. The ultimate choice of the optimal management solutions has to be performed only within the limits of the found set of the Pareto-optimal solutions, which is obtained due to exclusion of the unconditionally worst solutions.

One of the most widely used methods of narrowing of the great number of the Pareto-optimal solutions is to develop the scalar value function, the optimization of which results in selection of one of the optimal variants of the system. At that, there can be used the additive, the multiplication and the multilinear value functions, which, in the general case, have the following representation

$$F(v_1, v_2, ..., v_m) = \sum_{j=1}^{m} c_j f_j(v_j), \qquad (6)$$

where c_j are the scaling coefficients; $f_j(v_j)$ are some one-dimensional value functions being the estimates of usefulness of the system option ϕ upon the parameter $k_j(\phi)$.

The data obtained as the result of expert estimation of the analyzed system options are substantially used while developing the usefulness (value) functions. There exist special methodologies aimed at obtaining of some additional information related to preferences, which, in particular, are based on attraction of some additional information from the available database and the network conditions statistics as well as upon the hierarchy analysis method.

In order to develop the scalar target function there can also be used the approach based on the theory of fuzzy multitudes. The most general form of the belonging function interpreted in the terms of the fuzzy multitudes theory has the representation

$$\xi_{\bar{k}}(k_1, k_2, ..., k_m) = \frac{1}{m}\left\{\sum_{j=1}^{m}\left[\xi_{k_j}(k_j)\right]^{\beta}\right\}^{\frac{1}{\beta}}. \quad (7)$$

Depending upon the value of the parameter β it is realized a wide class of functions from the linear additive form at β = 1 up to strictly non-linear dependencies at $\beta \rightarrow \infty$.

At strictly ordered upon the importance parameters of quality, selection of the only managing solution can be performed using the lexical and graphic relations. At that, it is assumed as possible to obtain a larger value of one of the parameters, e.g. k_1, even at the expense of the 'loss' with respect of the rest of the parameters. This corresponds to the situation when the entire set of the parameters $k_1, k_2, ..., k_m$ is strictly ordered upon importance and, while comparing the project solutions, the lexical and graphic relation of the estimates $\vec{v}' \underset{\succ}{lex} \vec{v}''$ is used. While performing the correlation $\vec{v}' \underset{\succ}{lex} \vec{v}''$ it is said that the vector $\vec{v}'$ is lexically and graphically larger than the vector $\vec{v}''$. At m = 1 the lexical and graphic relation is matching with the relation > upon the subset of the real numbers.

SOME INVESTIGATION RESULTS OF THE MULTICRITERION MANAGEMENT OF THE TELECOMMUNICATION NETWORK

There were performed investigations of the methods of the multicriterion management of a telecommunication network for the case of the centrally distributed structure. In each of the switching nodes it is realized the mechanism of managing of the input flow with the help of a 'window'. It is also performed the collection of statistical data related to operation of the nodes. The data from each of the switching nodes are transmitted to the central control and management device where the database, which contains the information of the network operation as a whole, is formed and the appropriate management solutions are taken. Then, there are developed the necessary controlling influences aimed at setting of the discipline of servicing for the message queues in the switching nodes (considering the law of time distribution for the service time and the priority of messages) as well as at setting of the means for determining of the routes of messages transmission via the network from the sender to the addressee (upon the shortest route, the least queue and the minimal delay).

The investigations were performed upon the mathematical model of the packet switching network. The model was realized on the PC with application of the simulation modeling DASIM packet. The model structure includes the user simulators, the procedures of packing of messages into the packages, their transmission via the communication link, routing and servicing in the switching nodes, errors in transmission channels. The user simulators are designed for modeling of the external load generated by the out-of-system message sources with the Poisson law of distribution and the set intensities of the arrival of requests. The procedures of packing of messages into the packages are aimed at modeling of the package data transmission in the window load management mode and simulation of the network access devices operation with package switching. The procedures of transmission of packages are modeling the process of data packages transmission via the duplex channel of communication. It is envisaged simulation of delays in transmission of packages via the communication link, which is related to the finite velocity of the signal propagation within the communication link, fixed throughput value of in the link and the length of the data package as well as the duration of the package queuing for being transmitted via the communication link. The procedures of imitation of errors within the link are intended for modeling of the processes of loss of the transmitted information connected both with origination of distortions in the communication links and with equipment failures in the switching nodes.

In the considered example the network model structurally consists of the communication links and seven switching nodes, into which the users are connected with the help of the end terminals. The full-circuit network topology is set. The processes of forming up of the messages and data transmission in the network are simulated with application of the basic provisions of the theory of mass servicing.

In the process of modeling there was realized a certain set of various network operation options, which differed in various disciplines of servicing of the data packages in queues (random order servicing, priority-based servicing, servicing in the order of arrival, cyclic servicing with a time quantum), different modes of routing at transmission of messages (uniformly pursuant to the communication channels weights, randomly selected route, upon the least loaded channels) as well as in different dimensions of the transport connection window.

As the result of the simulation there were obtained thirty-six different network operation options, the characteristic of which are represented in Table 1. The network operation options were estimated upon the following quality parameters – the average time of delivery $k_1 = \overline{T}$ and the average probability of a loss of the message $k_2 = \overline{P}$.

Table 1:

No.	k_1	k_2	W	Discipline of service/ Route	No.	k_1	k_2	W	Discipline of service/ Route
1	0.171	0.652	10		19	0.246	0.670	10	
2	0.282	0.475	8		20	0.337	0.449	8	
3	0.408	0.566	7		21	0.488	0.436	7	
4	0.546	0.490	6		22	0.546	0.437	6	
5	0.557	0.509	5	A/1	23	0.612	0.530	5	A/2
6	0.685	0.477	4		24	0.648	0.507	4	
7	0.730	0.423	3		25	0.773	0.463	3	
8	0.784	0.505	2		26	0.735	0.580	2	
9	0.827	0.719	1		27	0.904	0.443	1	
10	0.096	0.734	10		28	0.255	0.729	10	
11	0.278	0.466	8		29	0.345	0.472	8	
12	0.396	0.463	7		30	0.468	0.477	7	
13	0.428	0.416	6		31	0.525	0.494	6	
14	0.499	0.469	5	B/1	32	0.531	0.415	5	B/2
15	0.536	0.587	4		33	0.430	0.474	4	
16	0.574	0.469	3		34	0.765	0.488	3	
17	0.595	0.407	2		35	0.695	0.282	2	
18	0.691	0.465	1		36	0.770	0.459	1	

Note: discipline of service (A – in the order of arrival; B – randomly); routing mode (1 – uniform according to the weight values; 2 – random selection).

These quality parameters are interrelated and possess the antagonistic mode of interrelation. Table 1 indicates the normalized (to the maximal values) values of the quality parameters. The obtained set of the network operation options is represented in the criterion space (Fig. 1). Further on we specified the subset of the Pareto-optimal network operation options with exclusion of the unconditionally worst options. The Pareto-optimal options are marked as bold in Table 1 and the lower left boundary of the initial set is matched with them in Fig.1.

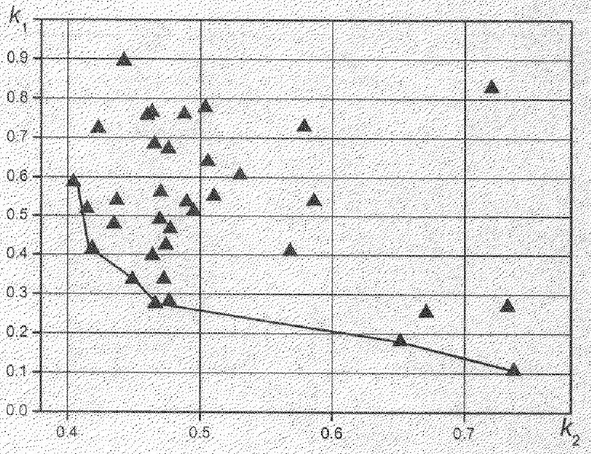

FIGURE 1.

Among the Pareto-optimal network operation options there was selected the only one Φ_0 from the condition of the minimum for the resulting parameter of quality $\Phi_0 = \arg \min\limits_{\Phi \in \Phi_{popt}} k_{dp}(\Phi)$, where $k_{dp} = C_1 k_1 + C_2 k_2$; C_1, C_2 are the weight coefficients determining the degree of the importance for specified quality parameters. For the case with $C_1 = 0.4$, $C_2 = 0.6$ there was selected the one only network operation option – No. 11. For this option the management device has to give the commands for setting of the discipline of requests servicing in the random order, to establish the uniform routing mode pursuant to the weight values and to set the transmission 'window' size equal to 8.

CONCLUSIONS

Some particularities of application of the methods of multicriterion optimization at operation management of the telecommunication network with regard of the totality of the quality parameters, are considered. The investigation were performed for the control processes of messages transmission in the packet switching network. The example considers the problem of managing of the time period for the delivery and the package loss probability. These problems are actual for the networks operating in a real time scale, i.e., within the systems of video and voice message transmission, banking terminal systems; signaling systems etc. the suggested optimal management methods can be applied both for creation of new and at development of the already existing telecommunication networks using the centrally-distributive management mode.

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